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Technical Paper #6

Modeling of Releases from Ammonia Refrigeration Pressure Relief Valves Using Dispersion Modeling Software

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Abstract

Sophisticated software is available commercially to model outdoor dispersion of pure gases such as ammonia from pressure relief valves, or ammonia-air mixtures from machinery room ventilation systems. A previous paper presented in 2013 provided a case study of using this software to model ammonia releases from inside an ammonia machinery room, or from piping or vessel leak points outdoors near ground level [1]. In this paper, the author applies the same analysis techniques to outdoor pressure relief discharges from single relief valves, discharge headers, and water diffusion tank vents. The analysis examines the impact of decisions such as release orientation (up or horizontal), discharge velocity, discharge elevation, etc.

1. Introduction

Ammonia refrigeration systems are required by codes and standards to utilize pressure relief valves to protect vessels, heat exchangers, and piping from damaging overpressure. The relief valves are intended to open if pressure reaches the value for which they have been selected. This pressure set point can be lower but cannot be higher than the design maximum allowable working pressure. The discharging ammonia vapor may be directed internally to another part of the system if this is feasible and can be done safely, or may be discharged externally to a treatment system or a safe outdoor location.

Minimum standards for relief valve sizing and for the location of outdoor discharge points are embodied in industry guidelines, standards, model codes, and in local, state, provincial, or federal regulations that typically adopt these model codes in whole or in part. Industry standards include IIAR-2 [2], ASHRAE Standard 15 [3], and CSA Standard B52 [4]. The model building and mechanical codes include the IMC (International Mechanical Code)[5] and UMC (Uniform Mechanical Code) [6].

The safe location to receive discharges from relief valves may be into another part of the contained, pressurized system, to a treatment system, or to atmosphere. Treatment systems may include water tanks for absorbing the ammonia, scrubber systems utilizing absorbent chemicals, flares for burning the ammonia, etc.
The design of flares has been extensively covered in past IIAR and industry publications[7–12].

The design of water diffusion tanks has also been covered[13,14]. For discharge to atmosphere where allowed by local code, the discharge point must be at a minimum elevation and distance from building openings, walkways, etc. U.S. codes and standards require that the discharge be 15 feet above grade (ground level) or the nearest walkway, and 20 feet horizontally from building openings.

In recent years, changes in IIAR standards and model building codes have introduced the use of emergency pressure control systems (EPCS), which reduce the likelihood that pressures will rise high enough in the system to cause actuation of relief devices discharging into treatment systems or the atmosphere. But pressure relief valves are still required, and decisions must still be made regarding the best way to handle discharges from the relief valves.

The design of relief valve discharge piping requires consideration of many factors, including:

- Satisfying well defined formal sizing requirements in local building or mechanical codes, typically based on vessel size or compressor capacity
- Rated flow rate of selected relief valves must equal or exceed the code requirements
- The selected valve may have much higher capacity than required if the "next smaller" valve has insufficient capacity
- Use of common shared discharge headers vs. dedicated discharge lines for each relief valve
- Minimum and maximum flow within common discharge headers, and resulting variation in discharge velocity
- Optimum location, elevation, and velocity for the actual release to atmosphere
- Selecting relief valves that are much larger than required can actually be detrimental, driving up purchase and installation costs for the valves and associated piping, and resulting in higher instantaneous flow rates to the discharge point

This paper explores the implications of decisions regarding relief valve discharges to atmosphere regarding orientation, elevation, and discharge velocity.

Discharge from hydrostatic reliefs used to relieve pressure from trapped liquid are expected to be very short duration, small mass quantity releases and are outside the scope of this paper.

2. Refrigeration Industry Literature Review

There have been several papers presented at IIAR meetings over the years that discussed the performance of pressure relief valves and/or the sizing of the discharge lines leading from them[15–17]. While excellent, these papers have tended to focus on the diameter and length of the discharge line(s), rather than how the lines terminate when they reach atmosphere. References discussed below have been more focused on how discharge piping from relief valves terminates when it reaches atmosphere. A comprehensive literature review of ammonia dispersion studies outside of the ammonia refrigeration industry is beyond the scope of this paper.

2.1 Discharge Velocity at Relief Valves

Cornwell, Johnson, and Martinsen discuss the fact that dispersing toxic materials to a safe concentration is usually more challenging than dispersing flammable materials to a nonflammable concentration[18]. They mention that API RP-521[19] requires a vertical release orientation and release velocity of at least 100 ft/sec (30.5 m/sec) for flammable materials. They conclude that much higher exit velocities are required with toxic materials because they must be diluted to a greater extent than flammable materials. They compare API recommended practices with test data and model predictions. They mention that in the petrochemical industry, relief vent stack normally discharge vertically upward, except in the case of discharges from low pressure tanks. They caution that for some toxic materials, vertical up discharge orientation and high velocity alone may not be sufficient to reduce concentrations to a safe level. Other safeguards (presumably such as increased elevation, or flaring) may be required.

The 2008 edition of API RP-521 does mention the 100 ft/sec criteria for relief valve flammable vapor discharges. But it is in the context that relief valve discharge pipes sized for 500 ft/sec discharge velocity will still have sufficient velocity to provide good mixing to below the hydrocarbon flammable limit as the flow rate is reduced from the flow at opening to the perhaps 25% of that flow rate as the inlet pressure drops low enough for the relief valve to reseat. The intent would not be met if the tail pipe diameter were selected for 100 ft/sec at opening, which would result in velocity dropping to 20 ft/sec as the valve approaches the reclosing condition. RP-521 does have equations for estimating downwind concentrations near single relief valve tail pipes, but they are mainly useful in the context of describing the volume within the hydrocarbon flammable range in the vicinity of the tail pipe. In any case, this 100 ft/sec criteria is not particularly useful for determining the safe location of ammonia relief discharges in that the concentration of ammonia would still be on the order of 30,000 PPM when active jet momentum driven dispersion transitions to passive dispersion with the ammonia being carried along with the wind and diluted by passive mixing and diffusion.

2.2 Ammonia Refrigeration Dispersion Modeling

The first IIAR paper focusing on ammonia vapor dispersion issues was by Stoecker in 1988[20]. He discussed intentional and unintentional releases. While he touched on treatment systems, he focused on atmospheric discharges from relief valves. He discussed aerosol formation from large releases such as transport accidents, as well as dispersion of vapor or aerosol from smaller releases. He mentioned various dispersion mechanisms including diffusion and wind effects, and the early efforts by IIAR at identifying software suitable for use by end-users in the refrigeration community, or their consultants. In the 1988 paper, he did not address design decisions regarding discharge stack height, discharge orientation, discharge velocity, etc.

Two years later, Stoecker wrote a much more detailed paper for IIAR to address concentrations of ammonia in the vicinity of vapor releases[21]. Stoecker stated that concentrations can be reduced significantly by proper stack design. He emphasized the use of high stacks discharging vertically upward with a high velocity. The paper focused on vapor releases but anticipated that further work would be needed on other types of releases including aerosols. Release rates modeled were rather low at 20 lb/min or less. This study used a U.S. EPA guassian dispersion model ISCST, part of the UNAMAP program[22]. While perhaps a sophisticated screening tool at the time, it would be considered limited by today's standards, and Stoecker warned that results from it should be considered preliminary by the refrigeration industry. The study evaluated vertical up discharges only, but did look at concentrations to the side of the centerline of the plume. Stoecker observed that increasing the stack height is a fundamental means of reducing ground level concentrations of ammonia. He also emphasized the advantage of high discharge velocities approaching sonic velocity, and of discharging vertically upward. He mentioned the adverse impact of pointing the discharge towards the ground to keep out rain and snow, suggesting instead that that other measures be used to keep out rain, such as dual u-bends with a drain hole in the lower u-bend, or plastic caps on the pipes, etc. Stoecker also mentioned the importance of assumptions regarding wind and weather, such as atmospheric stability, mixing layer height, etc.

Stewart, Clark, and Stickler's ASHRAE paper in 1995 described a small field trial in which ammonia was released at two different rates, and resulting concentrations were compared to predictions from two different public domain computer programs, SLAB and DEGADIS [23]. The releases were horizontal at an elevation of 3.3 feet (1 m) above the ground and directed downward, and volumetric rates were quite low at 4 and 8 SCFM (0.11 and 0.22 m^3/min). The authors reported that one of the two software programs provided reasonably accurate predictions of the measured concentrations, within 25%. The test conditions, with low release height and low flow rate, are more relevant to accidental leaks from fittings, pumps seals, etc, and less relevant to the high flow rates at higher elevations from relief valves that are of interest in the present paper.

Kaiser's IIAR paper in 1996 addressed selection of the worst case and alternative case for EPA RMP reporting [24]. It also commented on considerations in dispersion modeling of selected scenarios. It mentioned that predictions may be overly conservative in that they neglect “dry deposition” reactive mechanisms that may cause ammonia to desorb onto the ground or other surfaces during passage; they neglect the fact that ERPG-2 and other concentrations of interest are based on exposure durations such as 60 minutes that may be longer than the actual exposure time for a given scenario; and they fail to take into account changes in wind direction that cause the cloud centerline to shift from side-to-side, which tends to reduce the average concentration at any one point for a given exposure duration.

Woodward’s IIAR paper in 1997 addressed improvements in data to support assumptions about the wind (weather) stability class[25]. It explained that recently released data from Germany provided the means to better support and validate the available dispersion models, including an earlier version of the PHAST/Safeti software. Woodward’s paper did not examine the design details or optimization regarding discharge stack elevation, orientation, velocity, etc.

In 1998, Kuespert and Anderson[26] published a study of dispersion of ammonia from relief valves, based on a jet dispersion model from Hoot, Meroney and Peterka[27]. They identified the limitations of the model, including inability to take into account atmospheric stability and the change in temperature and buoyancy of the plume as mixing with ambient air progresses. They referred to the model as outdated, but still useful, and conservative. Based on use of the model, they concluded that the smallest possible stack diameter consistent with the backpressure limits of the relief system should be used, discharging upward. They provided some sizing tables based on not exceeding 1000 PPMV at ground level.

Fenton, Walenta, and Chapman conducted experimental releases of ammonia and air-ammonia mixtures in 2000, and compared measured downwind concentrations to predictions from a plume dispersion model, ISCST2 [28]. Release elevations varied from 6.5 ft (2 meters) to 26.5 feet (8.1 meters). Discharge velocities were in the range of 32.8 ft/sec (10 m/s) to 164 ft/sec (50 m/s). The relatively low velocities chosen appear to be more relevant to fan discharges from machinery room mechanical ventilation systems then to the much higher, near-sonic velocities expected at relief valve discharge pipes. They reported that downwind concentration of ammonia could be influenced by the following parameters in increasing order of effectiveness: increased vertical (up) velocity, pre-dilution with air (most effective in the near-field), and increases in elevation.

Bonebrake and Kuespert addressed several timely issues regarding pressure relief valves in 2002, and included guidance on terminating the discharge line[17]. They emphasized the importance of keeping moisture and insects out of the relief piping, avoiding downward discharge, and the benefits of upward discharge at an elevation above roofs or more) and walls. They recommended discharging 15 feet (4.6 meters) above roofs.

Current guidance from IIAR in the 2012 piping handbook[29] includes the following recommendations:

- Discharge vapor relief valves to atmosphere whenever possible
- Discharge 15 feet (4.6 m) above grade or any adjoining roof
- Discharge at least 20 feet (6.1 m) away from any opening into the building
- Prevent the entry of rain or foreign material
- Direct discharge away from where persons may conduct service work
- Reduce the hazard to persons down wind of the release by directing discharge up with the highest practical velocity
- Inspect regularly

Figure 6-3 in the piping handbook shows four different possible arrangements for the discharge to atmosphere, including a tee with 2-way horizontal discharge, a “broken vent” with vertical up discharge, a mixing diffuser with horizontal discharge, and an exhaust vent with vertical discharge from a duct with much larger cross section than the release pipe. All four arrangements result in lower effective discharge velocity than the velocity at the exit of the relief valve pipe itself, but each does feature geometry that reduces the likelihood that rain will enter the pipe and fill low points or flow all the way back to the relief device(s).

Hodges and Fenton reported in 2013 on analysis of ammonia release mitigation options, and quantitative risk analysis taking into account possible release frequencies, and probability of failure on demand of the mitigation systems[30,31]. In the dispersion analysis section of [31], they modeled vertical up releases, at two different ammonia mass flow rates, 35.3 and 70.6 lbm/min (16 and 32 kg/min) at elevations of 10, 20, or 30 feet (3,6, and 9 meters), and at several weather conditions covering a range of wind speeds and atmospheric stabilities. The software they used was SLAB. All the releases were modeled with a constant stack diameter of 1 ft (0.304 meters), resulting in a discharge velocity of 16.6 to 33.3 ft/second (7.5 to 15.1 m/sec). Concentration results were calculated using several different averaging times, which can help determine sensitivity to wind direction fluctuations. Release from two points with possibly overlapping plumes was considered. Graphical results gave predicted centerline concentrations as well as estimates for off-center line concentration. The results are interesting, but are representative of a lower mass flow rate and a much lower discharge velocity than was considered of interest in the present study. Hodges and Fenton concluded that the most effective way of reducing down wind ammonia concentration from atmospheric releases is increasing stack height. They also concluded that splitting the discharge into two widely separated stacks (on the order of 33 feet (10 meters) separation was beneficial.

2.3 Other Relevant Literature

Leung reviewed the ASHRAE Standard 15-1978 inherent assumptions around sizing of pressure vessel relief valves for the fire case, and compared with practices in other industries[32]. He discussed the importance of understanding whether discharge was single or two-phase flow to properly size relief systems, but did not address relief discharge elevation, orientation, or discharge velocity.

Sung and Wheeler discussed three different softwares for modeling ammonia releases in a 1997 paper[33]. While not specific to the ammonia refrigeration industry, this paper did emphasize the possibility of ammonia releases being in different thermodynamic conditions, and of using good engineering judgment in selecting software with appropriate modeling capabilities for the type of release considered. Thermodynamic conditions mentioned included single and two-phase flow, choked and non-choked flow, flashing liquid, and pool boiling.

Reindl and Jekel described methods for relief discharge pipe sizing [34]. A consulting firm has published a report suggesting possible improvements to those methods[35].

Reindl, Jekel, and Dettmers recently published a newsletter article considering scenarios for size of pressure relief headers[36]. They discuss the sometimes complex set of scenarios that can result in a single relief valve or a combination of several relief valves discharging simultaneously into a relief header system.

3. Modeling Software and General Assumptions

3.1 Software Overview

A previous paper by the author provided [1]:

- References regarding the general principles of dispersion modeling
- Details regarding the software used here, and why it was selected
- References for validation of the software used here
- Comments regarding other types of software that could be used

The same version of that software, PHAST version 6.7, has been used in the calculations for this paper.

As with the author's previous paper, the default modeling parameter values in PHAST 6.7 were used except as follows:

- Height for reporting concentration effects was changed from 0 ft (0 meters) to 3 feet (1 meter)
- Maximum duration of releases was increased from 60 to 240 minutes. This deviation from default values was retained for consistency with the author's previous paper, but for outdoor dispersion, many plumes reach their maximum extent to a concentration of interest in a much shorter period of time.

The PHAST outdoor dispersion model is referred to as Uniform Dispersion Model (UDM). The UDM belongs to a class of software that utilize integral-type dispersion algorithms, which is also commonly used by other commercial software.

The "free" public domain versions of software in this class tend to not have all the modeling flexibility required for this case study, specifically the ability to vary elevation, orientation, discharge velocity, and liquid fraction of the releasing material. Although the commercially available software in this class tends to have more features and flexibility, it does suffer from increased complexity and software cost which present a barrier to use.

Integral models like the PHAST dispersion model UDM solve a simplified set of differential equations based on empirical concentration profiles presuming dispersion over flat terrain (with a uniform surface roughness). CFD programs have more extensive computational capabilities, but are labor and cost intensive to model even simple arrangements.

3.2 Weather

A single weather condition was used in this paper, for the same reasons as were discussed in the previous case study.

The weather was chosen to match the default weather used for calculating the distance to the ERPG-2 ammonia concentration for the "worst case" scenario for U.S. facilities that are covered by the EPA RMP regulation:

> "F" stability, wind speed 3.35 mph (1.5 meters/second), 50% RH

While lower wind speeds are experienced for some fraction of the annual hours at almost every geographic location, this wind speed was selected both because many analysts use this as a "lower wind speed" reference point, and because the software is considered most accurate at wind speeds higher than 2.2 mph (1 meter/sec).

The use of F stability is conservative in that it is the most stable condition that is routinely used in off-site consequence analysis, and results in longer downwind distances to concentrations of interest for most situations.

The weather condition chosen would not be conservative for dead-calm, fog-like conditions, which while possible, tend to be of low frequency.

3.3 Topography

As with the previous case study, a single topography type (surface type) with average surface roughness of 1 meter was used in this paper. The PHAST program documentation refers to this surface type as "1 meter, regular large obstacle coverage, suburban/forest."

The surface type selected for this paper would be conservative for most locations with urban or suburban populations. Specifying a "taller" average obstacle height (larger surface roughness) typical of urban surroundings would result in shorter distances to concentrations of interest. Selecting very low average obstacle height such as for farm land would yield longer distances, but presumably this would be less of a concern given the low population density in a rural setting.

3.4 Pool Vaporization

The three thermodynamic discharge conditions used in the paper include a "cold aerosol condition", for comparison with results in the previous paper.

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. This was accomplished by adjusting the liquid fraction of the releases. This approach simplifies the presentation of results.

Discharge of liquid or aerosol from the relief valve of an ammonia refrigeration system should only be possible during an upset or other unusual condition. The design intent of relief systems is to relieve vapor from the vapor space of vessels. One scenario for aerosol release from a relief valve is overfilling of a vessel or coil with liquid, followed by opening of the relief valve on that vessel or coil. In this scenario, there may not be enough volume and disengaging height in the vapor space to allow entrained liquid to separate from vapor before the vapor enters the relief valve inlet piping.

3.5 Concentrations of Interest

As explained in the previous paper, different individuals involved in facility design and operations, or emergency responders, may have an interest in evaluating different concentrations of interest, depending on whether they are focusing on on-site or off-site effects. Many different values of interest are shown in Figure 1 in the previous paper[1], including:

TLV-TWA 25 PPMV

ERPG-1 25 PPMV

STEL	35 PPMV
ERPG-2	150 PPMV current, 200 PPMV in RMP regulation
IDLH	300 PPMV
ERPG-3	750 PPMV

For facilities in the United States, the distance to downwind concentration of 200 PPMV is often of great interest, as this value must be reported under the RMP regulation to the Environmental Protection Agency for at least two scenarios for certain facilities. This includes those with ammonia inventory of 10,000 lbs (4,536 kg) or more [37]. 200 PPMV corresponds to the concentration of 0.14 mg/Liter published in Appendix A of the EPA RMP regulation.

3.6 Limitations of the Modeling

It is important that readers of this paper understand the inherent limitations of the modeling method and software. Therefore the limitations explained in the previous paper are repeated here in their entirety:

The software models the plume dispersion as if it were occurring in a flat open area with uniform surface roughness. In an area with taller and/or irregular obstacles, there are two competing factors that can cause actual concentration or distance to deviate from predicted concentration or distance:

- Obstacles such as trees, buildings, etc., can create additional turbulence and mixing, which tends to dissipate a plume more quickly, resulting in lower downwind or crosswind distance for a given concentration
- Buildings, streets, alleyways, etc. can cause channeling of the plume, which reduces mixing with the ambient air, and can result in the dispersing material traveling greater distances than expected.

Given the limitations of this class of software, the results presented here should be taken as a semi-quantitative indication of the expected distances at a given concentration during a given weather. Greater distances or concentrations are possible if a release occurs during a fog-like calm, and/or if building arrangement or topography cause wind shadows, channeling, or other local effects.

PHAST does not take into account chemical interactions between the ammonia and other components in the environment such as water. Because of this, ammonia concentrations in the "far field" downwind may be overestimated, because the tendency of soil or vegetation to absorb ammonia are not taken into account.

PHAST is not capable of dispersion modeling crosswind releases. All releases were modeled as downward, vertical up, or horizontal, in the direction the wind is flowing.

Distances to concentrations of interest, and the elevation and shape of dispersing plumes, are estimates. CFD modeling or other computationally intensive techniques, wind tunnel experiments, field experiments, etc., would be required to refine the accuracy of the results. Each method has it's own advantages and limitations.

4. Outdoor Release Modeling

4.1 Discharge Rate

One goal of this case study was to consider a range of discharge rates that was representative of medium to large relief valves used in ammonia refrigeration applications, as well as a range of discharge conditions. Considering several different relief valve sizes and several different upstream pressures in a parametric study can lead to a large number of combinations that are difficult to summarize in a paper.

To simplify the data analysis and presentation of results, four discharge rates were considered in this study:

10 lb/min	(4.5 kg/min)
100 lb/min	(45.4 kg/min)
500 lb/min	(227 kg/min)
1000 lb/min	(453.6 kg/min)

The two lower flow rates are commonly encountered in ammonia refrigeration applications. The two higher flow rates might only be seen in very large systems. It should not be assumed that discharging at the higher flow rates for the durations described in this paper is credible for all or most facilities during their lifetimes. Release rates depend on the relative size of the refrigeration system and the relief valves that protect it. The consideration of probability of relief valve discharges at various rates and for various durations is beyond the scope of this paper. For more information on conducting Layer of Protection Analysis (LOPA) or Quantitative Risk Analysis (QRA) that consider the probabilities of events as well as their consequences, see publications regarding hydrocarbon refrigerants and also from the chemical process industry[38–44].

4.2 Thermodynamic Condition of Ammonia Discharge

Three ammonia state conditions were chosen for the relief valve discharge modeling:

+77°F (25°C) superheated vapor at atmospheric pressure
(Labeled WV for warm vapor in the tables in this paper)

-28°F (-33.3°C) saturated vapor at atmospheric pressure
(Labeled CV for cold vapor in the tables in this paper)

-28°F (-33.3°C) two-phase 0.12 liquid fraction by weight
(Labeled AER for aerosol in the tables in this paper)

The "warm vapor" condition was chosen to provide results representative of discharge of buoyant, "lighter than air" gas. When compared to air at +77°F (25°C), specific gravity of the ammonia warm vapor is 0.58.

The "aerosol" condition was chosen to provide results representative of discharge of cold, dense aerosols. While good engineering practice is to only relieve vapor to atmosphere, it is possible that aerosol releases can occur due overfilling a vessel with liquid, liquid swelling leading to liquid carryover in sudden reduction of pressure in a vessel, etc. When compared to air at +77°F (25°C), specific gravity of the aerosol is 1.38.

The intermediate, "cold vapor" condition was chosen to be representative of releases in a thermodynamic state and density between that of warm vapor and cold aerosol. When compared to air at +77°F (25°C), specific gravity of the ammonia cold vapor is 0.74.

Specific gravity is shown below for four conditions. Three conditions are the discharge conditions before the discharge mixes with air. The fourth is for ammonia aerosol that has mixed adiabatically with air of sufficient quantity to evaporate all the ammonia droplets. The adiabatic mixing process was calculated using UNISIM software [45], not the PHAST software. The various properties for the streams in adiabatic mixing were easier to access in UNISIM than in PHAST.

The data in this table show that during initial stages of dispersion, evaporation of liquid droplets is expected to cause the mixture temperature to drop quite low, well below the temperature of ammonia vapor in equilibrium with ammonia liquid at atmospheric pressure. This low predicted temperature is consistent with anecdotal field observations. In the example shown, when the last liquid droplets in the air-ammonia mixture are just evaporating, the mole ratio of air to ammonia is about 10:1, meaning the ammonia concentration is still fairly high at about 118,000 PPMV. This mixture would then be expected to become diluted and warmed by turbulent mixing with air as it disperses, eventually passing through neutral density relative to ambient air, and eventually becoming lighter than air.

Fluid	**Condition**	**Density Lb/ft³ (kg/m³)**	**S.G. relative to air**
Air	+77°F (25°C)	0.074 (1.179)	-
Ammonia Before Mixing With Air	Warm Vapor +77°F (25°C)	0.043 (0.7032)	.58
	Cold Vapor -28°F (-33.3°C)	0.055 (0.8890)	.74
	Ammonia Vapor with liquid droplets -28°F (-33.3°C) 12% mass fraction liquid	0.451 (7.225)	6.04
Ammonia in air	Ammonia Aerosol in air -90°F (-67°C) 0.0001% mass liquid remaining 118,000 PPMV Ammonia	0.102 (1.633)	1.38

Note: All at 14.7 psia (1 bara)

4.3 Relief Valve Discharge Orientation and Elevation

Discharge was modeled at three elevations:

15 feet
30 feet
45 feet

The elevation of 15 feet was chosen because it is a common requirement in codes and standards for minimum elevation of a refrigerant discharge above grade (ground level). The elevation of 30 feet was chosen as more representative of common discharge elevations at outdoor tanks such as milk silos. The elevation of 45 feet was chosen as a typical elevation representative of discharges above a roof or at elevated equipment such as evaporative condensers. The 45 feet also is of interest in evaluating the benefits of raising a discharge elevation for a release point that is currently located at a lower elevation.

Discharge was modeled at three orientations:

Vertical Up
Horizontal
30° below horizontal (slanted towards the ground)

Vertical up was chosen because this orientation is expected to be most efficient for enhancing dispersion and minimizing the chance that a problematic concentration of ammonia will reach ground level. Horizontal discharge and 30° down were chosen because it has been common in the industry to discharge horizontally or downward to minimize the chance of rain entering a discharge pipe, or of the pipe exit being blocked by snow and ice.

4.4 Relief Valve Discharge Velocity

A wide range of discharge velocities was modeled for the current paper, ranging from a low velocity to a value near the sonic velocity of ammonia. Low velocities were chosen to evaluate the impact of combining many discharge pipes into a common header.

The practice of discharging into a common header systems 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.

High velocities were chosen to evaluate efficiency of dispersion when discharge conditions are at or near sonic (choked) conditions. Sonic velocity for ammonia vapor was obtained from the NIST Chemistry WebBook[46]. Values obtained are as follows for the two ammonia vapor conditions considered here, both at atmospheric pressure:

1420.7 ft/second at +77°F (25°C) superheated vapor
1267.1 ft/second at -28°F (-33.3°C) saturated vapor

The range of velocities included in this study is:

100 feet / second	(30 m/sec)
250 feet / second	(76 m/sec)
500 feet / second	(152 m/sec)
750 feet / second	(228 m/sec)
1,000 feet / second	(305 m/sec)
1,250 feet / second	(381 m/sec)

Analysis of relief valve discharge line sizing tables in ASHRAE Standard 15-2010 and the IIAR 2012 Piping Handbook shows that flow is choked for many of the table entries. According to Reindl and Jekel[34], for isothermal flow in pipes, choking on air occurs when mach number reaches the value of 0.84, where the mach number is the actual velocity divided by the speed of sound in air. For air, 84% of the sonic velocity is 0.8 x 1,126 ft/sec (343 m/s) = 952 ft/sec (290 m/s).

4.5 Discharge Velocity Compared to ASHRAE Standard 15

Some readers may be interested in how the range of velocities used in this study compare to the range of velocities implied by the line sizing tables in ASHRAE Standard 15.

Tables 1 and 2 show a recalculation of discharge line capacity that matches Standard 15 and the Piping handbook for the 150 PSIG and 250 PSIG settings shown. Tables 1 and 2 also show the estimated discharge velocity assuming the specific volume of air at 70°F, and the % of choked velocity this represents. The calculated % of choked velocity is greater than 100% in the shorter lines for all flows. The likelihood of exceeding 100% increases as the line diameter increases. Since tabulated flow rates include those near sonic velocity, velocities up to the sonic velocity were used in the modeling described below.

The rated discharge air flow rates in Tables 1 and 2 range from 1.9 to 1,836 lb/min (0.9 to 833 kg/min). One manufacturer states that air capacity of relief valves can be converted from lb/min air to lb/min ammonia by dividing by 1.33[47]. Using this as a rough conversion, the expected range of ammonia release rates discharging into 0.5" to 6" NPS discharge pipes is in the range of 1.4 to 1,380 lb/min (0.6 to 626 kg/min). A range of mass flows near the middle of this broad range was used in the modeling described below.

The rough conversion of 1.33 was double-checked by calculating the volumetric flow rate from standard pipe sizes as a % of the choked velocity of ammonia. The % choked velocity used in Figure 3 ranges from 20% to 210% of choked velocity, to match the values in Table 2. Velocities above 100% of choked velocity denote that the flow is choked at the pipe outlet, and expands once the flow leaves the end of the pipe. Using this approach, the mass flow rates of ammonia of 1.4 to 1,407 lb/min (0.63 to 638 kg/min) shown in Table 3 are consistent with the range estimated in the paragraph above. In terms of orders of magnitude, the mass flow rate of interest for evaluating discharges from ammonia pressure relief valves covers roughly three orders of magnitude, from 1 to 1,000 lb/min.

4.6 Vents from Water Diffusion Tanks

When water tanks are used to absorb ammonia from a discharging relief valve, the water may become saturated with ammonia if the flow rate in combination with the duration exceeds the design absorption capacity of the water in the tank. If the water in a diffusion tank becomes saturated with ammonia, and the discharge of ammonia continues into the tank, the ammonia will simply pass through the water pool and exit the tank to atmosphere through the tank vent.

Atmospheric vents on water diffusion tanks are typically 6" to 12" diameter. It is important that they are large enough to prevent damage to the tank from a vacuum that may be caused by draining water from the tank, or by sudden condensation of ammonia vapor that has displace air from the vapor space. Typically the vents are pointed downward to avoid changes in water level due to rain or other precipitation. Ammonia flow from the vent should be quite low early in release events, but could increase if a release continues for a long time, the ammonia inventory is large in relation to the tank size, and the water becomes saturated with ammonia and new ammonia bubbling in passes through the water without being absorbed. Since the absorption of ammonia into water is an exothermic process, the water in the tank will tend to warm up above 100°F (37.8°C) as it approaches saturation with ammonia.

So in the data and graphs to follow, the results for warm vapor, discharging downward at low velocity, would be most relevant to discharges from water diffusion tanks that have been "overused" with the water becoming saturated with ammonia vapor.

For small water tanks such as the one modeled in the study by Hodges and Fenton, the top of the tank may be relatively close to the ground. They assumed 10 feet (3 meters). For larger water tanks on the order of 20,000 to 30,000 gallons, the top of the tank, and the atmospheric vent, are more likely to be 30 feet or higher above grade.

Even with smaller water diffusion tanks, the designer may choose a taller atmospheric vent opening to atmosphere at a higher elevation, in the interest of keeping released ammonia away from ground level should the tank fail to fully absorb ammonia as designed.

5. Resulting Ammonia Concentration Outdoors Downwind

Throughout this section, ammonia concentrations are reported for an elevation 3 feet (0.91 meters) above the ground. In the following discussion, the shorthand "downward" is used to refer to releases that are in the "30° below horizontal" orientation.

Distances to concentrations of interest near ground level for various relief valve discharge rates, as predicted by the dispersion modeling software, are shown in the following tables:

5.1 Results of Dispersion Modeling for a Range of Concentrations

Tables A-1 through A-12 in the appendix show downwind distances to the following concentrations of interest in increasing level of concentration: ERPG-1, STEL, IDLH, ERPG-2, ERPG-3. All five concentrations are presented because different users of this paper may have different concerns, e.g. facility design vs. emergency response planning. Each of Tables 4 through 15 are specific to one discharge mass flow rate and one thermodynamic discharge conditions, e.g. aerosol, cold vapor, or warm vapor.

While useful, these results contain a lot of data in which it may be difficult to see patterns. Therefore they have been placed in an appendix as reference material. The sections below sort and present the information in various ways that help highlight the patterns, with focus on the ERPG-2 concentration values, 200 PPMV.

5.2 Results for Aerosol Releases

Table 4 shows the predicted downwind distance to the ERPG-2 concentration of 200 PPMV for aerosol releases at various release orientations, release elevations, and release velocities. Table 5 shows the % reduction in downwind distance when horizontal or vertical up discharge is used rather than downward release orientation.

The top rows of Table 4 show the downwind distance to 200 PPMV for aerosol releases of ammonia in a downward direction, over the range of flow rates of 10 to 1,000 lb/min. (5.5 to 454 kg/min). It can be observed that:

- Even at the lowest release rate of 10 lb/min (4.5 kg/min), fairly long distances are indicated. With releases 15 feet (4.6 m) above grade (ground level) at optimum discharge velocity of 250 ft/sec (76 m/s), the downwind distance is 700 feet (213 m). Lower velocities result in slightly higher downwind distance.
- At higher release rates at the 15 foot elevation (4.5 m), downwind distance to 200 PPMV is predicted to increase dramatically. At optimum discharge velocity,

downwind distances are 3,120 feet (951 m) at 100 lb/min (45.4 kg/min), 7,890 feet (2,405 m) at 500 lb/min (227 kg/min) and 11,830 feet (3,600 m) at 1,000 lb/min (454 kg/min).
- Only a marginal reduction (improvement) in downwind distance is predicted when discharge elevation is 30 or 45 feet (9.1 or 13.7 m).

The middle and lower rows of Table 4 show the downwind distance to 200 PPMV for horizontal and vertical up discharges. Table 5 quantifies the improvement in downwind distances when horizontal or vertical up discharge is used rather than downward discharge. Tables 4 and 5 show:
- With horizontal discharge, the reduction (improvement) in downwind distance averages 42%, and ranges from 14% improvement to 100% improvement.

  Note: When a value of 100% improvement is shown, it means the downward discharge resulted in concentration of 200 PPMV or more at some distance downwind, but the result for the scenario being compared never reaches 200 PPMV within 3 feet of the ground at any distance downwind.

- With vertical discharge, the reduction (improvement) is more dramatic. The average reduction in downwind distance is 81%, with a range of 13% to 100%. Vertical up discharge provides the least benefit when discharge velocity is low at 100 to 250 feet/sec (30 to 76 m/sec), and flow rate is 100 lb/min (45.4 kg/min) or higher.

5.3 Results for Cold Gas Releases

Table 6 shows the predicted downwind distance to the ERPG-2 concentration of 200 PPMV for cold vapor releases at various release orientations, release elevations, and release velocities. Table 7 shows the % reduction in downwind distance when horizontal or vertical up discharge is used rather than downward release orientation.

The top rows of Table 6 show the downwind distance to 200 PPMV for cold vapor releases of ammonia in a downward direction, over the range of flow rates of 10 to 1,000 lb/min. (5.5 to 454 kg/min). It can be observed that:

- Even at the lowest release rate of 10 lb/min (4.5 kg/min), ammonia at concentrations of 200 PPMV or more is found near the ground downwind. With releases 15 feet (4.6 m) above grade at optimum discharge velocity of 100 ft/sec (30 m/s), the downwind distance is 150 feet (46 m). Higher velocities result in increased downwind distance. Presumably this is because the higher velocities drive the momentum jet closer to the ground before the momentum is dissipated and the dispersion becomes passive. Unlike the aerosol release, the cold vapor release is still less dense than air, so velocity (momentum) is required to propel the ammonia down towards the ground, not just gravity.
- At higher release rates at the 15 foot elevation (4.5 m), downwind distance to 200 PPMV increases. At optimum discharge velocity, downwind distances are 260 feet (79 m) at 100 lb/min (45.4 kg/min), 540 feet (165 m) at 500 lb/min (227 kg/min) and 790 feet (241 m) at 1,000 lb/min (454 kg/min).
- A large increase in downwind distance is predicted with the two highest mass flow rates and at discharge velocity of 500 ft/sec (152 m/s) or higher. For these conditions, the software predicts that cloud liftoff does not occur.
- Only a marginal reduction (improvement) in downwind distance is predicted when discharge elevation is 30 or 45 feet (9.1 or 13.7 m) and discharge velocity is 250 ft/sec (76 m/s) or slower. There is a notable exception for the prediction at 1000 lb/min (454 kg/min) and 1,250 feet/sec velocity (381 m/s), where it is again predicted that liftoff does not occur.

The middle and lower rows of Table 6 show the downwind distance to 200 PPMV for horizontal and vertical up discharges. Table 7 quantifies the improvement in downwind distances when horizontal or vertical up discharge is used rather than downward discharge. Tables 6 and 7 show:

- Horizontal discharge provides a marginal improvement over downward discharge, except at the lowest discharge rate of 10 lb/min (4.5 kg/min), where "no hazard" is predicted when the release elevation is 30 or 45 feet (9.1 or 13.7 m).
- With horizontal discharge, the reduction (improvement) in downwind distance averages 31%, and ranges from worse performance to 100% improvement.
- With vertical discharge, the reduction (improvement) is dramatic. It is predicted that the 200 PPMV concentration does not reach within 3 feet (0.9 m) of the ground at any distance downwind.

5.4 Results for Warm Gas Releases

Table 8 shows the predicted downwind distance to the ERPG-2 concentration of 200 PPMV for warm vapor releases at various release orientations, release elevations, and release velocities. Table 9 shows the % reduction in downwind distance when horizontal or vertical up discharge is used rather than downward release orientation.

The top rows of Table 8 show the downwind distance to 200 PPMV for warm vapor releases of ammonia in a downward direction, over the range of flow rates of 10 to 1,000 lb/min. (5.5 to 454 kg/min). It can be observed that:

- Even at the lowest release rate of 10 lb/min (4.5 kg/min), ammonia at concentrations of 200 PPMV or more is found near the ground downwind. With releases 15 feet (4.6 m) above grade at optimum discharge velocity of 100 ft/sec (30 m/s), the downwind distance is 100 feet (30 m). Higher velocities result in increased downwind distance. Again, this is probably because the higher velocity (momentum) propels the vapor jet closer to the ground before the momentum is dissipated and the dispersion becomes passive.
- At higher release rates at the 15 foot elevation (4.5 m), downwind distance to 200 PPMV increases. At optimum discharge velocity, downwind distances are 230 feet (70 m) at 100 lb/min (45.4 kg/min), 380 feet (116 m) at 500 lb/min (227 kg/min) and 260 feet (79 m) at 1,000 lb/min (454 kg/min).

- A large increase in downwind distance is predicted at 100 lb/min (45.4 kg/m) mass flow rate and at discharge velocities of 1,000 ft/sec (305 m/s) or higher. For these conditions, the software predicts that cloud liftoff does not occur.
- Higher discharge elevation does not provide a consistent improvement in downwind distance to 200 PPMV when discharge mass flow rate is 100 lb/min (45.4 kg/min) or higher. There are notable exceptions for the predictions at 100 lb/min (45.4 kg/min) mass flow rate, at 1,000 ft/sec (305 m/s) and 1,250 ft/sec (381 m/s) velocities, where it is predicted that liftoff does occur. Presumably this is because the discharging gas does not loose it's momentum by impinging on the ground.

The middle and lower rows of Table 8 show the downwind distance to 200 PPMV for horizontal and vertical up discharges. Table 9 quantifies the improvement in downwind distances when horizontal or vertical up discharge is used rather than downward discharge. Tables 8 and 9 show:

- In about half the cases, horizontal discharge provides a marginal or dramatic improvement over downward discharge. The effect is most notable at the lowest flow rate at the 15 feet (4.6 meter) discharge elevation.
- With horizontal discharge, the reduction (improvement) in downwind distance averages 31%, and ranges from worse performance (130% increase in distance to 200 PPMV) to 100% improvement.
- With vertical discharge, the reduction (improvement) is dramatic. It is predicted that the 200 PPMV concentration does not with 3 feet (0.9 m) of the ground at any distance downwind.

5.5 Improvement Results (%) Tabulated by Discharge Velocity

Tables 10 through 13 show the % reduction (improvement) in downwind distance to 200 PPMV when discharge orientation is horizontal or vertical up, with a separate table for each velocity. Each table includes all three thermodynamic states, aerosol, cold vapor, and warm vapor.

Table 10 for 100 ft/sec (76 m/s) discharge velocity shows:

- Horizontal release provides an average improvement of 36%
- Vertical up release provides an average improvement of 73%

Table 11 for 250 ft/sec (76 m/s) discharge velocity shows:

- Horizontal release provides an average improvement of 28%
- Vertical up release provides an average improvement of 83%

Table 12 for 500 ft/sec (152 m/s) discharge velocity shows:

- Horizontal release provides an average improvement of 25%
- Vertical up release provides an average improvement of 92%

Table 13 for 750 ft/sec (152 m/s) discharge velocity shows:

- Horizontal release provides an average improvement of 20%
- Vertical up release provides an average improvement of 100%

These results show that when discharge velocity is held constant, horizontal release provides a 25% to 28% reduction (improvement) in downwind distance, and vertical up discharge provides an 83% to 100% reduction (improvement) in downwind distance.

5.5 Distance Results Tabulated by Release Orientation

Tables 14 through 16 show the downwind distance to 200 PPMV when discharge orientation is downward, horizontal, or vertical up, for a range of discharge flow rates and velocities. Each table includes all three thermodynamic states, aerosol, cold vapor, and warm vapor.

Table 14 for 30° downward discharges shows:

- The 200 PPMV concentration reach significant distances for all thermodynamic conditions and velocities, except for some discharge velocities at the 45 foot (13.7

m) discharge elevation for cold vapor and warm vapor at the lowest flow rate, and for a low discharge velocity at the low flow rate at the 30 ft (9.1 m) elevation.

Table 15 for horizontal discharges shows:

- The 200 PPMV concentration reaches significant distances for all thermodynamic conditions and most velocities at the three highest flow rates that were modeled. An exception is warm vapor discharge at an elevation of 45 feet (13.7 meters), where the 200 PPMV does not reach ground level even at the discharge rate of 100 lb/min (45.4 kg/min).

Table 16 for vertical up discharges shows:

- For cold vapor and warm vapor discharge, it is predicted that the 200 PPMV concentration does not reach within 3 feet (0.9 m) of the ground at any distance downwind.
- For aerosol discharge, it is predicted that the 200 PPMV concentration does not reach within 3 feet (0.9 m) of the ground at any distance downwind, as long as adequate discharge velocity is maintained.
- Adequate discharge velocity for aerosol is approximately:
  250 ft/sec (76 m/s) at 10 lb/min (4.5 kg/min)
  500 ft/sec (152 m/s) at 100 lb/min (45.4 kg/min)
  750 ft/sec (229 m/s) at 500 and 1000 lb/min (227 and 454 kg/min)

6. Conclusions and Recommendations

Modern dispersion modeling software can only estimate the concentration that results downwind when a material such as ammonia is released to atmosphere. Such modeling in this class is considered successful if field measurements of ammonia concentration match predictions within a factor of 2 to 3. While the results are not highly precise, the analysis can still provide trends and insights that are useful to the ammonia refrigeration facility designer.

In the future, the refrigeration industry should place more emphasis on placing the discharges at an orientation as well as elevation to minimize possible ammonia concentrations near ground level downwind from the release location, while still minimizing and controlling entry of water, dust, etc.

This may be accomplished by future coordinated changes to standards and model codes to emphasize the following when release to atmosphere is allowed:

1. There should be a combination of design features such as easily dislodged rain caps, drip legs and drain valves, and administrative controls such as periodic inspection and draining by operators, to control the entry and prevent the accumulation of water in the relief discharge piping. There will continue to be a need for high confidence that water will not accumulate and either freeze in place or severely corrode the pipe, leading to discharge pipe blockage.

2. Wording in standards should be adjusted to allow alternatives to pointing discharges down towards the ground just to keep out the rain. Such alternatives may be appropriate when they improve worker safety and reduce potential off-site exposure to ammonia while maintaining a very high availability and reliability of the relief system.

3. Assuming entry and accumulation of moisture can be properly managed, the release orientation should be vertical up for all but the smallest relief devices (This refers to "process" relief valves. Hydrostatic safeties are outside the scope of this paper.)

4. 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.

5. When the potential for an aerosol release exists, and probability of such a release cannot be reduced to a very low, tolerable level by appropriate

safeguards, a minimum velocity at the stack discharge should be maintained, on the order of:

250 ft/sec (76 m/s) at 10 lb/min (4.5 kg/min)
500 ft/sec (152 m/s) at 100 lb/min (45.4 kg/min)
750 ft/sec (229 m/s) at 500 and 1,000 lb/min (227 and 454 kg/min)

Note: 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.

6. Model standards and codes should allow the use of a reducer at the stack tip, to provide higher discharge velocity, as long as the pressure drop of the reducer is taken into account in calculating the back pressure on the relief valve(s) for the design case(s).

7. Further evaluation should be done to determine if the recommended measures represent a significant enough improvement in industry practices to justify the retirement of the use of water dump tanks in certain jurisdictions as an alternative safeguard measure.

Many of these recommendations are not new. The author hopes that this paper will provide analytic support for them, and provide an impetus for the industry to move these ideas from recommendations to requirements in the model codes and standards.

7. References

[1] Timm M., 2013, "Case Study: Use of Dispersion Modeling Software in Ammonia Refrigeration Facility Design," IIAR Proceedings, 35th Annual Meeting, IIAR, Colorado Springs, CO.

[2] ANSI/IIAR, 2008, "Standard IIAR-2-2008 Addendum A -Standard for Equipment, Design and Installation of Closed-Circuit Ammonia Mechanical Refrigerating Systems."

[3] ASHRAE, 2010, "Standard 15 Safety Standard for Refrigeration Systems."

[4] CSA, 2009, "B52-05 Mechanical Refrigeration Code."

[5] ICC, 2012, "2012 International Mechanical Code."

[6] 2012, Uniform Mechanical Code, IAPMO, Ontario, CA.

[7] Fenton D., Chapman K. S., Kelley R. D., and Khan A. S., 1995, "Operating Characteristics of a Flare/Oxidizer for the Disposal of Ammonia from an Industrial Refrigeration Facility," ASHRAE Trans., 101(Part 2).

[8] Fenton D., Khan A. S., Kelley R. D., and Chapman K. S., 1995, "Combustion Characteristics of Ammonia-Air Mixtures," ASHRAE Trans., 101(Part 2).

[9] Shepherd J. J., 1988, "Ammonia Flares: Incinerators-Oxidizers–A Proven Safe and Readily Used Method for Disposing of Ammonia in Industrial Applications," IIAR Proceedings, IIAR, Savannah, GA.

[10] Shepherd J. J., 1990, "Ammonia Flares: Costs, Codes, Installation and Design Considerations," IIAR Proceedings, IIAR, Memphis, TN.

[11] Shepherd J. J., "Ammonia Flaring Systems," IIAR Proceedings.

[12] Khan A. S., Kelley R. D., Chapman K. S., and Fenton D. L., "Flammability Limits of Ammonia-Air Mixtures," ASHRAE Trans., 101(2), pp. 454–462.

[13] Saye H. A., "Water Dilution Ammonia Tanks," IIAR Proceedings.

[14] Bonar II H. B., 1998, "Water Dump Tanks : Fact or Fiction ?," IIAR Proceedings, C. Combs, D. Kuespert, and K. Anderson, eds., IIAR.

[15] Krause R. J., 1995, "Relief Devices Revisited," IIAR Proceedings, W.F. Stoecker, K. Anderson, and L.E. Jones, eds., IIAR, San Diego, CA.

[16] Richards W. V., 1998, "How Piping Affects Safety Relief Valve Performance," IIAR Proceedings, C. Combs, D. Kuespert, and K. Anderson, eds., IIAR, pp. 55–86.

[17] Bonebrake L., and Kuespert D., 2002, "What the Heck Do I Do With My Relief Valves ?," IIAR Proceedings, G. Troy, and M.K. Anderson, eds., IIAR, Kansas City, MO.

[18] Johnson D. W., Martinsen W. E., and Cornwell J. B., 2008, "Relief Valves and Vents : How Exit Conditions Affect Hazard Zones," Rep. Internet.

[19] API, 2008, ANSI/API 521 Pressure-Relieving and Depressuring Systems, Washington, D.C.

[20] Stoecker W. F., 1988, "Discharge of Ammonia Vapor Into the Atmosphere," IIAR Proceedings, IIAR.

[21] Stoecker W. F., 1990, "Concentration of Ammonia in the Vicinity of Vapor Releases," IIAR Proceedings.

[22] Trinity_Consultants, 1990, "Breeze Air, Version of UNAMAP6."

[23] Stewart W. E. J., Clark R. W., and Stickler L. A., 1995, "Gaseous Ammonia Dispersion–Comparison of Experimental Data with Two Predictive Models," ASHRAE Trans.

[24] Kaiser G. D., 1996, ""Identification and Modeling of Worst-Case Scenarios for Ammonia Refrigeration Systems," IIAR Proceedings, IIAR, Atlanta, GA.

[25] Woodward J., 1997, "Improving Effect of Atmospheric Stability Class on Hazard Zone Predictions for an Ammonia Release," IIAR Proceedings, L.E. Jones, D.R. Kuespert, and K. Anderson, eds., IIAR, New Orleans, LA, pp. 111–141.

[26] Kuespert D. R., and Kent A. M., 1998, "Dispersion of Ammonia From Safety Relief Valves," IIR Gustav Lorentzen Conference on Natural Working Fluids, Oslo, Norway, pp. 755–764.

[27] Hoot T. ., Meroney R. N., and Peterka J. A., 1973, Wind Tunnel Tests of Negaively Bouyant Plumes CER73-74TGH-RNM-JAP-13, Washington.

[28] Fenton D., Walenta C., and Chapman K., 2001, "Forced Dispersion of Ammonia Plumes Into the Atmosphere," ASHRAE Trans., 107(Part 1).

[29] 2012, Ammonia Refrigeration Piping Handbook, IIAR, Washington, D.C.

[30] Hodges T., 2013, "Comparison of Various Methods of Mitigating Overpressure Induced Relief Events Involving Ammonia Refrigeration Using Quantitative Risk Analysis (QRA)," Kansas State University.

[31] Hodges T., and Fenton D., 2013, Comparison of Various Methods of Mitigating Over Pressure Induced Release Events Involving Ammonia Refrigeration Using Quantitative Risk Analysis (QRA).

[32] Leung J. C., 1996, "Pressure Relief Consideration for Refrigeration Equipment," Process Saf. Prog., 15(2).

[33] Sung H., and Wheeler J. G., 1997, "Source Characterization of Ammonia Accidental Releases for Various Storage and Process Conditions Thermodynamic Properties of Anhydrous Ammonia," Air and Waste Management Association Annual Meeting and Exhibition, Toronto, ON, pp. 1–11.

[34] Reindl D. T., and Jekel T. B., 2008, "Fundamentals of Safety Relief Systems," ASHRAE J.

[35] Kensington_Consulting_(Anon), 2013, Validating Ammonia Refrigeration System Pressure Relief Vent Designs.

[36] Reindl D. T., Jekel T. B., and Dettmers D., 2012, "Scenarios for Sizing Relief Vent Systems," IRC Newsletter, UW-Madison, 12(2), pp. 1–14.

[37] U.S.EPA, 1999, 40 CFR Part 68 Chemical Accident Prevention Provisions, USA.

[38] Baybutt P., 2012, "Risk Tolerance Criteria for Layers of Protection Analysis," Process Saf. Prog., 31(2), pp. 8–11.

[39] Beerens H. I., Post J. G., and Uijt De Haag P. A. M., 2006, "The use of generic failure frequencies in QRA: the quality and use of failure frequencies and how to bring them up-to-date.," J. Hazard. Mater., 130(3), pp. 265–70.

[40] Bridges W. B. (Bill), and Clark T., 2010, "Key issues with implementing LOPA," Process Saf. Prog., 29(2), p. n/a–n/a.

[41] CCPS, Guidelines for Chemical Process Quantitative Risk Analysis, Wiley-AIChE.

[42] Colbourne D., Colbourne D., and Ritter T. J., 2002, "Quantitative Risk Assessment Of Flammable Refrigerants In Room Air Conditioners," International Refrigeration and Air Conditioning Conference, West Lafayette, IN.

[43] Pitblado R. M., Bain B., Falck A., Litland K., and Spitzenberger C., 2011, "Frequency data and modification factors used in QRA studies," J. Loss Prev. Process Ind., 24(3), pp. 249–258.

[44] Reyes G. Z., 2008, "Layer of Protection Analysis Applied to Ammonia Refrigeration Systems," Texas A&M University.

[45] 2013, "UNISIM Design, Version R400, Honeywell Inc."

[46] 2013, "NIST Chemistry WebBook" [Online]. Available: http://www.nist.gov/mml/csd/informatics_research/webbook_chemident.cfm. [Accessed: 22-Sep-2013].

[47] Henry_Technologies, "Safety Devices–Pressure Relief Valves (internet download 2013)."

Appendix. Tables Showing Results of Dispersion Modeling for a Range of Concentrations

Table 1 Fluid: Air

Pressure-Relief Valve Discharge Line Exit Velocity at Rated Flow Rates

Set Pressure	**150 PSIG** (17.2 barg)	**Sonic Velocity**	**1126 ft/sec** (343.2 m/sec)
Allowed Back Pressure	**22.5 PSI** (3.6 bar)	**k, ratio of spec. heats**	**1.4 (dimensionless)**
Assumed density at atm. Pr.	**0.0764 lb/ft3** (1.195 kg/m3)	**$1/(k^{0.5})$**	**0.845 (dimensionless)**
Specific Gravity (air =1)	**1**	**Choked velocity**	**952 ft/sec** (290 m/sec)

		Nominal Pipe Size, NPS									
		Inches									
		0.5		1		2		4		6	
		Inside Diameter if SCH 40									
		0.622 Inches **15.8** mm		**1.049** Inches **26.6** mm		**2.067** Inches **52.5** mm		**4.026** Inches **102.3** mm		**6.065** Inches **154.1** mm	
Discharge Pipe Length		**Discharge Line Capacity**									
feet	meters	**lb/min**	kg/min	**lb/min**	kg/min	**lb/min**	kg/min	**lb/min**	kg/min	**lb/min**	kg/min
2	0.9	**12.6**	5.7	**39.2**	17.8	**163**	73.7	**636**	288	**1457**	661
5	2.3	**10.2**	4.6	**34.0**	15.4	**151**	68.5	**613**	278	**1425**	646
10	4.5	**8.1**	3.7	**28.7**	13.0	**136**	61.8	**581**	263	**1375**	624
15	6.8	**6.9**	3.1	**25.2**	11.4	**125**	56.7	**553**	251	**1330**	603
20	9.1	**6.2**	2.8	**22.8**	10.3	**116**	52.7	**528**	240	**1289**	585
25	11.3	**5.6**	2.5	**21.0**	9.5	**109**	49.5	**507**	230	**1252**	568
30	13.6	**5.2**	2.3	**19.5**	8.8	**103**	46.8	**488**	221	**1218**	553
40	18.1	**4.5**	2.1	**17.3**	7.9	**93.6**	42.4	**456**	207	**1158**	525
60	27.2	**3.8**	1.7	**14.5**	6.6	**80.5**	36.5	**407**	185	**1059**	480
100	45.4	**2.9**	1.3	**11.5**	5.2	**65.3**	29.6	**343**	156	**920**	417
160	72.6	**2.3**	1.1	**9.2**	4.2	**53.0**	24.1	**286**	130	**787**	357
250	113	**1.9**	0.9	**7.4**	3.4	**43.2**	19.6	**238**	108	**664**	301
Discharge Pipe Length		**Discharge Velocity, feet/second**									
feet	meters	**ft/sec**	m/sec	**ft/sec**	m/sec	**ft/sec**	m/sec	**ft/sec**	m/sec	**ft/sec**	m/sec
2	0.9	**1298**	396	**1424**	434	**1521**	464	**1569**	478	**1584**	483
5	2.3	**1051**	320	**1237**	377	**1413**	431	**1513**	461	**1549**	472
10	4.5	**838**	255	**1042**	318	**1275**	389	**1433**	437	**1495**	456
15	6.8	**717**	219	**917**	280	**1170**	357	**1364**	416	**1446**	441
20	9.1	**637**	194	**829**	253	**1088**	332	**1304**	397	**1402**	427
25	11.3	**579**	176	**762**	232	**1021**	311	**1251**	381	**1362**	415
30	13.6	**534**	163	**709**	216	**965**	294	**1205**	367	**1325**	404
40	18.1	**469**	143	**629**	192	**876**	267	**1125**	343	**1259**	384
60	27.2	**389**	118	**527**	161	**753**	230	**1004**	306	**1152**	351
100	45.4	**305**	92.9	**417**	127	**611**	186	**846**	258	**1000**	305
160	72.6	**242**	73.9	**334**	102	**497**	151	**707**	215	**855**	261
250	113	**195**	59.4	**270**	82.2	**404**	123	**586**	179	**722**	220
Discharge Pipe Length		**% of Choked Velocity (Shaded cells indicate that flow is choked)**									
feet	meters										
2	0.9	136%		150%		160%		165%		166%	
5	2.3	110%		130%		148%		159%		163%	
10	4.5	88%		109%		134%		151%		157%	
15	6.8	75%		96%		123%		143%		152%	
20	9.1	67%		87%		114%		137%		147%	
25	11.3	61%		80%		107%		131%		143%	
30	13.6	56%		74%		101%		127%		139%	
40	18.1	49%		66%		92%		118%		132%	
60	27.2	41%		55%		79%		105%		121%	
100	45.4	32%		44%		64%		89%		105%	
160	72.6	25%		35%		52%		74%		90%	
250	113	20%		28%		42%		62%		76%	

Table 2 Fluid: Air

Pressure-Relief Valve Discharge Line Exit Velocity at Rated Flow Rates

Set Pressure	**250 PSIG** (17.2 barg)	**Sonic Velocity**	**1126 ft/sec** (343.2 m/sec)
Allowed Back Pressure	**37.5 PSI** (3.6 bar)	**k, ratio of spec. heats**	**1.4 (dimensionless)**
Assumed density at atm. Pr.	**0.0764 lb/ft3** (1.195 kg/m3)	**$1/(k^{0.5})$**	**0.845 (dimensionless)**
Specific Gravity (air =1)	**1**	**Choked velocity**	**952 ft/sec** (290 m/sec)

Nominal Pipe Size, NPS — Inches

		0.5		1		2		4		6	
		Inside Diameter if SCH 40									
		0.622 Inches **15.8** mm		**1.049** Inches **26.6** mm		**2.067** Inches **52.5** mm		**4.026** Inches **102.3** mm		**6.065** Inches **154.1** mm	
Discharge Pipe Length		**Discharge Line Capacity**									
feet	meters	**lb/min**	kg/min	**lb/min**	kg/min	**lb/min**	kg/min	**lb/min**	kg/min	**lb/min**	kg/min
2	0.9	**16.5**	7.5	**50.6**	23.0	**207**	93.8	**803**	364	**1836**	833
5	2.3	**13.9**	6.3	**45.2**	20.5	**195**	88.7	**782**	355	**1805**	819
10	4.5	**11.3**	5.1	**39.1**	17.7	**180**	81.7	**750**	340	**1758**	797
15	6.8	**9.8**	4.5	**35.0**	15.9	**168**	76.1	**721**	327	**1713**	777
20	9.1	**8.8**	4.0	**31.9**	14.5	**158**	71.5	**696**	316	**1673**	759
25	11.3	**8.0**	3.6	**29.5**	13.4	**149**	67.7	**673**	305	**1634**	741
30	13.6	**7.4**	3.4	**27.6**	12.5	**142**	64.4	**652**	296	**1599**	725
40	18.1	**6.6**	3.0	**24.7**	11.2	**130**	59.1	**616**	279	**1534**	696
60	27.2	**5.5**	2.5	**20.9**	9.5	**114**	51.5	**558**	253	**1425**	646
100	45.4	**4.3**	1.9	**16.6**	7.5	**93.2**	42.3	**479**	217	**1263**	573
160	72.6	**3.4**	1.6	**13.4**	6.1	**76.4**	34.7	**406**	184	**1098**	498
250	113	**2.8**	1.2	**10.8**	4.9	**62.6**	28.4	**340**	154	**939**	426

Discharge Pipe Length		**Discharge Velocity, feet/second**									
feet	meters	**ft/sec**	m/sec	**ft/sec**	m/sec	**ft/sec**	m/sec	**ft/sec**	m/sec	**ft/sec**	m/sec
2	0.9	**1710**	521	**1841**	561	**1937**	590	**1981**	604	**1996**	608
5	2.3	**1433**	437	**1644**	501	**1830**	558	**1929**	588	**1963**	598
10	4.5	**1171**	357	**1422**	434	**1685**	514	**1850**	564	**1911**	582
15	6.8	**1015**	309	**1271**	387	**1571**	479	**1779**	542	**1863**	568
20	9.1	**908**	277	**1160**	354	**1476**	450	**1717**	523	**1819**	554
25	11.3	**829**	253	**1073**	327	**1397**	426	**1660**	506	**1777**	542
30	13.6	**768**	234	**1004**	306	**1330**	405	**1609**	490	**1738**	530
40	18.1	**677**	206	**897**	274	**1220**	372	**1519**	463	**1668**	508
60	27.2	**564**	172	**758**	231	**1063**	324	**1377**	420	**1550**	472
100	45.4	**444**	135	**605**	184	**873**	266	**1182**	360	**1373**	418
160	72.6	**354**	108	**486**	148	**716**	218	**1001**	305	**1194**	364
250	113	**285**	86.8	**393**	120	**586**	179	**839**	256	**1021**	311

Discharge Pipe Length		**% of Choked Velocity (Shaded cells indicate that flow is choked)**				
feet	meters	0.5	1	2	4	6
2	0.9	180%	193%	203%	208%	210%
5	2.3	151%	173%	192%	203%	206%
10	4.5	123%	149%	177%	194%	201%
15	6.8	107%	134%	165%	187%	196%
20	9.1	95%	122%	155%	180%	191%
25	11.3	87%	113%	147%	174%	187%
30	13.6	81%	105%	140%	169%	183%
40	18.1	71%	94%	128%	160%	175%
60	27.2	59%	80%	112%	145%	163%
100	45.4	47%	64%	92%	124%	144%
160	72.6	37%	51%	75%	105%	125%
250	113	30%	41%	62%	88%	107%

Table 3 Fluid: Ammonia

Pressure-Relief Valve Ammonia Volume and Mass Flow at % of Choked Velocity

Fluid:	**Ammonia**	**Sonic Velocity**	**1421 ft/sec** (433.1 m/sec)
Assumed density at atm. Pr.	**0.045 lb/ft3** (0.721 kg/m3)	**k, ratio of spec. heats**	**1.32** (dimensionless)
Specific Gravity (air =1)	**0.589**	**$1/(k^{0.5})$**	**0.870** (dimensionless)
		Choked velocity	**1237** ft/sec (290 m/sec)

	Nominal Discharge Pipe Size, NPS									
	Inches									
	0.5		**1**		**2**		**4**		**6**	
	Inside Diameter if SCH 40									
	0.622 Inches **15.8** mm		**1.049** Inches **26.6** mm		**2.067** Inches **52.5** mm		**4.026** Inches **102.3** mm		**6.065** Inches **154.1** mm	
% Choked Velocity at Pipe Outlet	**Discharge Line Volumetric Capacity** (Shaded cells indicate that flow is choked)									
feet	**ft3/min**	m3/min	**ft3/min**	m3/min	**ft3/min**	m3/min	**ft3/min**	m3/min	**ft3/min**	m3/min
20%	**31.3**	0.9	**89.1**	2.5	**346**	9.8	**1,312**	37.1	**2,978**	84.3
30%	**47.0**	1.3	**134**	3.8	**519**	14.7	**1,968**	55.7	**4,467**	126
40%	**62.6**	1.8	**178**	5.0	**692**	19.6	**2,624**	74.3	**5,955**	169
50%	**78.3**	2.2	**223**	6.3	**865**	24.5	**3,280**	92.8	**7,444**	211
60%	**94.0**	2.7	**267**	7.6	**1,038**	29.4	**3,936**	111	**8,933**	253
70%	**110**	3.1	**312**	8.8	**1,210**	34.3	**4,592**	130	**10,422**	295
80%	**125**	3.5	**356**	10.1	**1,383**	39.2	**5,248**	149	**11,911**	337
90%	**141**	4.0	**401**	11.3	**1,556**	44.0	**5,904**	167	**13,400**	379
100%	**157**	4.4	**445**	12.6	**1,729**	48.9	**6,560**	186	**14,888**	421
110%	**172**	4.9	**490**	13.9	**1,902**	53.8	**7,216**	204	**16,377**	463
120%	**188**	5.3	**534**	15.1	**2,075**	58.7	**7,873**	223	**17,866**	506
130%	**204**	5.8	**579**	16.4	**2,248**	63.6	**8,529**	241	**19,355**	548
140%	**219**	6.2	**624**	17.6	**2,421**	68.5	**9,185**	260	**20,844**	590
150%	**235**	6.6	**668**	18.9	**2,594**	73.4	**9,841**	278	**22,333**	632
160%	**251**	7.1	**713**	20.2	**2,767**	78.3	**10,497**	297	**23,821**	674
170%	**266**	7.5	**757**	21.4	**2,940**	83.2	**11,153**	316	**25,310**	716
180%	**282**	8.0	**802**	22.7	**3,113**	88.1	**11,809**	334	**26,799**	758
190%	**298**	8.4	**846**	23.9	**3,286**	93.0	**12,465**	353	**28,288**	801
200%	**313**	8.9	**891**	25.2	**3,459**	97.9	**13,121**	371	**29,777**	843
210%	**329**	9.3	**935**	26.5	**3,631**	103	**13,777**	390	**31,266**	885
% Choked Velocity at Pipe Outlet	**Discharge Mass Flow** **(Shaded cells indicate that flow is choked)**									
feet	**lb/min**	kg/min	**lb/min**	kg/min	**lb/min**	kg/min	**lb/min**	kg/min	**lb/min**	kg/min
20%	**1.4**	0.6	**4.0**	1.8	**15.6**	7.1	**59.0**	26.8	**134**	60.8
30%	**2.1**	1.0	**6.0**	2.7	**23.3**	10.6	**88.6**	40.2	**201**	91.2
40%	**2.8**	1.3	**8.0**	3.6	**31.1**	14.1	**118**	53.6	**268**	122
50%	**3.5**	1.6	**10.0**	4.5	**38.9**	17.6	**148**	67.0	**335**	152
60%	**4.2**	1.9	**12.0**	5.5	**46.7**	21.2	**177**	80.3	**402**	182
70%	**4.9**	2.2	**14.0**	6.4	**54.5**	24.7	**207**	93.7	**469**	213
80%	**5.6**	2.6	**16.0**	7.3	**62.3**	28.2	**236**	107	**536**	243
90%	**6.3**	2.9	**18.0**	8.2	**70.0**	31.8	**266**	121	**603**	274
100%	**7.0**	3.2	**20.0**	9.1	**77.8**	35.3	**295**	134	**670**	304
110%	**7.8**	3.5	**22.0**	10.0	**85.6**	38.8	**325**	147	**737**	334
120%	**8.5**	3.8	**24.1**	10.9	**93.4**	42.4	**354**	161	**804**	365
130%	**9.2**	4.2	**26.1**	11.8	**101**	45.9	**384**	174	**871**	395
140%	**9.9**	4.5	**28.1**	12.7	**109**	49.4	**413**	187	**938**	425
150%	**10.6**	4.8	**30.1**	13.6	**117**	52.9	**443**	201	**1,005**	456
160%	**11.3**	5.1	**32.1**	14.5	**125**	56.5	**472**	214	**1,072**	486
170%	**12.0**	5.4	**34.1**	15.5	**132**	60.0	**502**	228	**1,139**	517
180%	**12.7**	5.8	**36.1**	16.4	**140**	63.5	**531**	241	**1,206**	547
190%	**13.4**	6.1	**38.1**	17.3	**148**	67.1	**561**	254	**1,273**	577
200%	**14.1**	6.4	**40.1**	18.2	**156**	70.6	**590**	268	**1,340**	608
210%	**14.8**	6.7	**42.1**	19.1	**163**	74.1	**620**	281	**1,407**	638

Shaded area for "supersonic" flow indicates that choked flow exists within the discharge pipe.

Table 4
Distance to Concentrations of Interest for Outdoor Release from PSV
Aerosol Release at Various Release Rates **1.5 F Weather**

Release Condition:
-28°F, 0.12 liquid fraction
-33.3°C, 0.12 liquid fraction

Orientation	Discharge Elevation		Discharge Velocity		Distance to ERPG-2 Concentration, ft (meters)							
					10 lb/min (4.5 kg/min)		100 lb/min (45.4 kg/min)		500 lb/min (227 kg/min)		1000 lb/min (454 kg/min)	
	ft	meters	ft /sec	meters /sec	ft	meters	ft	meters	ft	meters	ft	meters
Down 30°	15	4.6	100	30	760	232	3,650	1,113	9,480	2,890	14,120	4,304
			250	76	700	213	3,570	1,088	9,110	2,777	13,630	4,154
			500	152	710	216	3,410	1,039	8,690	2,649	13,010	3,965
			750	229	710	216	3,280	1,000	8,380	2,554	12,550	3,825
			1000	305	720	219	3,200	975	8,110	2,472	12,160	3,706
			1250	381	710	216	3,120	951	7,890	2,405	11,830	3,606
	30	9.1	100	30	540	165	2,850	869	8,560	2,609	13,280	4,048
			250	76	320	98	2,830	863	8,230	2,509	12,520	3,816
			500	152	230	70	2,770	844	7,680	2,341	11,590	3,533
			750	229	250	76	2,690	820	7,260	2,213	10,890	3,319
			1000	305	320	98	2,620	799	6,920	2,109	10,400	3,170
			1250	381	380	116	2,550	777	6,680	2,036	10,050	3,063
	45	13.7	100	30	450	137	2,450	747	7,560	2,304	12,070	3,679
			250	76	NH	NH	2,260	689	7,340	2,237	11,580	3,530
			500	152	NH	NH	2,060	628	6,970	2,124	10,770	3,283
			750	229	NH	NH	2,000	610	6,610	2,015	10,130	3,088
			1000	305	120	37	1,960	597	6,330	1,929	9,610	2,929
			1250	381	130	40	1,920	585	6,060	1,847	9,180	2,798
Horiz.	15	4.6	100	30	540	165	2,890	881	7,980	2,432	12,160	3,706
			250	76	360	110	2,530	771	7,190	2,192	10,980	3,347
			500	152	250	76	2,160	658	6,330	1,929	9,730	2,966
			750	229	270	82	1,920	585	5,730	1,747	8,860	2,701
			1000	305	320	98	1,750	533	5,280	1,609	8,210	2,502
			1250	381	350	107	1,610	491	4,920	1,500	7,660	2,335
	30	9.1	100	30	460	140	2,520	768	7,090	2,161	11,040	3,365
			250	76	NH	NH	2,100	640	6,220	1,896	9,820	2,993
			500	152	140	43	1,600	488	5,280	1,609	8,490	2,588
			750	229	150	46	1,320	402	4,640	1,414	7,580	2,310
			1000	305	NH	NH	1,320	402	4,190	1,277	6,870	2,094
			1250	381	NH	NH	1,370	418	3,820	1,164	6,280	1,914
	45	13.7	100	30	NH	NH	2,010	613	6,420	1,957	10,280	3,133
			250	76	NH	NH	1,500	457	5,550	1,692	9,010	2,746
			500	152	NH	NH	990	302	4,640	1,414	7,680	2,341
			750	229	NH	NH	650	198	4,050	1,234	6,730	2,051
			1000	305	NH	NH	700	213	3,590	1,094	6,000	1,829
			1250	381	NH	NH	790	241	3,300	1,006	5,420	1,652
Up	15	4.6	100	30	620	189	2,750	838	7,170	2,185	10,930	3,332
			250	76	NH	NH	1,560	475	4,600	1,402	7,370	2,246
			500	152	NH	NH	NH	NH	1,930	588	3,960	1,207
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	NH	NH	2,450	747	6,810	2,076	10,550	3,216
			250	76	NH	NH	1,280	390	4,320	1,317	7,080	2,158
			500	152	NH	NH	NH	NH	NH	NH	3,620	1,103
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	2,120	646	6,460	1,969	10,160	3,097
			250	76	NH	NH	NH	NH	4,050	1,234	6,740	2,054
			500	152	NH	NH	NH	NH	NH	NH	3,210	978
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table 5
% Reduction in Concentration with Horizontal or Vertical Discharge
Aerosol Release at Various Release Rates

Release Condition:
-28°F, 0.12 liquid fraction
-33.3°C, 0.12 liquid fraction

					% Reduction in Distance to ERPG-2 Concentration Compared with Distance for 30°Down Discharge				
	Discharge Elevation		**Discharge Velocity**		**10 lb/min** (4.5 kg/min)	**100 lb/min** (45.4 kg/min)	**500 lb/min** (227 kg/min)	**1000 lb/min** (454 kg/min)	**Average**
Orientation	**ft**	meters	**ft/sec**	meters/sec	**%**	**%**	**%**	**%**	**%**
Horiz.	**15**	4.6	100	30	29%	21%	16%	14%	20%
			250	76	49%	29%	21%	19%	30%
			500	152	65%	37%	27%	25%	38%
			750	229	62%	41%	32%	29%	41%
			1000	305	56%	45%	35%	32%	42%
			1250	381	51%	48%	38%	35%	43%
	30	9.1	100	30	15%	12%	17%	17%	15%
			250	76	100%	26%	24%	22%	43%
			500	152	39%	42%	31%	27%	35%
			750	229	40%	51%	36%	30%	39%
			1000	305	100%	50%	39%	34%	56%
			1250	381	100%	46%	43%	38%	57%
	45	13.7	100	30	100%	18%	15%	15%	37%
			250	76	NH 30°Down	34%	24%	22%	27%
			500	152	NH 30°Down	52%	33%	29%	38%
			750	229	NH 30°Down	68%	39%	34%	47%
			1000	305	100%	64%	43%	38%	61%
			1250	381	100%	59%	46%	41%	61%
	Average for all elevations		100	30	48%	17%	16%	15%	24%
			250	76	74%	30%	23%	21%	37%
			500	152	52%	44%	31%	27%	38%
			750	229	51%	53%	35%	31%	43%
			1000	305	85%	53%	39%	35%	53%
			1250	381	84%	51%	42%	38%	54%
			Aveage		67%	41%	31%	28%	42%
Up	**15**	4.6	100	30	18%	25%	24%	23%	23%
			250	76	100%	56%	50%	46%	63%
			500	152	100%	100%	78%	70%	87%
			750	229	100%	100%	100%	100%	100%
			1000	305	100%	100%	100%	100%	100%
			1250	381	100%	100%	100%	100%	100%
	30	9.1	100	30	100%	14%	20%	21%	39%
			250	76	100%	55%	48%	43%	61%
			500	152	100%	100%	100%	69%	92%
			750	229	100%	100%	100%	100%	100%
			1000	305	100%	100%	100%	100%	100%
			1250	381	100%	100%	100%	100%	100%
	45	13.7	100	30	100%	13%	15%	16%	36%
			250	76	NH 30°Down	100%	45%	42%	62%
			500	152	NH 30°Down	100%	100%	70%	90%
			750	229	NH 30°Down	100%	100%	100%	100%
			1000	305	100%	100%	100%	100%	100%
			1250	381	100%	100%	100%	100%	100%
	Average for all elevations		100	30	73%	17%	20%	20%	32%
			250	76	100%	70%	47%	44%	62%
			500	152	100%	100%	93%	70%	90%
			750	229	100%	100%	100%	100%	100%
			1000	305	100%	100%	100%	100%	100%
			1250	381	100%	100%	100%	100%	100%
			Aveage		**95%**	**81%**	**77%**	**72%**	**81%**

Grey shading indicates that the base case for the comparison, 30°Down Discharge, has no harm (conc. Below 200 PPMV)
Yellow shading indicates that the base case for the comparison, 30°Down Discharge, has a shorter distance to 200 PPMV

Table 6
Distance to Concentrations of Interest for Outdoor Release from PSV
Cold Vapor Release at Various Release Rates **1.5 F Weather**

Release Condition:
-28°F, Saturated Vapor
-33.3°C, Saturated Vapor

					Distance to ERPG-2 Concentration, ft (meters)							
	Discharge Elevation		Discharge Velocity		10 lb/min (4.5 kg/min)		100 lb/min (45.4 kg/min)		500 lb/min (227 kg/min)		1000 lb/min (454 kg/min)	
Orientation	ft	meters	ft /sec	meters /sec	ft	meters	ft	meters	ft	meters	ft	meters
Down 30°	15	4.6	100	30	150	46	260	79	540	165	790	241
			250	76	200	61	320	98	580	177	860	262
			500	152	240	73	370	113	7,190	2,192	10,560	3,219
			750	229	270	82	2,840	866	6,890	2,100	10,110	3,082
			1000	305	290	88	2,760	841	6,670	2,033	9,770	2,978
			1250	381	300	91	2,680	817	6,490	1,978	9,480	2,890
	30	9.1	100	30	NH	NH	270	82	510	155	820	250
			250	76	150	46	440	134	650	198	940	287
			500	152	170	52	550	168	770	235	1,050	320
			750	229	190	58	630	192	890	271	1,120	341
			1000	305	270	82	680	207	960	293	1,190	363
			1250	381	330	101	730	223	1,060	323	8,170	2,490
	45	13.7	100	30	NH	NH	190	58	470	143	800	244
			250	76	NH	NH	410	125	680	207	960	293
			500	152	NH	NH	630	192	920	280	1,140	347
			750	229	NH	NH	750	229	1,070	326	1,280	390
			1000	305	NH	NH	820	250	1,170	357	1,370	418
			1250	381	130	40	890	271	1,280	390	1,520	463
Horiz.	15	4.6	100	30	130	40	280	85	530	162	800	244
			250	76	160	49	390	119	660	201	880	268
			500	152	170	52	540	165	930	283	1,140	347
			750	229	200	61	660	201	1,130	344	1,390	424
			1000	305	230	70	750	229	1,290	393	1,600	488
			1250	381	260	79	820	250	1,410	430	1,770	540
	30	9.1	100	30	NH	NH	190	58	480	146	790	241
			250	76	NH	NH	370	113	660	201	880	268
			500	152	NH	NH	450	137	880	268	1,120	341
			750	229	NH	NH	520	158	1,090	332	1,390	424
			1000	305	NH	NH	610	186	1,270	387	1,620	494
			1250	381	NH	NH	690	210	1,410	430	1,800	549
	45	13.7	100	30	NH	NH	NH	NH	410	125	740	226
			250	76	NH	NH	NH	NH	580	177	860	262
			500	152	NH	NH	400	122	850	259	1,110	338
			750	229	NH	NH	470	143	990	302	1,350	411
			1000	305	NH	NH	520	158	1,130	344	1,530	466
			1250	381	NH	NH	550	168	1,290	393	1,720	524
Up	15	4.6	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table 7
% Reduction in Concentration with Horizontal or Vertical Discharge
Cold Vapor Release at Various Release Rates

Release Condition:
-28°F, Saturated Vapor
-33.3°C, Saturated Vapor

Orientation	Discharge Elevation ft	Discharge Elevation meters	Discharge Velocity ft/sec	Discharge Velocity meters/sec	10 lb/min (4.5 kg/min) %	100 lb/min (45.4 kg/min) %	500 lb/min (227 kg/min) %	1000 lb/min (454 kg/min) %	Average %
					% Reduction in Distance to ERPG-2 Concentration Compared with Distance for 30°Down Discharge				
Horiz.	15	4.6	100	30	13%	-8%	2%	-1%	2%
			250	76	20%	-22%	-14%	-2%	-4%
			500	152	29%	-46%	87%	89%	40%
			750	229	26%	77%	84%	86%	68%
			1000	305	21%	73%	81%	84%	64%
			1250	381	13%	69%	78%	81%	61%
	30	9.1	100	30	NH 30°Down	30%	6%	4%	13%
			250	76	100%	16%	-2%	6%	30%
			500	152	100%	18%	-14%	-7%	24%
			750	229	100%	17%	-22%	-24%	18%
			1000	305	100%	10%	-32%	-36%	10%
			1250	381	100%	5%	-33%	78%	38%
	45	13.7	100	30	NH 30°Down	100%	13%	8%	40%
			250	76	NH 30°Down	100%	15%	10%	42%
			500	152	NH 30°Down	37%	8%	3%	16%
			750	229	NH 30°Down	37%	7%	-5%	13%
			1000	305	NH 30°Down	37%	3%	-12%	9%
			1250	381	100%	38%	-1%	-13%	31%
	Average for all elevations		100	30	13%	41%	7%	3%	16%
			250	76	60%	31%	0%	5%	24%
			500	152	65%	3%	27%	28%	31%
			750	229	63%	44%	23%	19%	37%
			1000	305	60%	40%	17%	12%	32%
			1250	381	71%	38%	15%	49%	43%
			Aveage		59%	33%	15%	19%	31%
Up	15	4.6	100	30	100%	100%	100%	100%	100%
			250	76	100%	100%	100%	100%	100%
			500	152	100%	100%	100%	100%	100%
			750	229	100%	100%	100%	100%	100%
			1000	305	100%	100%	100%	100%	100%
			1250	381	100%	100%	100%	100%	100%
	30	9.1	100	30	NH 30°Down	100%	100%	100%	100%
			250	76	100%	100%	100%	100%	100%
			500	152	100%	100%	100%	100%	100%
			750	229	100%	100%	100%	100%	100%
			1000	305	100%	100%	100%	100%	100%
			1250	381	100%	100%	100%	100%	100%
	45	13.7	100	30	NH 30°Down	100%	100%	100%	100%
			250	76	NH 30°Down	100%	100%	100%	100%
			500	152	NH 30°Down	100%	100%	100%	100%
			750	229	NH 30°Down	100%	100%	100%	100%
			1000	305	NH 30°Down	100%	100%	100%	100%
			1250	381	100%	100%	100%	100%	100%
	Average for all elevations		100	30	100%	100%	100%	100%	100%
			250	76	100%	100%	100%	100%	100%
			500	152	100%	100%	100%	100%	100%
			750	229	100%	100%	100%	100%	100%
			1000	305	100%	100%	100%	100%	100%
			1250	381	100%	100%	100%	100%	100%
			Aveage		**100%**	**100%**	**100%**	**100%**	**100%**

Grey shading indicates that the base case for the comparison, 30°Down Discharge, has no harm (conc. Below 200 PPMV)
Yellow shading indicates that the base case for the comparison, 30°Down Discharge, has a shorter distance to 200 PPMV

Table 8
Distance to Concentrations of Interest for Outdoor Release from PSV
Warm Vapor Release at Various Release Rates **1.5 F Weather**

Release Condition:
+77°F, Superheated Vapor
+25°C, Superheated Vapor

Orientation	Discharge Elevation		Discharge Velocity		Distance to ERPG-2 Concentration, ft (meters)							
					10 lb/min (4.5 kg/min)		100 lb/min (45.4 kg/min)		500 lb/min (227 kg/min)		1000 lb/min (454 kg/min)	
	ft	meters	ft /sec	meters /sec	ft	meters	ft	meters	ft	meters	ft	meters
Down 30°	15	4.6	100	30	100	30	230	70	380	116	260	79
			250	76	140	43	270	82	570	174	370	113
			500	152	190	58	310	94	650	198	460	140
			750	229	210	64	320	98	700	213	560	171
			1000	305	220	67	2,530	771	730	223	630	192
			1250	381	230	70	2,460	750	760	232	700	213
	30	9.1	100	30	NH	NH	210	64	360	110	310	94
			250	76	90	27	300	91	710	216	590	180
			500	152	130	40	400	122	790	241	860	262
			750	229	170	52	460	140	830	253	1,070	326
			1000	305	230	70	500	152	860	262	1,150	351
			1250	381	280	85	540	165	900	274	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	760	232
			250	76	NH	NH	270	82	730	223	1,030	314
			500	152	NH	NH	420	128	830	253	1,150	351
			750	229	NH	NH	530	162	900	274	1,230	375
			1000	305	NH	NH	590	180	950	290	1,290	393
			1250	381	NH	NH	630	192	990	302	750	229
Horiz.	15	4.6	100	30	70	21	220	67	200	61	NH	NH
			250	76	120	37	290	88	680	207	540	165
			500	152	150	46	380	116	770	235	1,060	323
			750	229	170	52	460	140	850	259	1,220	372
			1000	305	190	58	530	162	920	280	1,300	396
			1250	381	210	64	570	174	980	299	1,360	415
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	240	73	NH	NH	NH	NH
			500	152	NH	NH	360	110	750	229	760	232
			750	229	NH	NH	420	128	800	244	1,130	344
			1000	305	NH	NH	460	140	880	268	1,250	381
			1250	381	NH	NH	500	152	950	290	1,330	405
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	750	229	790	241
			1000	305	NH	NH	NH	NH	850	259	1,160	354
			1250	381	NH	NH	NH	NH	920	280	1,220	372
Up	15	4.6	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table 9
% Reduction in Concentration with Horizontal or Vertical Discharge
Warm Vapor

Release Condition:
+77°F, Superheated Vapor
+25°C, Superheated Vapor

	Discharge Elevation		Discharge Velocity		% Reduction in Distance to ERPG-2 Concentration Compared with Distance for 30°Down Discharge				
					10 lb/min (4.5 kg/min)	100 lb/min (45.4 kg/min)	500 lb/min (227 kg/min)	1000 lb/min (454 kg/min)	Average
Orientation	ft	meters	ft/sec	meters/sec	%	%	%	%	%
Horiz.	15	4.6	100	30	30%	4%	47%	100%	45%
			250	76	14%	-7%	-19%	-46%	-15%
			500	152	21%	-23%	-18%	-130%	-38%
			750	229	19%	-44%	-21%	-118%	-41%
			1000	305	14%	79%	-26%	-106%	-10%
			1250	381	9%	77%	-29%	-94%	-9%
	30	9.1	100	30	NH 30°Down	100%	100%	100%	100%
			250	76	100%	20%	100%	100%	80%
			500	152	100%	10%	5%	12%	32%
			750	229	100%	9%	4%	-6%	27%
			1000	305	100%	8%	-2%	-9%	24%
			1250	381	100%	7%	-6%	NH 30°Down	34%
	45	13.7	100	30	NH 30°Down	NH 30°Down	NH 30°Down	100%	100%
			250	76	NH 30°Down	100%	100%	100%	100%
			500	152	NH 30°Down	100%	100%	100%	100%
			750	229	NH 30°Down	100%	17%	36%	51%
			1000	305	NH 30°Down	100%	11%	10%	40%
			1250	381	NH 30°Down	100%	7%	-63%	15%
	Average for all elevations		100	30	30%	52%	74%	100%	64%
			250	76	57%	38%	60%	51%	52%
			500	152	61%	29%	29%	-6%	28%
			750	229	60%	22%	0%	-29%	13%
			1000	305	57%	62%	-6%	-35%	20%
			1250	381	54%	61%	-9%	-78%	7%
			Aveage		54%	44%	22%	4%	31%
Up	15	4.6	100	30	100%	100%	100%	100%	100%
			250	76	100%	100%	100%	100%	100%
			500	152	100%	100%	100%	100%	100%
			750	229	100%	100%	100%	100%	100%
			1000	305	100%	100%	100%	100%	100%
			1250	381	100%	100%	100%	100%	100%
	30	9.1	100	30	NH 30°Down	100%	100%	100%	100%
			250	76	100%	100%	100%	100%	100%
			500	152	100%	100%	100%	100%	100%
			750	229	100%	100%	100%	100%	100%
			1000	305	100%	100%	100%	100%	100%
			1250	381	100%	100%	100%	NH 30°Down	100%
	45	13.7	100	30	NH 30°Down	NH 30°Down	NH 30°Down	100%	100%
			250	76	NH 30°Down	100%	100%	100%	100%
			500	152	NH 30°Down	100%	100%	100%	100%
			750	229	NH 30°Down	100%	100%	100%	100%
			1000	305	NH 30°Down	100%	100%	100%	100%
			1250	381	NH 30°Down	100%	100%	100%	100%
	Average for all elevations		100	30	100%	100%	100%	100%	100%
			250	76	100%	100%	100%	100%	100%
			500	152	100%	100%	100%	100%	100%
			750	229	100%	100%	100%	100%	100%
			1000	305	100%	100%	100%	100%	100%
			1250	381	100%	100%	100%	100%	100%
			Aveage		100%	100%	100%	100%	100%

Grey shading indicates that the base case for the comparison, 30°Down Discharge, has no harm (conc. Below 200 PPMV)
Yellow shading indicates that the base case for the comparison, 30°Down Discharge, has a shorter distance to 200 PPMV

Table 10
% Reduction in Downwind Distance Various Elevations and Orientations
At 100 feet/second Discharge Velocity (30 m/s)

Orientation	Discharge Elevation ft	Discharge Elevation meters	Condition	% Reduction in Distance to ERPG-2 Concentration Compared with Distance for 30°Down Discharge: 10 lb/min (4.5 kg/min) %	100 lb/min (45.4 kg/min) %	500 lb/min (227 kg/min) %	1000 lb/min (454 kg/min) %	Average
Horiz.	15	4.6	Aerosol	29%	21%	16%	14%	20%
			Cold vapor	13%	-8%	2%	-1%	20%
			Warm vapor	30%	4%	47%	100%	45%
	30	9.1	Aerosol	15%	12%	17%	17%	17%
			Cold vapor	NH 30°Down	30%	6%	4%	4%
			Warm vapor	NH 30°Down	100%	100%	100%	100%
	45	13.7	Aerosol	100%	18%	15%	15%	15%
			Cold vapor	NH 30°Down	100%	13%	8%	8%
			Warm vapor	NH 30°Down	NH 30°Down	NH 30°Down	100%	100%
	Average for all elevations		Aerosol	48%	17%	16%	15%	17%
			Cold vapor	13%	41%	7%	3%	10%
			Warm vapor	30%	52%	74%	100%	82%
			Aveage	**37%**	**35%**	**27%**	**39%**	**36%**
Up	15	4.6	Aerosol	18%	25%	24%	23%	23%
			Cold vapor	100%	100%	100%	100%	100%
			Warm vapor	100%	100%	100%	100%	100%
	30	9.1	Aerosol	100%	14%	20%	21%	21%
			Cold vapor	NH 30°Down	100%	100%	100%	100%
			Warm vapor	NH 30°Down	100%	100%	100%	100%
	45	13.7	Aerosol	100%	13%	15%	16%	16%
			Cold vapor	NH 30°Down	100%	100%	100%	100%
			Warm vapor	NH 30°Down	NH 30°Down	NH 30°Down	100%	100%
	Average for all elevations		Aerosol	100%	17%	15%	16%	20%
			Cold vapor	100%	100%	100%	100%	100%
			Warm vapor	100%	100%	100%	100%	100%
			Aveage	**90%**	**70%**	**70%**	**73%**	**73%**

Grey shading indicates that the base case for the comparison, 30°Down Discharge, has no harm (conc. Below 200 PPMV)
Yellow shading indicates that the base case for the comparison, 30°Down Discharge, has a shorter distance to 200 PPMV
"100% Reduction" Indicates base case resulted in 200 PPMV near the ground, but did not reach the ground for the compared case.

Table 11
% Reduction in Downwind Distance Various Elevations and Orientations
At 250 feet/second Discharge Velocity (76 m/s)

Orientation	Discharge Elevation ft	Discharge Elevation meters	Condition	% Reduction in Distance to ERPG-2 Concentration Compared with Distance for 30°Down Discharge: 10 lb/min (4.5 kg/min) %	100 lb/min (45.4 kg/min) %	500 lb/min (227 kg/min) %	1000 lb/min (454 kg/min) %	Average
Horiz.	15	4.6	Aerosol	49%	29%	21%	19%	30%
			Cold vapor	20%	-22%	-14%	-2%	-4%
			Warm vapor	14%	-7%	-19%	-46%	-15%
	30	9.1	Aerosol	100%	26%	24%	22%	22%
			Cold vapor	100%	16%	-2%	6%	6%
			Warm vapor	100%	20%	100%	100%	80%
	45	13.7	Aerosol	NH 30°Down	34%	24%	22%	22%
			Cold vapor	NH 30°Down	100%	15%	10%	10%
			Warm vapor	NH 30°Down	100%	100%	100%	100%
	Average for all elevations		Aerosol	74%	30%	23%	21%	24%
			Cold vapor	60%	31%	0%	5%	4%
			Warm vapor	57%	38%	60%	51%	55%
			Aveage	**64%**	**33%**	**28%**	**26%**	**28%**
Up	15	4.6	Aerosol	100%	56%	50%	46%	63%
			Cold vapor	100%	100%	100%	100%	100%
			Warm vapor	100%	100%	100%	100%	100%
	30	9.1	Aerosol	100%	55%	48%	43%	43%
			Cold vapor	100%	100%	100%	100%	100%
			Warm vapor	100%	100%	100%	100%	100%
	45	13.7	Aerosol	NH 30°Down	100%	45%	42%	42%
			Cold vapor	NH 30°Down	100%	100%	100%	100%
			Warm vapor	NH 30°Down	100%	100%	100%	100%
	Average for all elevations		Aerosol	NH 30°Down	70%	45%	42%	49%
			Cold vapor	100%	100%	100%	100%	100%
			Warm vapor	100%	100%	100%	100%	100%
			Aveage	**100%**	**90%**	**82%**	**81%**	**83%**

Grey shading indicates that the base case for the comparison, 30°Down Discharge, has no harm (conc. Below 200 PPMV)
Yellow shading indicates that the base case for the comparison, 30°Down Discharge, has a shorter distance to 200 PPMV
"100% Reduction" Indicates base case resulted in 200 PPMV near the ground, but did not reach the ground for the compared case.

Table 12
% Reduction in Downwind Distance Various Elevations and Orientations
At 500 feet/second Discharge Velocity (152 m/s)

Orientation	Discharge Elevation ft	Discharge Elevation meters	Condition	% Reduction in Distance to ERPG-2 Concentration Compared with Distance for 30°Down Discharge: 10 lb/min (4.5 kg/min) %	100 lb/min (45.4 kg/min) %	500 lb/min (227 kg/min) %	1000 lb/min (454 kg/min) %	Average
Horiz.	15	4.6	Aerosol	65%	37%	27%	25%	38%
			Cold vapor	29%	-46%	87%	89%	40%
			Warm vapor	21%	-23%	-18%	-130%	-38%
	30	9.1	Aerosol	39%	42%	31%	27%	27%
			Cold vapor	100%	18%	-14%	-7%	-7%
			Warm vapor	100%	10%	5%	12%	32%
	45	13.7	Aerosol	NH 30°Down	52%	33%	29%	29%
			Cold vapor	NH 30°Down	37%	8%	3%	3%
			Warm vapor	NH 30°Down	100%	100%	100%	100%
	Average for all elevations		Aerosol	52%	44%	31%	27%	31%
			Cold vapor	65%	3%	27%	28%	12%
			Warm vapor	61%	29%	29%	-6%	31%
			Aveage	**59%**	**25%**	**29%**	**16%**	**25%**
Up	15	4.6	Aerosol	100%	100%	78%	70%	87%
			Cold vapor	100%	100%	100%	100%	100%
			Warm vapor	100%	100%	100%	100%	100%
	30	9.1	Aerosol	100%	100%	100%	69%	69%
			Cold vapor	100%	100%	100%	100%	100%
			Warm vapor	100%	100%	100%	100%	100%
	45	13.7	Aerosol	NH 30°Down	100%	100%	70%	70%
			Cold vapor	NH 30°Down	100%	100%	100%	100%
			Warm vapor	NH 30°Down	100%	100%	100%	100%
	Average for all elevations		Aerosol	NH 30°Down	100%	100%	70%	75%
			Cold vapor	100%	100%	100%	100%	100%
			Warm vapor	100%	100%	100%	100%	100%
			Aveage	**100%**	**100%**	**98%**	**90%**	**92%**

Grey shading indicates that the base case for the comparison, 30°Down Discharge, has no harm (conc. Below 200 PPMV)
Yellow shading indicates that the base case for the comparison, 30°Down Discharge, has a shorter distance to 200 PPMV
"100% Reduction" Indicates base case resulted in 200 PPMV near the ground, but did not reach the ground for the compared case.

Table 13
% Reduction in Downwind Distance Various Elevations and Orientations
At 750 feet/second Discharge Velocity (229 m/s)

Orientation	Discharge Elevation ft	Discharge Elevation meters	Condition	% Reduction in Distance to ERPG-2 Concentration Compared with Distance for 30°Down Discharge: 10 lb/min (4.5 kg/min) %	100 lb/min (45.4 kg/min) %	500 lb/min (227 kg/min) %	1000 lb/min (454 kg/min) %	Average
Horiz.	15	4.6	Aerosol	62%	41%	32%	29%	41%
			Cold vapor	26%	77%	84%	86%	68%
			Warm vapor	19%	-44%	-21%	-118%	-41%
	30	9.1	Aerosol	40%	51%	36%	30%	30%
			Cold vapor	100%	17%	-22%	-24%	-24%
			Warm vapor	100%	9%	4%	-6%	27%
	45	13.7	Aerosol	NH 30°Down	68%	39%	34%	34%
			Cold vapor	NH 30°Down	37%	7%	-5%	-5%
			Warm vapor	NH 30°Down	100%	17%	36%	51%
	Average for all elevations		Aerosol	51%	53%	35%	31%	35%
			Cold vapor	63%	44%	23%	19%	13%
			Warm vapor	60%	22%	0%	-29%	12%
			Aveage	**58%**	**40%**	**19%**	**7%**	**20%**
Up	15	4.6	Aerosol	100%	100%	100%	100%	100%
			Cold vapor	100%	100%	100%	100%	100%
			Warm vapor	100%	100%	100%	100%	100%
	30	9.1	Aerosol	100%	100%	100%	100%	100%
			Cold vapor	100%	100%	100%	100%	100%
			Warm vapor	100%	100%	100%	100%	100%
	45	13.7	Aerosol	NH 30°Down	100%	100%	100%	100%
			Cold vapor	NH 30°Down	100%	100%	100%	100%
			Warm vapor	NH 30°Down	100%	100%	100%	100%
	Average for all elevations		Aerosol	NH 30°Down	100%	100%	100%	100%
			Cold vapor	100%	100%	100%	100%	100%
			Warm vapor	100%	100%	100%	100%	100%
			Aveage	**100%**	**100%**	**100%**	**100%**	**100%**

Grey shading indicates that the base case for the comparison, 30°Down Discharge, has no harm (conc. Below 200 PPMV)
Yellow shading indicates that the base case for the comparison, 30°Down Discharge, has a shorter distance to 200 PPMV
"100% Reduction" Indicates base case resulted in 200 PPMV near the ground, but did not reach the ground for the compared case.

Table 14
Distance to Concentrations of Interest for Outdoor Release from PSV
30°Down Discharges at Various Conditions

					Distance to ERPG-2 Concentration, ft (meters)							
	Discharge Elevation		Discharge Velocity		10 lb/min (4.5 kg/min)		100 lb/min (45.4 kg/min)		500 lb/min (227 kg/min)		1000 lb/min (454 kg/min)	
State	ft	meters	ft /sec	meters /sec	ft	meters	ft	meters	ft	meters	ft	meters
Aerosol	15	4.6	100	30	760	232	3,650	1,113	9,480	2,890	14,120	4,304
			250	76	700	213	3,570	1,088	9,110	2,777	13,630	4,154
			500	152	710	216	3,410	1,039	8,690	2,649	13,010	3,965
			750	229	710	216	3,280	1,000	8,380	2,554	12,550	3,825
			1000	305	720	219	3,200	975	8,110	2,472	12,160	3,706
			1250	381	710	216	3,120	951	7,890	2,405	11,830	3,606
	30	9.1	100	30	540	165	2,850	869	8,560	2,609	13,280	4,048
			250	76	320	98	2,830	863	8,230	2,509	12,520	3,816
			500	152	230	70	2,770	844	7,680	2,341	11,590	3,533
			750	229	250	76	2,690	820	7,260	2,213	10,890	3,319
			1000	305	320	98	2,620	799	6,920	2,109	10,400	3,170
			1250	381	380	116	2,550	777	6,680	2,036	10,050	3,063
	45	13.7	100	30	450	137	2,450	747	7,560	2,304	12,070	3,679
			250	76	NH	NH	2,260	689	7,340	2,237	11,580	3,530
			500	152	NH	NH	2,060	628	6,970	2,124	10,770	3,283
			750	229	NH	NH	2,000	610	6,610	2,015	10,130	3,088
			1000	305	120	37	1,960	597	6,330	1,929	9,610	2,929
			1250	381	130	40	1,920	585	6,060	1,847	9,180	2,798
Cold Vapor	15	4.6	100	30	150	46	260	79	540	165	790	241
			250	76	200	61	320	98	580	177	860	262
			500	152	240	73	370	113	7,190	2,192	10,560	3,219
			750	229	270	82	2,840	866	6,890	2,100	10,110	3,082
			1000	305	290	88	2,760	841	6,670	2,033	9,770	2,978
			1250	381	300	91	2,680	817	6,490	1,978	9,480	2,890
	30	9.1	100	30	NH	NH	270	82	510	155	820	250
			250	76	150	46	440	134	650	198	940	287
			500	152	170	52	550	168	770	235	1,050	320
			750	229	190	58	630	192	890	271	1,120	341
			1000	305	270	82	680	207	960	293	1,190	363
			1250	381	330	101	730	223	1,060	323	8,170	2,490
	45	13.7	100	30	NH	NH	190	58	470	143	800	244
			250	76	NH	NH	410	125	680	207	960	293
			500	152	NH	NH	630	192	920	280	1,140	347
			750	229	NH	NH	750	229	1,070	326	1,280	390
			1000	305	NH	NH	820	250	1,170	357	1,370	418
			1250	381	130	40	890	271	1,280	390	1,520	463
Warm Vapor	15	4.6	100	30	100	30	230	70	380	116	260	79
			250	76	140	43	270	82	570	174	370	113
			500	152	190	58	310	94	650	198	460	140
			750	229	210	64	320	98	700	213	560	171
			1000	305	220	67	2,530	771	730	223	630	192
			1250	381	230	70	2,460	750	760	232	700	213
	30	9.1	100	30	NH	NH	210	64	360	110	310	94
			250	76	90	27	300	91	710	216	590	180
			500	152	130	40	400	122	790	241	860	262
			750	229	170	52	460	140	830	253	1,070	326
			1000	305	230	70	500	152	860	262	1,150	351
			1250	381	280	85	540	165	900	274	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	760	232
			250	76	NH	NH	270	82	730	223	1,030	314
			500	152	NH	NH	420	128	830	253	1,150	351
			750	229	NH	NH	530	162	900	274	1,230	375
			1000	305	NH	NH	590	180	950	290	1,290	393
			1250	381	NH	NH	630	192	990	302	750	229

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table 15
Distance to Concentrations of Interest for Outdoor Release from PSV Horizontal Discharges at Various Conditions

State	Discharge Elevation		Discharge Velocity		Distance to ERPG-2 Concentration, ft (meters)							
					10 lb/min (4.5 kg/min)		100 lb/min (45.4 kg/min)		500 lb/min (227 kg/min)		1000 lb/min (454 kg/min)	
	ft	meters	ft /sec	meters /sec	ft	meters	ft	meters	ft	meters	ft	meters
Aerosol	15	4.6	100	30	540	165	2,890	881	7,980	2,432	12,160	3,706
			250	76	360	110	2,530	771	7,190	2,192	10,980	3,347
			500	152	250	76	2,160	658	6,330	1,929	9,730	2,966
			750	229	270	82	1,920	585	5,730	1,747	8,860	2,701
			1000	305	320	98	1,750	533	5,280	1,609	8,210	2,502
			1250	381	350	107	1,610	491	4,920	1,500	7,660	2,335
	30	9.1	100	30	460	140	2,520	768	7,090	2,161	11,040	3,365
			250	76	NH	NH	2,100	640	6,220	1,896	9,820	2,993
			500	152	140	43	1,600	488	5,280	1,609	8,490	2,588
			750	229	150	46	1,320	402	4,640	1,414	7,580	2,310
			1000	305	NH	NH	1,320	402	4,190	1,277	6,870	2,094
			1250	381	NH	NH	1,370	418	3,820	1,164	6,280	1,914
	45	13.7	100	30	NH	NH	2,010	613	6,420	1,957	10,280	3,133
			250	76	NH	NH	1,500	457	5,550	1,692	9,010	2,746
			500	152	NH	NH	990	302	4,640	1,414	7,680	2,341
			750	229	NH	NH	650	198	4,050	1,234	6,730	2,051
			1000	305	NH	NH	700	213	3,590	1,094	6,000	1,829
			1250	381	NH	NH	790	241	3,300	1,006	5,420	1,652
Cold Vapor	15	4.6	100	30	130	40	280	85	530	162	800	244
			250	76	160	49	390	119	660	201	880	268
			500	152	170	52	540	165	930	283	1,140	347
			750	229	200	61	660	201	1,130	344	1,390	424
			1000	305	230	70	750	229	1,290	393	1,600	488
			1250	381	260	79	820	250	1,410	430	1,770	540
	30	9.1	100	30	NH	NH	190	58	480	146	790	241
			250	76	NH	NH	370	113	660	201	880	268
			500	152	NH	NH	450	137	880	268	1,120	341
			750	229	NH	NH	520	158	1,090	332	1,390	424
			1000	305	NH	NH	610	186	1,270	387	1,620	494
			1250	381	NH	NH	690	210	1,410	430	1,800	549
	45	13.7	100	30	NH	NH	NH	NH	410	125	740	226
			250	76	NH	NH	NH	NH	580	177	860	262
			500	152	NH	NH	400	122	850	259	1,110	338
			750	229	NH	NH	470	143	990	302	1,350	411
			1000	305	NH	NH	520	158	1,130	344	1,530	466
			1250	381	NH	NH	550	168	1,290	393	1,720	524
Warm Vapor	15	4.6	100	30	70	21	220	67	200	61	NH	NH
			250	76	120	37	290	88	680	207	540	165
			500	152	150	46	380	116	770	235	1,060	323
			750	229	170	52	460	140	850	259	1,220	372
			1000	305	190	58	530	162	920	280	1,300	396
			1250	381	210	64	570	174	980	299	1,360	415
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	240	73	NH	NH	NH	NH
			500	152	NH	NH	360	110	750	229	760	232
			750	229	NH	NH	420	128	800	244	1,130	344
			1000	305	NH	NH	460	140	880	268	1,250	381
			1250	381	NH	NH	500	152	950	290	1,330	405
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	750	229	790	241
			1000	305	NH	NH	NH	NH	850	259	1,160	354
			1250	381	NH	NH	NH	NH	920	280	1,220	372

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table 16
Distance to Concentrations of Interest for Outdoor Release from PSV Vertical Up Discharge at Various Conditions

					Distance to ERPG-2 Concentration, ft (meters)							
	Discharge Elevation		Discharge Velocity		10 lb/min (4.5 kg/min)		100 lb/min (45.4 kg/min)		500 lb/min (227 kg/min)		1000 lb/min (454 kg/min)	
State	ft	meters	ft /sec	meters /sec	ft	meters	ft	meters	ft	meters	ft	meters
Aerosol	15	4.6	100	30	620	189	2,750	838	7,170	2,185	10,930	3,332
			250	76	NH	NH	1,560	475	4,600	1,402	7,370	2,246
			500	152	NH	NH	NH	NH	1,930	588	3,960	1,207
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	NH	NH	2,450	747	6,810	2,076	10,550	3,216
			250	76	NH	NH	1,280	390	4,320	1,317	7,080	2,158
			500	152	NH	NH	NH	NH	NH	NH	3,620	1,103
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	2,120	646	6,460	1,969	10,160	3,097
			250	76	NH	NH	NH	NH	4,050	1,234	6,740	2,054
			500	152	NH	NH	NH	NH	NH	NH	3,210	978
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
Cold Vapor	15	4.6	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
Warm Vapor	15	4.6	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table A- 1
Distance to Concentrations of Interest for Outdoor Release from PSV
Aerosol Release at 10 lbs/min (4.45 kg/min) **1.5F Weather**

Release Condition:
-28°F, 0.12 liquid fraction
-33.3°C, 0.12 liquid fraction

	Discharge Elevation		Discharge Velocity		Distance to Concentration, ft (meters)									
					ERPG1 25 PPMV @ 60 min		STEL 35 PPMV @ 60 min		ERPG2 200 PPMV @ 60 min		IDLH 300 PPMV @ 30 min		ERPG3 750 PPMV @ 60 min	
Orientation	ft	meters	ft /sec	meters /sec	ft	meters	ft	meters	ft	meters	ft	meters	ft	meters
Down 30°	15	4.6	100	30	3,500	1,067	3,360	1,024	760	232	590	180	170	52
			250	76	3,430	1,045	3,290	1,003	700	213	530	162	170	52
			500	152	3,440	1,049	3,300	1,006	710	216	540	165	200	61
			750	229	3,430	1,045	3,290	1,003	710	216	550	168	220	67
			1000	305	3,410	1,039	3,280	1,000	720	219	550	168	240	73
			1250	381	3,390	1,033	3,260	994	710	216	550	168	260	79
	30	9.1	100	30	2,730	832	2,620	799	540	165	420	128	NH	NH
			250	76	2,340	713	2,240	683	320	98	210	64	NH	NH
			500	152	2,300	701	2,200	671	230	70	130	40	70	21
			750	229	2,390	728	2,280	695	250	76	210	64	120	37
			1000	305	2,480	756	2,360	719	320	98	290	88	160	49
			1250	381	2,550	777	2,430	741	380	116	340	104	190	58
	45	13.7	100	30	2,430	741	2,320	707	450	137	310	94	NH	NH
			250	76	2,070	631	1,970	600	NH	NH	NH	NH	NH	NH
			500	152	1,760	536	1,670	509	NH	NH	NH	NH	NH	NH
			750	229	1,630	497	1,550	472	NH	NH	NH	NH	NH	NH
			1000	305	1,590	485	1,500	457	120	37	NH	NH	NH	NH
			1250	381	1,560	475	1,470	448	130	40	NH	NH	NH	NH
Horiz.	15	4.6	100	30	2,950	899	2,840	866	540	165	410	125	80	24
			250	76	2,620	799	2,510	765	360	110	250	76	90	27
			500	152	2,410	735	2,300	701	250	76	200	61	120	37
			750	229	2,300	701	2,200	671	270	82	240	73	120	37
			1000	305	2,240	683	2,130	649	320	98	270	82	110	34
			1250	381	2,180	664	2,070	631	350	107	300	91	110	34
	30	9.1	100	30	2,470	753	2,360	719	460	140	350	107	NH	NH
			250	76	1,980	604	1,900	579	NH	NH	NH	NH	NH	NH
			500	152	1,690	515	1,610	491	140	43	NH	NH	NH	NH
			750	229	1,560	475	1,480	451	150	46	NH	NH	NH	NH
			1000	305	1,450	442	1,370	418	NH	NH	NH	NH	NH	NH
			1250	381	1,370	418	1,290	393	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	2,120	646	2,020	616	NH	NH	NH	NH	NH	NH
			250	76	1,740	530	1,660	506	NH	NH	NH	NH	NH	NH
			500	152	1,430	436	1,350	411	NH	NH	NH	NH	NH	NH
			750	229	1,230	375	1,150	351	NH	NH	NH	NH	NH	NH
			1000	305	1,100	335	1,030	314	NH	NH	NH	NH	NH	NH
			1250	381	1,000	305	930	283	NH	NH	NH	NH	NH	NH
Up	15	4.6	100	30	2,900	884	2,790	850	620	189	490	149	NH	NH
			250	76	2,000	610	1,920	585	NH	NH	NH	NH	NH	NH
			500	152	1,320	402	1,230	375	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	2,220	677	2,130	649	NH	NH	NH	NH	NH	NH
			250	76	1,520	463	1,430	436	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	1,640	500	1,560	475	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table A- 2 **Release Condition:**

Distance to Concentrations of Interest for Outdoor Release from PSV -28°F, Saturated Vapor

Cold Gas Release at 10 lbs/min (4.45 kg/min) **1.5F Weather** -33.3°C, Saturated Vapor

					Distance to Concentration, ft (meters)									
	Discharge Elevation		Discharge Velocity		ERPG1 25 PPMV @ 60 min		STEL 35 PPMV @ 60 min		ERPG2 200 PPMV @ 60 min		IDLH 300 PPMV @ 30 min		ERPG3 750 PPMV @ 60 min	
Orientation	ft	meters	ft /sec	meters /sec	ft	meters	ft	meters	ft	meters	ft	meters	ft	meters
Down 30°	15	4.6	100	30	260	79	260	79	150	46	130	40	70	21
			250	76	370	113	360	110	200	61	180	55	130	40
			500	152	470	143	460	140	240	73	220	67	170	52
			750	229	520	158	510	155	270	82	250	76	190	58
			1000	305	550	168	550	168	290	88	260	79	200	61
			1250	381	580	177	560	171	300	91	270	82	210	64
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	720	219	700	213	150	46	90	27	NH	NH
			500	152	930	283	900	274	170	52	130	40	NH	NH
			750	229	960	293	940	287	190	58	170	52	80	24
			1000	305	950	290	930	283	270	82	240	73	120	37
			1250	381	950	290	930	283	330	101	290	88	150	46
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	870	265	820	250	NH	NH	NH	NH	NH	NH
			750	229	1,070	326	1,020	311	NH	NH	NH	NH	NH	NH
			1000	305	1,110	338	1,060	323	NH	NH	NH	NH	NH	NH
			1250	381	1,140	347	1,090	332	130	40	NH	NH	NH	NH
Horiz.	15	4.6	100	30	390	119	380	116	130	40	110	34	NH	NH
			250	76	630	192	610	186	160	49	130	40	NH	NH
			500	152	770	235	740	226	170	52	150	46	NH	NH
			750	229	860	262	830	253	200	61	170	52	NH	NH
			1000	305	920	280	890	271	230	70	200	61	NH	NH
			1250	381	950	290	920	280	260	79	210	64	NH	NH
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	440	134	420	128	NH	NH	NH	NH	NH	NH
			500	152	750	229	710	216	NH	NH	NH	NH	NH	NH
			750	229	830	253	790	241	NH	NH	NH	NH	NH	NH
			1000	305	860	262	810	247	NH	NH	NH	NH	NH	NH
			1250	381	860	262	810	247	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	270	82	240	73	NH	NH	NH	NH	NH	NH
Up	15	4.6	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table A- 3
Distance to Concentrations of Interest for Outdoor Release from PSV
Warm Gas Release at 10 lbs/min (4.45 kg/min) **1.5F Weather**

Release Condition:
+77°F, Superheated Vapor
+25°C, Superheated Vapor

Orientation	Discharge Elevation		Discharge Velocity		Distance to Concentration, ft (meters)									
					ERPG1 25 PPMV @ 60 min		STEL 35 PPMV @ 60 min		ERPG2 200 PPMV @ 60 min		IDLH 300 PPMV @ 30 min		ERPG3 750 PPMV @ 60 min	
	ft	meters	ft /sec	meters /sec	ft	meters	ft	meters	ft	meters	ft	meters	ft	meters
Down 30°	15	4.6	100	30	150	46	150	46	100	30	90	27	60	18
			250	76	240	73	230	70	140	43	130	40	100	30
			500	152	340	104	330	101	190	58	170	52	130	40
			750	229	380	116	370	113	210	64	190	58	140	43
			1000	305	400	122	390	119	220	67	200	61	150	46
			1250	381	430	131	420	128	230	70	210	64	150	46
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	270	82	270	82	90	27	NH	NH	NH	NH
			500	152	450	137	440	134	130	40	120	37	NH	NH
			750	229	510	155	500	152	170	52	150	46	NH	NH
			1000	305	540	165	530	162	230	70	200	61	90	27
			1250	381	560	171	550	168	280	85	240	73	120	37
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	310	94	290	88	NH	NH	NH	NH	NH	NH
			750	229	540	165	520	158	NH	NH	NH	NH	NH	NH
			1000	305	670	204	650	198	NH	NH	NH	NH	NH	NH
			1250	381	740	226	720	219	NH	NH	NH	NH	NH	NH
Horiz.	15	4.6	100	30	140	43	140	43	70	21	60	18	NH	NH
			250	76	320	98	320	98	120	37	110	34	NH	NH
			500	152	420	128	410	125	150	46	130	40	NH	NH
			750	229	470	143	460	140	170	52	140	43	NH	NH
			1000	305	530	162	520	158	190	58	160	49	NH	NH
			1250	381	560	171	550	168	210	64	170	52	NH	NH
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	360	110	350	107	NH	NH	NH	NH	NH	NH
			750	229	460	140	440	134	NH	NH	NH	NH	NH	NH
			1000	305	530	162	510	155	NH	NH	NH	NH	NH	NH
			1250	381	560	171	540	165	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
Up	15	4.6	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table A- 4
Distance to Concentrations of Interest for Outdoor Release from PSV
Aerosol Release at 100 lbs/min (45 kg/min) **1.5F Weather**

Release Condition:
-28°F, 0.12 liquid fraction
-33.3°C, 0.12 liquid fraction

Orientation	Discharge Elevation ft	Discharge Elevation meters	Discharge Velocity ft /sec	Discharge Velocity meters /sec	ERPG1 25 PPMV @ 60 min ft	ERPG1 meters	STEL 35 PPMV @ 60 min ft	STEL meters	ERPG2 200 PPMV @ 60 min ft	ERPG2 meters	IDLH 300 PPMV @ 30 min ft	IDLH meters	ERPG3 750 PPMV @ 60 min ft	ERPG3 meters
Down 30°	15	4.6	100	30	14,150	4,313	13,630	4,154	3,650	1,113	3,040	927	1,360	415
			250	76	13,920	4,243	13,400	4,084	3,570	1,088	2,950	899	1,300	396
			500	152	13,600	4,145	13,090	3,990	3,410	1,039	2,810	856	1,190	363
			750	229	13,360	4,072	12,850	3,917	3,280	1,000	2,680	817	1,100	335
			1000	305	13,200	4,023	12,700	3,871	3,200	975	2,610	796	1,040	317
			1250	381	13,060	3,981	12,560	3,828	3,120	951	2,540	774	980	299
	30	9.1	100	30	12,980	3,956	12,470	3,801	2,850	869	2,270	692	770	235
			250	76	12,890	3,929	12,380	3,773	2,830	863	2,250	686	750	229
			500	152	12,680	3,865	12,180	3,713	2,770	844	2,200	671	700	213
			750	229	12,450	3,795	11,960	3,645	2,690	820	2,140	652	750	229
			1000	305	12,240	3,731	11,760	3,584	2,620	799	2,070	631	790	241
			1250	381	12,050	3,673	11,570	3,527	2,550	777	2,000	610	870	265
	45	13.7	100	30	11,590	3,533	11,130	3,392	2,450	747	1,930	588	570	174
			250	76	11,980	3,652	11,480	3,499	2,260	689	1,730	527	530	162
			500	152	11,640	3,548	11,150	3,399	2,060	628	1,550	472	670	204
			750	229	11,520	3,511	11,040	3,365	2,000	610	1,490	454	750	229
			1000	305	11,420	3,481	10,930	3,332	1,960	597	1,440	439	800	244
			1250	381	11,320	3,450	10,840	3,304	1,920	585	1,400	427	860	262
Horiz.	15	4.6	100	30	13,060	3,981	12,540	3,822	2,890	881	2,310	704	800	244
			250	76	12,460	3,798	11,950	3,642	2,530	771	1,980	604	570	174
			500	152	11,810	3,600	11,310	3,447	2,160	658	1,630	497	710	216
			750	229	11,380	3,469	10,890	3,319	1,920	585	1,420	433	790	241
			1000	305	11,060	3,371	10,570	3,222	1,750	533	1,270	387	860	262
			1250	381	10,790	3,289	10,310	3,143	1,610	491	1,330	405	910	277
	30	9.1	100	30	11,920	3,633	11,440	3,487	2,520	768	1,980	604	570	174
			250	76	11,510	3,508	11,030	3,362	2,100	640	1,570	479	440	134
			500	152	10,700	3,261	10,230	3,118	1,600	488	1,130	344	610	186
			750	229	10,100	3,079	9,640	2,938	1,320	402	1,070	326	660	201
			1000	305	9,630	2,935	9,180	2,798	1,320	402	1,140	347	690	210
			1250	381	9,250	2,819	8,810	2,685	1,370	418	1,230	375	680	207
	45	13.7	100	30	10,220	3,115	9,800	2,987	2,010	613	1,580	482	430	131
			250	76	9,310	2,838	8,900	2,713	1,500	457	1,080	329	250	76
			500	152	8,450	2,576	8,060	2,457	990	302	470	143	NH	NH
			750	229	8,000	2,438	7,620	2,323	650	198	530	162	NH	NH
			1000	305	7,680	2,341	7,300	2,225	700	213	600	183	NH	NH
			1250	381	7,410	2,259	7,040	2,146	790	241	660	201	NH	NH
Up	15	4.6	100	30	11,850	3,612	11,390	3,472	2,750	838	2,240	683	890	271
			250	76	8,830	2,691	8,450	2,576	1,560	475	1,160	354	NH	NH
			500	152	6,290	1,917	5,990	1,826	NH	NH	NH	NH	NH	NH
			750	229	4,810	1,466	4,520	1,378	NH	NH	NH	NH	NH	NH
			1000	305	3,440	1,049	3,110	948	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	11,120	3,389	10,670	3,252	2,450	747	1,970	600	740	226
			250	76	8,090	2,466	7,740	2,359	1,280	390	NH	NH	NH	NH
			500	152	5,750	1,753	5,460	1,664	NH	NH	NH	NH	NH	NH
			750	229	4,230	1,289	3,940	1,201	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	10,260	3,127	9,840	2,999	2,120	646	1,680	512	NH	NH
			250	76	7,320	2,231	6,990	2,131	NH	NH	NH	NH	NH	NH
			500	152	5,150	1,570	4,870	1,484	NH	NH	NH	NH	NH	NH
			750	229	3,470	1,058	3,130	954	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table A- 5
Distance to Concentrations of Interest for Outdoor Release from PSV
Cold Gas Release at 100 lbs/min (45 kg/min) 1.5F Weather

Release Condition:
-28°F, Saturated Vapor
-33.3°C, Saturated Vapor

					Distance to Concentration, ft (meters)									
	Discharge Elevation		Discharge Velocity		ERPG1 25 PPMV @ 60 min		STEL 35 PPMV @ 60 min		ERPG2 200 PPMV @ 60 min		IDLH 300 PPMV @ 30 min		ERPG3 750 PPMV @ 60 min	
Orientation	ft	meters	ft /sec	meters /sec	ft	meters	ft	meters	ft	meters	ft	meters	ft	meters
Down 30°	15	4.6	100	30	380	116	370	113	260	79	240	73	180	55
			250	76	490	149	490	149	320	98	300	91	230	70
			500	152	580	177	570	174	370	113	340	104	270	82
			750	229	12,360	3,767	11,880	3,621	2,840	866	2,290	698	830	253
			1000	305	12,200	3,719	11,730	3,575	2,760	841	2,220	677	780	238
			1250	381	12,070	3,679	11,600	3,536	2,680	817	2,160	658	730	223
	30	9.1	100	30	400	122	400	122	270	82	250	76	180	55
			250	76	680	207	670	204	440	134	400	122	310	94
			500	152	940	287	930	283	550	168	520	158	380	116
			750	229	1,100	335	1,090	332	630	192	580	177	420	128
			1000	305	1,220	372	1,190	363	680	207	620	189	440	134
			1250	381	1,320	402	1,300	396	730	223	660	201	460	140
	45	13.7	100	30	380	116	370	113	190	58	170	52	NH	NH
			250	76	680	207	670	204	410	125	370	113	240	73
			500	152	1,040	317	1,020	311	630	192	570	174	430	131
			750	229	1,310	399	1,290	393	750	229	680	207	490	149
			1000	305	1,490	454	1,460	445	820	250	750	229	520	158
			1250	381	1,620	494	1,590	485	890	271	790	241	540	165
Horiz.	15	4.6	100	30	460	140	460	140	280	85	260	79	180	55
			250	76	690	210	680	207	390	119	350	107	260	79
			500	152	1,050	320	1,030	314	540	165	490	149	340	104
			750	229	1,310	399	1,290	393	660	201	590	180	370	113
			1000	305	1,520	463	1,490	454	750	229	660	201	400	122
			1250	381	1,670	509	1,640	500	820	250	710	216	430	131
	30	9.1	100	30	400	122	400	122	190	58	170	52	NH	NH
			250	76	830	253	810	247	370	113	320	98	NH	NH
			500	152	1,130	344	1,110	338	450	137	410	125	NH	NH
			750	229	1,330	405	1,310	399	520	158	470	143	NH	NH
			1000	305	1,520	463	1,490	454	610	186	530	162	NH	NH
			1250	381	1,680	512	1,650	503	690	210	590	180	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	650	198	640	195	NH	NH	NH	NH	NH	NH
			500	152	1,200	366	1,170	357	400	122	NH	NH	NH	NH
			750	229	1,490	454	1,450	442	470	143	380	116	NH	NH
			1000	305	1,670	509	1,630	497	520	158	400	122	NH	NH
			1250	381	1,800	549	1,750	533	550	168	NH	NH	NH	NH
Up	15	4.6	100	30	100	30	90	27	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table A- 6
Distance to Concentrations of Interest for Outdoor Release from PSV
Warm Gas Release at 100 lbs/min (45 kg/min) **1.5F Weather**

Release Condition:
+77°F, Superheated Vapor
+25°C, Superheated Vapor

Orientation	Discharge Elevation ft	Discharge Elevation meters	Discharge Velocity ft /sec	Discharge Velocity meters /sec	ERPG1 25 PPMV @ 60 min ft	ERPG1 meters	STEL 35 PPMV @ 60 min ft	STEL meters	ERPG2 200 PPMV @ 60 min ft	ERPG2 meters	IDLH 300 PPMV @ 30 min ft	IDLH meters	ERPG3 750 PPMV @ 60 min ft	ERPG3 meters
Down 30°	15	4.6	100	30	370	113	370	113	230	70	220	67	160	49
			250	76	450	137	450	137	270	82	260	79	190	58
			500	152	480	146	470	143	310	94	280	85	210	64
			750	229	500	152	490	149	320	98	300	91	220	67
			1000	305	11,800	3,597	11,330	3,453	2,530	771	2,000	610	610	186
			1250	381	11,650	3,551	11,180	3,408	2,460	750	1,930	588	560	171
	30	9.1	100	30	360	110	350	107	210	64	190	58	NH	NH
			250	76	460	140	450	137	300	91	270	82	210	64
			500	152	640	195	640	195	400	122	370	113	260	79
			750	229	750	229	740	226	460	140	420	128	280	85
			1000	305	830	253	810	247	500	152	450	137	300	91
			1250	381	900	274	890	271	540	165	470	143	320	98
	45	13.7	100	30	190	58	190	58	NH	NH	NH	NH	NH	NH
			250	76	460	140	460	140	270	82	250	76	NH	NH
			500	152	660	201	660	201	420	128	390	119	270	82
			750	229	860	262	850	259	530	162	470	143	320	98
			1000	305	970	296	960	293	590	180	520	158	350	107
			1250	381	1,080	329	1,070	326	630	192	550	168	370	113
Horiz.	15	4.6	100	30	390	119	390	119	220	67	200	61	NH	NH
			250	76	500	152	490	149	290	88	260	79	170	52
			500	152	650	198	640	195	380	116	340	104	220	67
			750	229	810	247	800	244	460	140	410	125	250	76
			1000	305	950	290	940	287	530	162	450	137	270	82
			1250	381	1,080	329	1,060	323	570	174	480	146	290	88
	30	9.1	100	30	300	91	290	88	NH	NH	NH	NH	NH	NH
			250	76	430	131	430	131	240	73	NH	NH	NH	NH
			500	152	710	216	690	210	360	110	300	91	NH	NH
			750	229	850	259	830	253	420	128	360	110	NH	NH
			1000	305	950	290	940	287	460	140	390	119	NH	NH
			1250	381	1,040	317	1,020	311	500	152	410	125	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	300	91	300	91	NH	NH	NH	NH	NH	NH
			500	152	570	174	560	171	NH	NH	NH	NH	NH	NH
			750	229	800	244	780	238	NH	NH	NH	NH	NH	NH
			1000	305	980	299	960	293	NH	NH	NH	NH	NH	NH
			1250	381	1,100	335	1,070	326	NH	NH	NH	NH	NH	NH
Up	15	4.6	100	30	220	67	220	67	NH	NH	NH	NH	NH	NH
			250	76	210	64	190	58	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

Distance to Concentration, ft (meters)

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table A-7
Distance to Concentrations of Interest for Outdoor Release from PSV
Aerosol Release at 500 lbs/min (227 kg/min) 3D Weather

Release Condition:
-28°F, 0.12 liquid fraction
-33.3°C, 0.12 liquid fraction

	Discharge Elevation		Discharge Velocity		Distance to Concentration, ft (meters)									
					ERPG1 25 PPMV @ 60 min		STEL 35 PPMV @ 60 min		ERPG2 200 PPMV @ 60 min		IDLH 300 PPMV @ 30 min		ERPG3 750 PPMV @ 60 min	
Orientation	**ft**	meters	**ft /sec**	meters /sec	**ft**	meters	**ft**	**meters**	**ft**	**meters**	**ft**	**meters**	**ft**	**meters**
Down 30°	**15**	4.6	**100**	30	**38,150**	11,628	**36,650**	11,171	**9,480**	2,890	**7,910**	2,411	**3,720**	1,134
			250	76	**37,440**	11,412	**35,950**	10,958	**9,110**	2,777	**7,560**	2,304	**3,460**	1,055
			500	152	**36,570**	11,147	**35,100**	10,699	**8,690**	2,649	**7,170**	2,185	**3,160**	963
			750	229	**35,930**	10,952	**34,480**	10,510	**8,380**	2,554	**6,880**	2,097	**2,940**	896
			1000	305	**35,380**	10,784	**33,940**	10,345	**8,110**	2,472	**6,640**	2,024	**2,760**	841
			1250	381	**34,920**	10,644	**33,490**	10,208	**7,890**	2,405	**6,440**	1,963	**2,610**	796
	30	9.1	**100**	30	**36,720**	11,192	**35,230**	10,738	**8,560**	2,609	**7,030**	2,143	**3,000**	914
			250	76	**35,790**	10,909	**34,340**	10,467	**8,230**	2,509	**6,740**	2,054	**2,820**	860
			500	152	**34,540**	10,528	**33,120**	10,095	**7,680**	2,341	**6,230**	1,899	**2,460**	750
			750	229	**33,620**	10,248	**32,220**	9,821	**7,260**	2,213	**5,850**	1,783	**2,180**	664
			1000	305	**32,880**	10,022	**31,500**	9,601	**6,920**	2,109	**5,540**	1,689	**1,950**	594
			1250	381	**32,340**	9,857	**30,970**	9,440	**6,680**	2,036	**5,310**	1,619	**1,790**	546
	45	13.7	**100**	30	**35,170**	10,720	**33,710**	10,275	**7,560**	2,304	**6,090**	1,856	**2,290**	698
			250	76	**34,360**	10,473	**32,920**	10,034	**7,340**	2,237	**5,900**	1,798	**2,160**	658
			500	152	**33,300**	10,150	**31,900**	9,723	**6,970**	2,124	**5,560**	1,695	**1,940**	591
			750	229	**32,420**	9,882	**31,050**	9,464	**6,610**	2,015	**5,250**	1,600	**1,720**	524
			1000	305	**31,740**	9,674	**30,390**	9,263	**6,330**	1,929	**4,990**	1,521	**1,670**	509
			1250	381	**31,100**	9,479	**29,770**	9,074	**6,060**	1,847	**4,740**	1,445	**1,870**	570
Horiz.	**15**	4.6	**100**	30	**35,850**	10,927	**34,380**	10,479	**7,980**	2,432	**6,480**	1,975	**2,580**	786
			250	76	**34,350**	10,470	**32,910**	10,031	**7,190**	2,192	**5,740**	1,750	**2,030**	619
			500	152	**32,770**	9,988	**31,360**	9,559	**6,330**	1,929	**4,950**	1,509	**1,480**	451
			750	229	**31,640**	9,644	**30,250**	9,220	**5,730**	1,747	**4,400**	1,341	**1,610**	491
			1000	305	**30,800**	9,388	**29,420**	8,967	**5,280**	1,609	**3,990**	1,216	**1,790**	546
			1250	381	**30,080**	9,168	**28,730**	8,757	**4,920**	1,500	**3,650**	1,113	**1,930**	588
	30	9.1	**100**	30	**34,470**	10,507	**33,020**	10,065	**7,090**	2,161	**5,650**	1,722	**1,980**	604
			250	76	**32,860**	10,016	**31,430**	9,580	**6,220**	1,896	**4,850**	1,478	**1,430**	436
			500	152	**31,120**	9,485	**29,720**	9,059	**5,280**	1,609	**4,000**	1,219	**1,590**	485
			750	229	**29,870**	9,104	**28,500**	8,687	**4,640**	1,414	**3,430**	1,045	**1,800**	549
			1000	305	**28,930**	8,818	**27,570**	8,403	**4,190**	1,277	**3,020**	921	**1,940**	591
			1250	381	**28,140**	8,577	**26,800**	8,169	**3,820**	1,164	**2,920**	890	**2,040**	622
	45	13.7	**100**	30	**33,400**	10,180	**31,960**	9,742	**6,420**	1,957	**5,030**	1,533	**1,590**	485
			250	76	**31,760**	9,681	**30,340**	9,248	**5,550**	1,692	**4,250**	1,295	**1,360**	415
			500	152	**29,920**	9,120	**28,540**	8,699	**4,640**	1,414	**3,430**	1,045	**1,650**	503
			750	229	**28,650**	8,733	**27,290**	8,318	**4,050**	1,234	**2,900**	884	**1,840**	561
			1000	305	**27,650**	8,428	**26,310**	8,019	**3,590**	1,094	**2,850**	869	**1,960**	597
			1250	381	**26,810**	8,172	**25,500**	7,772	**3,300**	1,006	**3,000**	914	**2,040**	622
Up	**15**	4.6	**100**	30	**31,880**	9,717	**30,560**	9,315	**7,170**	2,185	**5,870**	1,789	**2,490**	759
			250	76	**25,210**	7,684	**24,090**	7,343	**4,600**	1,402	**3,580**	1,091	**840**	256
			500	152	**18,130**	5,526	**17,250**	5,258	**1,930**	588	**NH**	NH	**NH**	NH
			750	229	**14,240**	4,340	**13,490**	4,112	**NH**	NH	**NH**	NH	**NH**	NH
			1000	305	**11,360**	3,463	**10,680**	3,255	**NH**	NH	**NH**	NH	**NH**	NH
			1250	381	**8,860**	2,701	**8,180**	2,493	**NH**	NH	**NH**	NH	**NH**	NH
	30	9.1	**100**	30	**30,900**	9,418	**29,620**	9,028	**6,810**	2,076	**5,550**	1,692	**2,290**	698
			250	76	**24,270**	7,398	**23,180**	7,065	**4,320**	1,317	**3,350**	1,021	**NH**	NH
			500	152	**17,340**	5,285	**16,490**	5,026	**NH**	NH	**NH**	NH	**NH**	NH
			750	229	**13,570**	4,136	**12,840**	3,914	**NH**	NH	**NH**	NH	**NH**	NH
			1000	305	**10,760**	3,280	**10,090**	3,075	**NH**	NH	**NH**	NH	**NH**	NH
			1250	381	**8,150**	2,484	**7,450**	2,271	**NH**	NH	**NH**	NH	**NH**	NH
	45	13.7	**100**	30	**29,940**	9,126	**28,680**	8,742	**6,460**	1,969	**5,240**	1,597	**2,120**	646
			250	76	**23,280**	7,096	**22,220**	6,773	**4,050**	1,234	**3,110**	948	**NH**	NH
			500	152	**16,620**	5,066	**15,800**	4,816	**NH**	NH	**NH**	NH	**NH**	NH
			750	229	**12,870**	3,923	**12,160**	3,706	**NH**	NH	**NH**	NH	**NH**	NH
			1000	305	**10,020**	3,054	**9,360**	2,853	**NH**	NH	**NH**	NH	**NH**	NH
			1250	381	**7,280**	2,219	**6,490**	1,978	**NH**	NH	**NH**	NH	**NH**	NH

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table A-8
Distance to Concentrations of Interest for Outdoor Release from PSV
Cold Gas Release at 500 lbs/min (227 kg/min) **3D Weather**

Release Condition:
-28°F, Saturated Vapor
-33.3°C, Saturated Vapor

Orientation	Discharge Elevation ft	Discharge Elevation meters	Discharge Velocity ft /sec	Discharge Velocity meters /sec	ERPG1 25 PPMV @ 60 min ft	ERPG1 meters	STEL 35 PPMV @ 60 min ft	STEL meters	ERPG2 200 PPMV @ 60 min ft	ERPG2 meters	IDLH 300 PPMV @ 30 min ft	IDLH meters	ERPG3 750 PPMV @ 60 min ft	ERPG3 meters
Down 30°	15	4.6	100	30	910	277	900	274	540	165	500	152	370	113
			250	76	940	287	940	287	580	177	540	165	400	122
			500	152	32,570	9,927	31,220	9,516	7,190	2,192	5,840	1,780	2,320	707
			750	229	31,890	9,720	30,560	9,315	6,890	2,100	5,570	1,698	2,140	652
			1000	305	31,380	9,565	30,060	9,162	6,670	2,033	5,370	1,637	1,990	607
			1250	381	30,960	9,437	29,650	9,037	6,490	1,978	5,210	1,588	1,880	573
	30	9.1	100	30	760	232	750	229	510	155	470	143	370	113
			250	76	970	296	960	293	650	198	610	186	470	143
			500	152	1,170	357	1,160	354	770	235	730	223	550	168
			750	229	1,390	424	1,380	421	890	271	810	247	610	186
			1000	305	1,590	485	1,570	479	960	293	900	274	650	198
			1250	381	1,750	533	1,720	524	1,060	323	960	293	680	207
	45	13.7	100	30	700	213	690	210	470	143	440	134	340	104
			250	76	1,050	320	1,040	317	680	207	650	198	510	155
			500	152	1,460	445	1,440	439	920	280	860	262	630	192
			750	229	1,760	536	1,740	530	1,070	326	980	299	700	213
			1000	305	1,970	600	1,950	594	1,170	357	1,080	329	740	226
			1250	381	2,200	671	2,170	661	1,280	390	1,150	351	770	235
Horiz.	15	4.6	100	30	860	262	840	256	530	162	470	143	360	110
			250	76	1,030	314	1,020	311	660	201	620	189	460	140
			500	152	1,600	488	1,580	482	930	283	860	262	600	183
			750	229	1,990	607	1,970	600	1,130	344	1,020	311	660	201
			1000	305	2,310	704	2,280	695	1,290	393	1,150	351	710	216
			1250	381	2,600	792	2,560	780	1,410	430	1,250	381	770	235
	30	9.1	100	30	810	247	800	244	480	146	450	137	NH	NH
			250	76	1,120	341	1,110	338	660	201	610	186	430	131
			500	152	1,550	472	1,540	469	880	268	800	244	550	168
			750	229	1,980	604	1,960	597	1,090	332	990	302	630	192
			1000	305	2,350	716	2,320	707	1,270	387	1,130	344	670	204
			1250	381	2,650	808	2,610	796	1,410	430	1,230	375	720	219
	45	13.7	100	30	720	219	710	216	410	125	NH	NH	NH	NH
			250	76	1,030	314	1,010	308	580	177	540	165	NH	NH
			500	152	1,670	509	1,660	506	850	259	770	235	NH	NH
			750	229	1,990	607	1,970	600	990	302	900	274	NH	NH
			1000	305	2,280	695	2,250	686	1,130	344	1,010	308	500	152
			1250	381	2,570	783	2,530	771	1,290	393	1,120	341	560	171
Up	15	4.6	100	30	600	183	590	180	NH	NH	NH	NH	NH	NH
			250	76	560	171	540	165	NH	NH	NH	NH	NH	NH
			500	152	540	165	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	480	146	460	140	NH	NH	NH	NH	NH	NH
			250	76	450	137	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

Distance to Concentration, ft (meters)

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table A-9
Distance to Concentrations of Interest for Outdoor Release from PSV
Warm Gas Release at 500 lbs/min (227 kg/min) 3D Weather

Release Condition:
+77°F, Superheated Vapor
+25°C, Superheated Vapor

Orientation	Discharge Elevation ft	Discharge Elevation meters	Discharge Velocity ft/sec	Discharge Velocity meters/sec	ERPG1 25 PPMV @ 60 min ft	ERPG1 meters	STEL 35 PPMV @ 60 min ft	STEL meters	ERPG2 200 PPMV @ 60 min ft	ERPG2 meters	IDLH 300 PPMV @ 30 min ft	IDLH meters	ERPG3 750 PPMV @ 60 min ft	ERPG3 meters
Down 30°	15	4.6	100	30	1,230	375	1,200	366	380	116	250	76	150	46
			250	76	1,290	393	1,260	384	570	174	320	98	190	58
			500	152	1,340	408	1,320	402	650	198	380	116	230	70
			750	229	1,370	418	1,350	411	700	213	440	134	260	79
			1000	305	1,410	430	1,380	421	730	223	480	146	290	88
			1250	381	1,460	445	1,430	436	760	232	520	158	320	98
	30	9.1	100	30	1,230	375	1,200	366	360	110	230	70	120	37
			250	76	1,360	415	1,340	408	710	216	470	143	280	85
			500	152	1,480	451	1,450	442	790	241	620	189	340	104
			750	229	1,520	463	1,500	457	830	253	690	210	380	116
			1000	305	1,540	469	1,520	463	860	262	730	223	420	128
			1250	381	1,580	482	1,550	472	900	274	760	232	450	137
	45	13.7	100	30	1,170	357	1,150	351	NH	NH	NH	NH	NH	NH
			250	76	1,320	402	1,300	396	730	223	610	186	320	98
			500	152	1,460	445	1,440	439	830	253	710	216	400	122
			750	229	1,580	482	1,560	475	900	274	760	232	450	137
			1000	305	1,650	503	1,640	500	950	290	810	247	490	149
			1250	381	1,740	530	1,700	518	990	302	850	259	520	158
Horiz.	15	4.6	100	30	1,210	369	1,180	360	200	61	NH	NH	NH	NH
			250	76	1,340	408	1,320	402	680	207	390	119	210	64
			500	152	1,350	411	1,340	408	770	235	660	201	360	110
			750	229	1,460	445	1,440	439	850	259	740	226	440	134
			1000	305	1,570	479	1,550	472	920	280	790	241	470	143
			1250	381	1,670	509	1,650	503	980	299	840	256	510	155
	30	9.1	100	30	1,150	351	1,130	344	NH	NH	NH	NH	NH	NH
			250	76	1,310	399	1,290	393	NH	NH	NH	NH	NH	NH
			500	152	1,390	424	1,370	418	750	229	460	140	NH	NH
			750	229	1,390	424	1,370	418	800	244	690	210	310	94
			1000	305	1,520	463	1,500	457	880	268	760	232	390	119
			1250	381	1,670	509	1,650	503	950	290	820	250	450	137
	45	13.7	100	30	1,100	335	1,070	326	NH	NH	NH	NH	NH	NH
			250	76	1,230	375	1,200	366	NH	NH	NH	NH	NH	NH
			500	152	1,350	411	1,330	405	NH	NH	NH	NH	NH	NH
			750	229	1,390	424	1,370	418	750	229	NH	NH	NH	NH
			1000	305	1,580	482	1,560	475	850	259	510	155	NH	NH
			1250	381	1,720	524	1,690	515	920	280	740	226	NH	NH
Up	15	4.6	100	30	930	283	910	277	NH	NH	NH	NH	NH	NH
			250	76	870	265	830	253	NH	NH	NH	NH	NH	NH
			500	152	790	241	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	880	268	840	256	NH	NH	NH	NH	NH	NH
			250	76	790	241	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	780	238	NH	NH	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table A-10
Distance to Concentrations of Interest for Outdoor Release from PSV
Aerosol Release at 1,000 lbs/min (454 kg/min) 1.5F Weather

Release Condition:
-28°F, 0.12 liquid fraction
-33.3°C, 0.12 liquid fraction

Orientation	Discharge Elevation ft	Discharge Elevation meters	Discharge Velocity ft /sec	Discharge Velocity meters /sec	ERPG1 25 PPMV @ 60 min ft	ERPG1 25 PPMV @ 60 min meters	STEL 35 PPMV @ 60 min ft	STEL 35 PPMV @ 60 min meters	ERPG2 200 PPMV @ 60 min ft	ERPG2 200 PPMV @ 60 min meters	IDLH 300 PPMV @ 30 min ft	IDLH 300 PPMV @ 30 min meters	ERPG3 750 PPMV @ 60 min ft	ERPG3 750 PPMV @ 60 min meters
Down 30°	15	4.6	100	30	59,230	18,054	56,800	17,313	14,120	4,304	11,750	3,581	5,540	1,689
			250	76	58,570	17,852	56,150	17,115	13,630	4,154	11,280	3,438	5,130	1,564
			500	152	57,290	17,462	54,900	16,734	13,010	3,965	10,710	3,264	4,690	1,430
			750	229	56,270	17,151	53,900	16,429	12,550	3,825	10,280	3,133	4,380	1,335
			1000	305	55,420	16,892	53,070	16,176	12,160	3,706	9,930	3,027	4,120	1,256
			1250	381	54,670	16,664	52,340	15,953	11,830	3,606	9,620	2,932	3,900	1,189
	30	9.1	100	30	58,240	17,752	55,810	17,011	13,280	4,048	10,930	3,332	4,820	1,469
			250	76	56,320	17,167	53,950	16,444	12,520	3,816	10,250	3,124	4,340	1,323
			500	152	54,170	16,511	51,860	15,807	11,590	3,533	9,400	2,865	3,730	1,137
			750	229	52,560	16,020	50,290	15,329	10,890	3,319	8,760	2,670	3,270	997
			1000	305	51,450	15,682	49,210	14,999	10,400	3,170	8,310	2,533	2,950	899
			1250	381	50,660	15,441	48,440	14,765	10,050	3,063	7,980	2,432	2,720	829
	45	13.7	100	30	56,100	17,099	53,710	16,371	12,070	3,679	9,800	2,987	3,940	1,201
			250	76	54,540	16,624	52,210	15,914	11,580	3,530	9,370	2,856	3,670	1,119
			500	152	52,500	16,002	50,230	15,310	10,770	3,283	8,640	2,634	3,170	966
			750	229	50,950	15,530	48,720	14,850	10,130	3,088	8,060	2,457	2,770	844
			1000	305	49,740	15,161	47,540	14,490	9,610	2,929	7,580	2,310	2,420	738
			1250	381	48,770	14,865	46,600	14,204	9,180	2,798	7,180	2,188	2,500	762
Horiz.	15	4.6	100	30	56,400	17,191	54,000	16,459	12,160	3,706	9,880	3,011	4,000	1,219
			250	76	53,900	16,429	51,560	15,716	10,980	3,347	8,790	2,679	3,210	978
			500	152	51,310	15,639	49,030	14,945	9,730	2,966	7,640	2,329	2,390	728
			750	229	49,530	15,097	47,290	14,414	8,860	2,701	6,840	2,085	2,230	680
			1000	305	48,240	14,704	46,030	14,030	8,210	2,502	6,250	1,905	2,440	744
			1250	381	47,140	14,368	44,960	13,704	7,660	2,335	5,740	1,750	2,640	805
	30	9.1	100	30	54,450	16,597	52,080	15,874	11,040	3,365	8,830	2,691	3,230	985
			250	76	51,950	15,835	49,640	15,130	9,820	2,993	7,710	2,350	2,440	744
			500	152	49,360	15,045	47,100	14,356	8,490	2,588	6,490	1,978	2,160	658
			750	229	47,650	14,524	45,420	13,844	7,580	2,310	5,660	1,725	2,430	741
			1000	305	46,290	14,109	44,090	13,439	6,870	2,094	5,040	1,536	2,660	811
			1250	381	45,100	13,747	42,920	13,082	6,280	1,914	4,510	1,375	2,850	869
	45	13.7	100	30	53,360	16,264	51,000	15,545	10,280	3,133	8,120	2,475	2,740	835
			250	76	50,780	15,478	48,480	14,777	9,010	2,746	6,960	2,121	1,990	607
			500	152	48,230	14,701	45,970	14,012	7,680	2,341	5,770	1,759	2,270	692
			750	229	46,290	14,109	44,070	13,433	6,730	2,051	4,920	1,500	2,560	780
			1000	305	44,730	13,634	42,530	12,963	6,000	1,829	4,280	1,305	2,750	838
			1250	381	43,390	13,225	41,220	12,564	5,420	1,652	4,160	1,268	2,900	884
Up	15	4.6	100	30	50,040	15,252	47,910	14,603	10,930	3,332	8,940	2,725	3,840	1,170
			250	76	40,130	12,232	38,300	11,674	7,370	2,246	5,780	1,762	1,870	570
			500	152	29,330	8,940	27,890	8,501	3,960	1,207	2,570	783	NH	NH
			750	229	22,860	6,968	21,660	6,602	NH	NH	NH	NH	NH	NH
			1000	305	18,430	5,618	17,370	5,294	NH	NH	NH	NH	NH	NH
			1250	381	14,880	4,535	13,890	4,234	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	48,950	14,920	46,840	14,277	10,550	3,216	8,610	2,624	3,640	1,109
			250	76	39,160	11,936	37,370	11,391	7,080	2,158	5,540	1,689	1,720	524
			500	152	28,350	8,641	26,950	8,214	3,620	1,103	NH	NH	NH	NH
			750	229	22,070	6,727	20,900	6,370	NH	NH	NH	NH	NH	NH
			1000	305	17,730	5,404	16,690	5,087	NH	NH	NH	NH	NH	NH
			1250	381	14,240	4,340	13,270	4,045	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	47,780	14,564	45,720	13,936	10,160	3,097	8,260	2,518	3,440	1,049
			250	76	38,010	11,586	36,260	11,052	6,740	2,054	5,250	1,600	1,490	454
			500	152	27,360	8,339	26,010	7,928	3,210	978	NH	NH	NH	NH
			750	229	21,330	6,501	20,190	6,154	NH	NH	NH	NH	NH	NH
			1000	305	17,040	5,194	16,020	4,883	NH	NH	NH	NH	NH	NH
			1250	381	13,480	4,109	12,510	3,813	NH	NH	NH	NH	NH	NH

Distance to Concentration, ft (meters)

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table A-11
Distance to Concentrations of Interest for Outdoor Release from PSV
Cold Gas Release at 1,000 lbs/min (454 kg/min) **1.5F Weather**

Release Condition:
-28°F, Saturated Vapor
-33.3°C, Saturated Vapor

Orientation	Discharge Elevation		Discharge Velocity		Distance to Concentration, ft (meters)									
					ERPG1 25 PPMV @ 60 min		STEL 35 PPMV @ 60 min		ERPG2 200 PPMV @ 60 min		IDLH 300 PPMV @ 30 min		ERPG3 750 PPMV @ 60 min	
	ft	meters	ft /sec	meters /sec	ft	meters	ft	meters	ft	meters	ft	meters	ft	meters
Down 30°	15	4.6	100	30	1,420	433	1,390	424	790	241	730	223	340	104
			250	76	1,530	466	1,500	457	860	262	780	238	420	128
			500	152	50,030	15,249	47,880	14,594	10,560	3,219	8,550	2,606	3,400	1,036
			750	229	48,900	14,905	46,780	14,259	10,110	3,082	8,150	2,484	3,120	951
			1000	305	48,010	14,634	45,910	13,994	9,770	2,978	7,840	2,390	2,910	887
			1250	381	47,270	14,408	45,200	13,777	9,480	2,890	7,580	2,310	2,750	838
	30	9.1	100	30	1,460	445	1,430	436	820	250	770	235	520	158
			250	76	1,600	488	1,590	485	940	287	880	268	620	189
			500	152	1,670	509	1,660	506	1,050	320	950	290	700	213
			750	229	1,840	561	1,810	552	1,120	341	1,050	320	760	232
			1000	305	1,930	588	1,920	585	1,190	363	1,110	338	800	244
			1250	381	43,740	13,332	41,770	12,732	8,170	2,490	6,410	1,954	2,260	689
	45	13.7	100	30	1,370	418	1,360	415	800	244	750	229	520	158
			250	76	1,610	491	1,600	488	960	293	910	277	670	204
			500	152	1,890	576	1,870	570	1,140	347	1,070	326	770	235
			750	229	2,030	619	2,000	610	1,280	390	1,170	357	850	259
			1000	305	2,220	677	2,200	671	1,370	418	1,270	387	900	274
			1250	381	2,500	762	2,470	753	1,520	463	1,380	421	940	287
Horiz.	15	4.6	100	30	1,420	433	1,400	427	800	244	750	229	350	107
			250	76	1,390	424	1,380	421	880	268	800	244	610	186
			500	152	1,900	579	1,880	573	1,140	347	1,070	326	760	232
			750	229	2,340	713	2,320	707	1,390	424	1,280	390	850	259
			1000	305	2,760	841	2,720	829	1,600	488	1,440	439	900	274
			1250	381	3,130	954	3,080	939	1,770	540	1,570	479	960	293
	30	9.1	100	30	1,390	424	1,380	421	790	241	710	216	NH	NH
			250	76	1,480	451	1,460	445	880	268	800	244	570	174
			500	152	1,870	570	1,850	564	1,120	341	1,030	314	730	223
			750	229	2,400	732	2,360	719	1,390	424	1,280	390	830	253
			1000	305	2,850	869	2,810	856	1,620	494	1,440	439	880	268
			1250	381	3,230	985	3,190	972	1,800	549	1,580	482	940	287
	45	13.7	100	30	1,340	408	1,330	405	740	226	NH	NH	NH	NH
			250	76	1,440	439	1,420	433	860	262	780	238	NH	NH
			500	152	1,970	600	1,950	594	1,110	338	1,020	311	520	158
			750	229	2,490	759	2,450	747	1,350	411	1,230	375	710	216
			1000	305	2,760	841	2,710	826	1,530	466	1,370	418	800	244
			1250	381	3,180	969	3,130	954	1,720	524	1,520	463	860	262
Up	15	4.6	100	30	1,040	317	1,020	311	NH	NH	NH	NH	NH	NH
			250	76	930	283	910	277	NH	NH	NH	NH	NH	NH
			500	152	870	265	790	241	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	910	277	890	271	NH	NH	NH	NH	NH	NH
			250	76	830	253	780	238	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	780	238	760	232	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance

Table A-12
Distance to Concentrations of Interest for Outdoor Release from PSV
Warm Gas Release at 1,000 lbs/min (454 kg/min) 1.5F Weather

Release Condition:
+77°F, Superheated Vapor
+25°C, Superheated Vapor

Orientation	Discharge Elevation ft	Discharge Elevation meters	Discharge Velocity ft /sec	Discharge Velocity meters /sec	ERPG1 25 PPMV @ 60 min ft	ERPG1 meters	STEL 35 PPMV @ 60 min ft	STEL meters	ERPG2 200 PPMV @ 60 min ft	ERPG2 meters	IDLH 300 PPMV @ 30 min ft	IDLH meters	ERPG3 750 PPMV @ 60 min ft	ERPG3 meters
Down 30°	15	4.6	100	30	1,780	543	1,730	527	260	79	200	61	130	40
			250	76	1,850	564	1,800	549	370	113	270	82	180	55
			500	152	1,920	585	1,880	573	460	140	350	107	230	70
			750	229	1,960	597	1,930	588	560	171	410	125	270	82
			1000	305	2,010	613	1,970	600	630	192	460	140	300	91
			1250	381	2,050	625	2,010	613	700	213	520	158	330	101
	30	9.1	100	30	1,800	549	1,760	536	310	94	230	70	150	46
			250	76	1,960	597	1,920	585	590	180	440	134	280	85
			750	229	2,190	668	2,150	655	860	262	640	195	420	128
			1000	305	2,250	686	2,210	674	1,070	326	720	219	460	140
			1250	381	2,300	701	2,260	689	1,150	351	780	238	500	152
			100	30	1,770	540	1,730	527	NH	NH	NH	NH	NH	NH
	45	13.7	250	76	1,990	607	1,960	597	760	232	550	168	350	107
			500	152	2,180	664	2,140	652	1,030	314	680	207	440	134
			750	229	2,290	698	2,260	689	1,150	351	780	238	510	155
			1000	305	2,420	738	2,370	722	1,230	375	860	262	550	168
			1250	381	2,510	765	2,460	750	1,290	393	920	280	600	183
			500	152	2,100	640	2,050	625	750	229	550	168	360	110
Horiz.	15	4.6	100	30	1,780	543	1,730	527	NH	NH	NH	NH	NH	NH
			250	76	1,960	597	1,930	588	540	165	390	119	230	70
			500	152	2,130	649	2,090	637	1,060	323	700	213	410	125
			750	229	2,330	710	2,290	698	1,220	372	880	268	530	162
			1000	305	2,470	753	2,430	741	1,300	396	960	293	590	180
			1250	381	2,580	786	2,540	774	1,360	415	1,020	311	640	195
	30	9.1	100	30	1,710	521	1,670	509	NH	NH	NH	NH	NH	NH
			250	76	1,930	588	1,890	576	NH	NH	NH	NH	NH	NH
			500	152	2,100	640	2,060	628	760	232	530	162	260	79
			750	229	2,200	671	2,160	658	1,130	344	760	232	420	128
			1000	305	2,310	704	2,280	695	1,250	381	940	287	520	158
			1250	381	2,470	753	2,430	741	1,330	405	1,050	320	600	183
	45	13.7	100	30	1,670	509	1,640	500	NH	NH	NH	NH	NH	NH
			250	76	1,900	579	1,850	564	NH	NH	NH	NH	NH	NH
			500	152	2,060	628	2,010	613	NH	NH	NH	NH	NH	NH
			750	229	2,160	658	2,120	646	790	241	490	149	NH	NH
			1000	305	2,220	677	2,180	664	1,160	354	720	219	NH	NH
			1250	381	2,200	671	2,170	661	1,220	372	980	299	NH	NH
Up	15	4.6	100	30	1,510	460	1,450	442	NH	NH	NH	NH	NH	NH
			250	76	1,410	430	1,310	399	NH	NH	NH	NH	NH	NH
			500	152	1,250	381	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	30	9.1	100	30	1,460	445	1,380	421	NH	NH	NH	NH	NH	NH
			250	76	1,330	405	1,130	344	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	45	13.7	100	30	1,390	424	1,200	366	NH	NH	NH	NH	NH	NH
			250	76	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			500	152	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			750	229	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1000	305	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
			1250	381	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

Distance to Concentration, ft (meters)

Shaded cells indicate concentration of interest does not reach ground level at any downwind distance