THE CHLORINE INSTITUTE

Pamphlet 74

Guidance on Estimating the Area Affected by a Chlorine Release

Edition 6

A LEGACY OF
1924
since
SAFETY STEWARDSHIP

Pamphlet 74 is currently under revision to create a more user-friendly document. The next revision will include clarifying language in the explanatory appendix that distinguishes concentration from dosage, maximum downwind instantaneous concentration plots, consistent units of measure, and an altered color scheme for optimized black and white printing.

June 2015

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1. INTRODUCTION

1.1 SCOPE

The intent of this pamphlet is to provide a simplified document to assist chlorine producers/users, local emergency planning committees, fire departments, and municipalities in estimating the area affected by a chlorine release for emergency planning and hazard assessment purposes, and to provide a general understanding of the expectations of chlorine cloud release scenarios. As noted elsewhere herein, the scenarios modeled in this pamphlet are based upon numerous assumptions prescribed by EPA in their RMP guidance. The reader must bear in mind that these assumptions are, in most cases, highly unlikely to occur.

1.2 CHLORINE INSTITUTE STEWARDSHIP PROGRAM

The Chlorine Institute (CI) exists to support the chlor-alkali industry and serve the public by fostering continuous improvements to safety and the protection of human health and the environment connected with the production, distribution and use of chlorine, sodium and potassium hydroxides, and sodium hypochlorite, and the distribution and use of hydrogen chloride. This support extends to giving continued attention to the security and safety of chlorine-handling operations.

Chlorine Institute members are committed to adopting CI's safety and stewardship initiatives, including pamphlets, checklists, and incident sharing, that will assist members in achieving measurable improvement. For more information on the Institute's stewardship program, visit CI's website at www.chlorineinstitute.org.

1.3 DEPARTMENT OF HOMELAND SECURITY – CHEMICAL SECURITY ANALYSIS CENTER

The Department of Homeland Security (DHS) Chemical Security Analysis Center (CSAC), part of the Science & Technology (S&T) Directorate, collaborated with the Chlorine Institute to develop updated guidance in this version of Pamphlet 74, based upon new experimental research into chlorine releases and the associated chemical and physical phenomena. The Hazard Prediction and Analysis Capability (HPAC) model, developed and widely used by the U.S. Government, was used to simulate the release scenarios in this pamphlet to provide new modeling results. New data and findings available from the chlorine release field trials performed in CSAC's Project Jack Rabbit in 2010 have been applied to the modeling and guidance presented in this pamphlet, representing the most current knowledge of chlorine releases to date.

1.4 DEFINITIONS AND ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association

AEGL	Acute Exposure Guideline Levels – The threshold exposure limits for the general public as defined by the National Advisory Committee for the Development of Acute Exposure Guideline Levels for Hazardous Substances.
AEGL-2	The airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
AEGL-3	The airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.
Accidental Release	An unanticipated emission of a regulated substance or other highly hazardous substance into the environment.
CSAC	Chemical Security Analysis Center
Crosswind Distance(s)	A point or points that are in the 90° direction from the path of the wind. If the wind is blowing from the west, points in the north and south directions constitute crosswind distances. The concentration at a specific crosswind distance will vary as the downwind distance is changed. In this pamphlet concentrations at crosswind distances are reported at ground level elevation. At different elevations, the concentration at a specific crosswind point will vary.
DHS	Department of Homeland Security
Downwind Distance(s)	A point or points that are directly in the path of the wind direction. If the wind is blowing from the west, points directly east of and downwind from the release source constitute downwind distances. In this pamphlet concentrations at downwind distances are reported at ground level elevation. For any release, the maximum concentration of the material being released will occur at some downwind distance. At different elevations, the concentration at a specific downwind point will vary.
HPAC	Hazard Prediction and Analysis Capability model
ERPG	Emergency Response Planning Guidelines as defined by AIHA
ERPG-2	The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual’s ability to take protective action. For chlorine, this value is 3 ppm (as defined by AIHA).

ERPG-3	The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects. For chlorine, this value is 20 ppm (as defined by AIHA).
Footprint	As used in this pamphlet, a graphical depiction of the maximum downstream area affected by a chlorine release at specified concentrations without regard to time. In this pamphlet, footprints are shown at ground level elevation. At different elevations, the footprint will be different.
Institute	The Chlorine Institute (CI)
LEPC	Local Emergency Planning Committee
Maximum Crosswind Distance	The maximum distance in the crosswind direction that a specific concentration reaches. The maximum crosswind distance will occur at some point both downwind and crosswind from the release point.
m/s	Meters per second
TWA	Time-weighted average
Worst-Case Scenario	As used in this pamphlet, the instantaneous release of the entire contents of chlorine from a container and the complete evaporation at a constant rate in a ten-minute period with no mitigating devices allowed. Under specific circumstances, passive mitigation devices, such as diking, may be utilized to mitigate the consequences of a release. However, the worst-case scenarios described in this pamphlet assume no mitigating devices are available.

1.5 DISCLAIMER

The information in this pamphlet is drawn from sources believed to be reliable. The Institute, its members, and its partners jointly or severally, make no guarantee and assume no liability in connection with any of this information. Moreover, it should not be assumed that every acceptable safety procedure is included or that special circumstances may not warrant modified or additional procedures. The user should be aware that changing technology or regulations may require a change in the recommendations herein. Appropriate steps should be taken to assure that the information is current when used. These suggestions should not be confused with federal, state, provincial, municipal, or insurance requirements or with national safety codes.

1.6 APPROVAL

The Chlorine Institute Health and Safety Issue Team approved Edition 6 of this pamphlet on June 12, 2015.

1.7 REVISIONS

Suggestions for revisions should be directed to the Secretary of the Chlorine Institute.

1.7.1 Significant Revisions in Current Edition

Significant revisions have been made to Edition 6 of this pamphlet to account for new experimental data and findings relevant to chlorine releases that affect the dispersion modeling and expected chlorine cloud behavior.

1.8 REPRODUCTION

The contents of this pamphlet are not to be copied for publication, in whole or part, without prior Chlorine Institute permission.

1.9 ABSTRACT

Because of the toxicity of chlorine, the chlor-alkali industry has established strict safety measures for the handling of chlorine under normal circumstances, process upset, or disrupted conditions.

In planning for emergency response to a chlorine release, it is necessary to estimate the area affected by the release. This pamphlet provides examples of scenarios that may help facilities and personnel better understand the characteristics, behavior, and potential impact area of a chlorine release cloud. These scenarios were conceptualized and selected based upon typical chlorine industry containers, equipment, and operations.

Results are provided as graphical representations (footprints) of the estimated downwind distances for specific chlorine concentrations and dosages that would be expected to be encountered during various release scenarios.

Additionally, other outputs are depicted. These include the following:

- Graphs showing centerline concentrations as a function of distance
- Concentrations as a function of time at 25%, 50%, 75%, and 100% of the maximum distance that a 3 ppm cloud travels
- The time for the release to stop, or effectively stop due to evaporative cooling (auto refrigeration) slowing the release to less than 1% of its initial discharge rate.
- Where applicable, the time for any accumulated liquid chlorine to evaporate.

These results have been prepared using the Hazard Prediction and Analysis Capability (HPAC) model, developed by the U.S. Department of Defense (DOD) through the Defense Threat Reduction Agency (DTRA). Descriptions of this model and their application to the scenarios in Pamphlet 74 can be found in Appendix A.

The modeling results included in this pamphlet represent the general range of expectations from chlorine release scenarios, and they are relevant to typical industrial facilities. However, it is important to note that every individual facility will have its own unique set of characteristics that will affect how a released chlorine cloud will behave. Where more precision or different scenarios are required, it is recommended that a person skilled in the modeling of dense gases or computational fluid dynamics should be consulted to perform site-specific simulations.

1.10 LIMITATIONS OF MODELING

The real-world dispersion of a chemical release into the atmosphere is a very complex phenomenon. Every chemical will move and interact with its surroundings differently due to its own unique physical and chemical characteristics. The chemical's dispersion and the area impacted is also highly dependent upon the specifics of the release source (known as the "source term"), which includes the amount, rate, and direction of release, and the chemical's phase upon release (i.e. vapor, liquid, aerosol). Additionally, dispersion is affected by a great number of environmental variables such as temperature, wind direction and velocity, moisture (humidity, precipitation, bodies of water), the surface roughness near the release, and many other components. With this inherent complexity, all models must make simplifying assumptions. It follows that all attempts to exactly model a chemical release via a mathematical algorithm must, by the limitations of the technology, be only an approximation. The accuracy of the model's estimation of cloud dispersion is determined by both the assumptions contained within the model, by the assumptions made by the user, and by the accuracy of the input data and parameters used in the simulations.

Data sets from real-world chemical releases are very limited, and for many chemicals, the extensive experimentation and research needed to generate reliable data for atmospheric dispersion is also limited or nonexistent. Using available data, many mathematical models have been compared to real world releases. It is generally accepted that a model that predicts the atmospheric concentration of a chemical release within a factor of 2 (model prediction falls between one half and twice the actual concentration) if operating within the limits of current modeling technology. Such uncertainty factors are particularly relevant when looking at the low concentrations that are discussed in this pamphlet.

Even with the limits of the technology, dispersion modeling still provides the best working estimate of the potential impact of a chemical release. Such modeling is a useful tool that contributes to the continuous improvement process for chemical operations. As a screening tool, dispersion modeling can help establish priorities for detailed analysis, and as a portion of the detailed analysis, modeling can help guide, plan, and evaluate mitigation opportunities. Additionally, it is through the understanding of the potential impact of an incident that appropriate emergency response plans and procedures are developed to minimize the impact on the community and the environment should a chemical release occur.

Several chlorine release scenarios are described within this pamphlet. Each scenario has been modeled under a range of meteorological conditions and other variables. The information developed as a result of this modeling exercise is intended to allow the reader to appreciate the magnitude of a potential chlorine release. However, it is impossible to represent here every possible combination of meteorological conditions, release configurations, and environmental variables. The reader should consider additional detailed modeling studies, beyond the scope of this pamphlet, as required to understand and mitigate the specific risk associated with the storage and/or use of chlorine for other unique and relevant scenarios.

For a variety of reasons there may be a need to evaluate scenarios beyond those presented in this pamphlet. Because of model variability, it is highly desirable that outputs from the same computer model and methodology be compared whenever possible. This pamphlet provides all the release and meteorological conditions used to model each scenario. If a model other than HPAC is used, it is recommended that this model be used to simulate each of the worst-case and alternate scenarios from this pamphlet. Side-by-side comparisons of the relative impact from various release scenarios will be more meaningful using this approach.

To use the same modeling input and setup conditions in Pamphlet 74 in another model, please refer to that model's technical documentation. The services of an experienced modeling professional should be sought if needed. The U.S. Environmental Protection Agency provides several reference sources for modeling and other information pertaining to consequence analysis methods.

2. CHARACTERISTICS OF CHLORINE RELEASES

2.1 SOURCES

Under process upset or other abnormal circumstances (for example; equipment failure, or natural disaster), chlorine could be released from a number of sources. Common sources may include:

a) Storage facilities (tanks or spheres)

b) Pipelines

c) Process vessels

d) Vents

e) Relief valves

f) Railroad tank cars

g) Highway cargo tanks

h) Portable containers or cylinders

i) Chemical reactions (for example: if acid and sodium hypochlorite were accidently mixed together)

2.2 PHYSICAL FORM

Chlorine occurs as a greenish-yellow gas or an amber liquid depending on the pressure and temperature. Typically, chlorine is stored and transported as a liquid under pressure. However, at standard atmospheric pressure (1 atm) and temperatures well above its boiling point (-29°F / -34°C), liquid chlorine boils extremely rapidly in a process known as "flashing", and expands in volume by nearly 460 times to a vapor. Chlorine vapor is 2.5 times denser than air and as a result, chlorine clouds will tend to flow into and accumulate in low-lying areas. During a release, chlorine can escape from a containment vessel as a vapor, a liquid, or both, depending upon where the breach occurs on the vessel and the release conditions.

2.2.1 Chemical Action/Reactions

Chlorine has a very strong chemical affinity for many substances. It will react with organic compounds, usually with the evolution of heat. Chlorine reacts with some metals under a variety of conditions. It is especially important to not use any titanium in dry chlorine service. Chlorine will react with steel and other metals at temperatures above 149°C (300°F).

2.2.2 Corrosive Action on Steel and Other Metals

At ambient temperatures, dry chlorine, either liquid or gas, does not corrode steel. Wet chlorine is highly corrosive because it forms hydrochloric and hypochlorous acids. Precautions should be taken to keep chlorine and chlorine equipment dry. Piping, valves, and containers should be closed or capped when not in use to keep out atmospheric moisture such as precipitation or humidity. Materials of construction must be chosen carefully, depending on the conditions that are expected. If water is used on a chlorine leak the resulting corrosive conditions will make the leak worse.

2.3 CHLORINE VAPOR RELEASE

A "vapor release" of chlorine occurs when there is a breach in containment in the headspace (or ullage) of a pressurized tank. When the hole is formed, the pressurized chlorine gas in the headspace will escape to the outside as a jet of vapor. Once outside the tank, the chlorine vapor will cool as it expands and slump to the ground as a dense gas. If the jet impinges against an object or the ground, frost may be observed forming from condensed humidity on surfaces impacted by the cold jet.

Inside the tank the dropping pressure will cause the liquid chlorine to boil, which sustains the escaping jet with additional chlorine vapor, however the boiling causes the remaining liquid chlorine in the tank to rapidly cool in a process known as "auto-refrigeration". As the liquid chlorine cools, the boiling will slow and eventually stop once the boiling point has been reached. At this stage, chlorine vapor will only be generated at a very slow rate. The remaining liquid chlorine in the tank will be maintained at -29°F (-34°C), and in some cases may remain for hours or days. For breached tanks that have reached an auto-refrigerated state, a frost line can often be observed on the outside of the tank as an indication of the approximate amount and location of liquid chlorine that still remains in the tank.

2.4 CHLORINE LIQUID RELEASE

A "liquid release" of chlorine occurs when there is a breach in containment at or below the liquid level of a pressurized tank. When the hole is formed, the pressure inside the tank will force liquid chlorine out of the opening, which will immediately flash to a vapor at the exit. Because the liquid is nearly 460 times denser than the vapor, the rate at which chlorine leaves the tank in a liquid release is much greater than a vapor release. A liquid chlorine release will therefore generate a substantially larger and more concentrated cloud, at a much faster rate, and impact a significantly greater area compared to an otherwise equivalent vapor release.

As the liquid chlorine exits the tank and flashes to a vapor jet, it will expand greatly and cool down to temperatures near its boiling point. At these low temperatures, the vapor's density will be substantially greater than that of air, and the resulting cloud will sink toward the ground, tend to flow with gravity and the terrain downhill, and accumulate in low-lying areas near the release site, especially under low wind conditions.

Auto-refrigeration will not initially be a significant factor inside the tank during the release, because nearly all of the chlorine's vaporization, expansion, and cooling occur outside the tank. However once the liquid level drains below the level of the hole, the process takes on the characteristics of a "chlorine vapor release", as described in Section 2.3. At this point the remaining liquid inside the tank will boil and rapidly cool to the point where the contents have been auto-refrigerated, and the vapor will only very slowly be released thereafter.

In some cases involving a chlorine liquid release, escaping liquid may collect in a pool or flow to the lowest level. Generally, liquid chlorine will boil and be rapidly vaporized upon contact with a heat source such as the air, the ground, or water. However, as the heat sources surrounding the chlorine pool are cooled, its vaporization rate will slow and liquid chlorine can accumulate outside the tank. Pooling is more likely to be observed in releases that involve large quantities, large holes, or when the escaping jet impinges against the ground or another object. Chlorine aerosols can also be formed in a release where there is not enough heat available in the surroundings to fully vaporize the escaping liquid chlorine. Favorable conditions for the formation of chlorine aerosols can develop during the release as the area is chilled rapidly by the expanding gas. Droplets of chlorine aerosol that are small enough to be suspended reduce the cloud's transparency and can significantly add to its density. Additionally, the aerosol can undergo evaporative cooling which can further drop the cloud temperature below even the boiling point. Chlorine clouds have been measured at temperatures of -100^{o}F (-73^{o}C) and lower due to this effect.

Since water in bulk provides a vast heat source for evaporation, water will rapidly vaporize liquid chlorine upon contact. This can quickly cause a chlorine vapor cloud to grow significantly larger and more concentrated. Water should therefore not be applied to liquid chlorine, and liquid chlorine should be prevented from flowing into areas with water such puddles, drains, and streams, ponds, or natural sources of water. Humidity in the air may result in the formation of an ice layer [consisting primarily of chlorine hydrate (freezing point of 49.3°F)] at a liquid pool or the container. Such effects may reduce the evaporation or release rate, and in some cases the area affected by such an incident may be lessened. None of the scenarios depicted in this pamphlet assume the formation of any such ice layer, and this possible effect is not further discussed.

2.5 MODE OF RELEASE

For modeling purposes, chlorine releases can be classified into two categories based upon the duration of the release into the atmosphere:

a) Immediate/Rapid

b) Continuous

An immediate/rapid release is characterized by the release of chlorine to the atmosphere in a relatively short period of time (usually less than 5-10 minutes), resulting in a cloud which moves downwind while diffusing and mixing with the air. Diffusion spreads out the cloud which results in it growing in size but decreasing in concentration (see Figure 2.1). Thus, the concentration of chlorine monitored at any given point downwind will vary over time depending on the position of the chlorine cloud. As depicted in Figure 2.1, the footprint of the cloud at a given concentration initially increases as the cloud expands. As the cloud continues to expand and diffuse into the atmosphere, however, the footprint will decrease along with the overall chlorine cloud concentration. The rupture of a chlorine container is an example of an immediate/rapid release.

A continuous release is characterized by the release of chlorine to the atmosphere over a longer period of time (usually more than 5-10 minutes), resulting in a continuous plume which reaches an equilibrium size and concentration gradient (see Figure 2.2). Thus, the concentration of chlorine monitored at any given point downwind from the source will be constant for the duration that the equilibrium is established. It will ramp up and tail off at the beginning and the end of the release. The failure of a valve or fitting on a large container is an example of a continuous release.

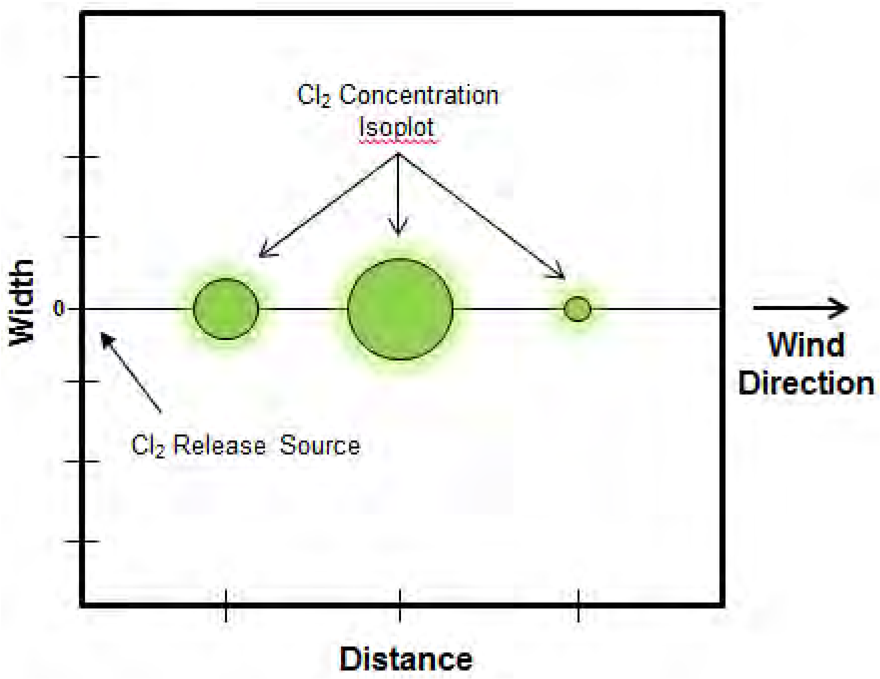


Figure 2.1 - Immediate/Rapid Release Footprint
The perimeters of the three circles represent the same concentration (isoplots) at different times.

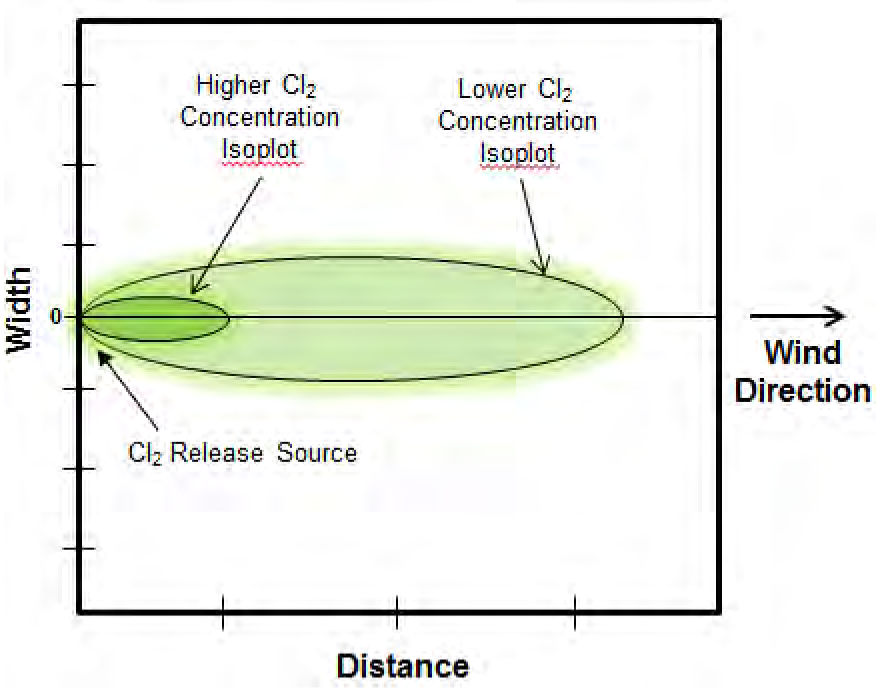


Figure 2.2 - Continuous Release Footprint
An equilibrium is reached in a continuous release where the chlorine concentration remains relatively stable at a given distance for the duration of the release.

3. DISPERSION

When chlorine is released to the atmosphere, its behavior and subsequent dispersion in the atmosphere can be considered in three stages:

- Release stage
- Transition stage
- Dispersion stage

3.1 THE RELEASE STAGE

In this stage, as chlorine is released, it enters the atmosphere and begins to disperse. Initially, the release is influenced by the source conditions and by the physical properties of chlorine itself. Therefore, the factors characterizing this stage of the release include:

1. The type of release (vapor, liquid, or both)
2. Geometry of the source
3. Location and orientation of the source
4. Conditions at the source (temperature, pressure)

5. Atmospheric conditions existing during the release (wind speed, temperature, solar radiation and humidity)

If vapor chlorine is released, it will start mixing with air immediately. If liquid chlorine is released under pressure, a portion of the escaping liquid is flashed off to a vapor. The remaining chlorine will either aerosolize or fall to the ground as a liquid. Figure 3.1 depicts some of these conditions.

3.2 THE TRANSITION STAGE

In this stage, the released chlorine transitions from the influence of its initial source conditions to the increasing influence of the atmosphere. The released chlorine continues to mix with air and with moisture in the air. The cooling effect of the evaporating chlorine may cause sufficient cooling to enable the formation of an aerosol. Aerosols will contribute to the excess density of the cloud and may cool the cloud even further through evaporative cooling. Eddy currents may also form, which can enhance the turbulence and the mixing of the plume.

As the heavier-than-air chlorine plume moves downwind, the chlorine concentration at a given downwind distance will typically be higher at lower elevations than at raised elevations. However, due to internal turbulence (eddies) and atmospheric motion, the mixture is further diluted by atmospheric air as it is being transported by the wind (Figure 3.2). Eventually, the plume is diluted to the point that its density approaches that of the surrounding air and it no longer behaves as a heavy gas, ending the transition stage.

The energy and mass transfer processes taking place between the chlorine, the ground and the atmosphere (Figure 3.3), again, are approximated by complex mathematical equations.

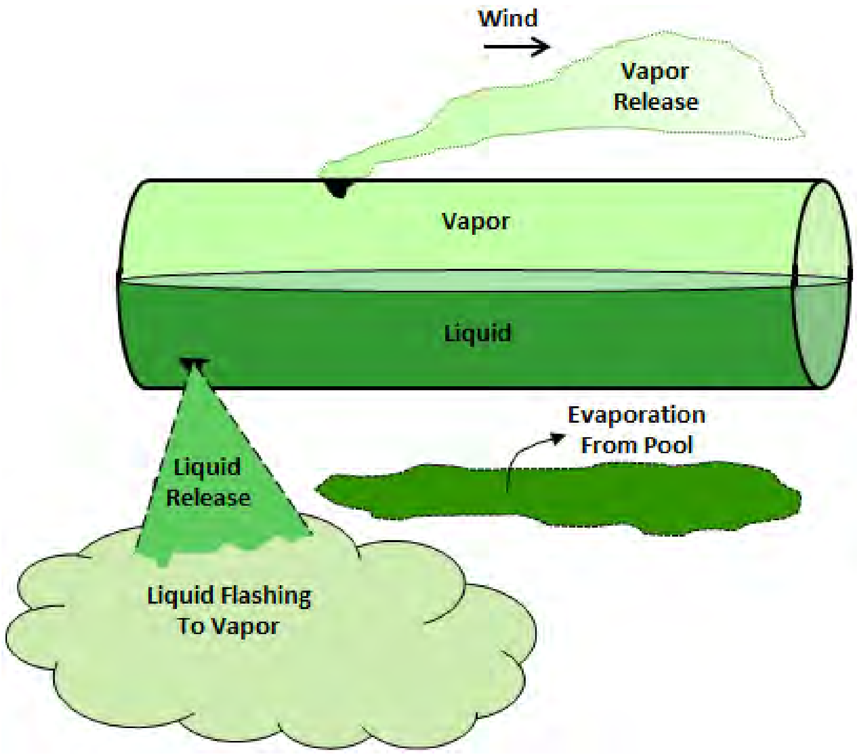


Figure 3.1 - Chlorine Vessel Leak Scenarios

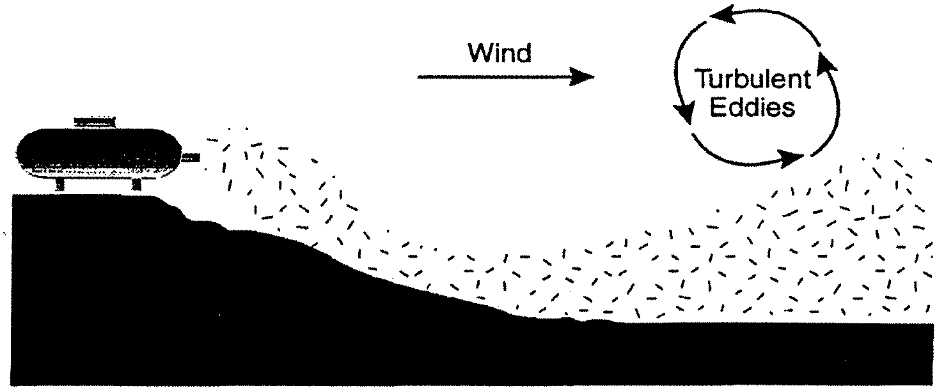


Figure 3.2 - Dense Gas Behavior

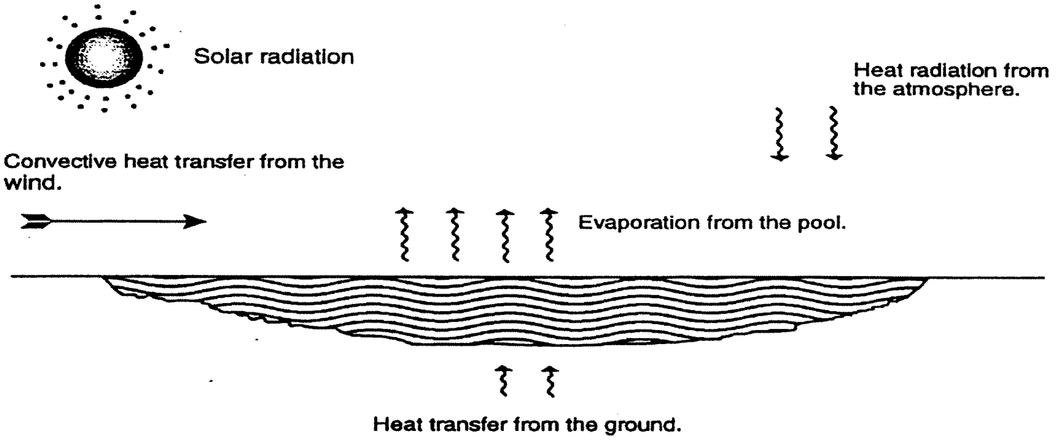


Figure 3.3 - Heat Sources Affecting Evaporation Rate

3.3 THE DISPERSION STAGE

In the final stage, the plume is almost completely dominated by the dynamics of the atmosphere. The dynamics of the atmosphere, on the other hand, are controlled by the level of incoming solar radiation. This radiation (Figure 3.4) causes the heating of the earth surface, which then generates the vertical and horizontal movement of the atmosphere (wind).

Normally, the earth's surface absorbs the incoming heat and in turn heats the air layer directly above it. As a result, the ambient air temperature decreases as the altitude increases. During daytime, since the warmer air on the earth's surface has lower density, it tends to rise inducing a vertical atmospheric movement and consequently, vertical instability of the atmosphere. In this situation the atmosphere is referred to as being unstable. In the pre-dawn hours, after the earth's surface has cooled down during the evening, the reverse is true. In that case, the atmosphere is called stable. To characterize the vertical and horizontal movements (turbulence or stability) of the atmosphere, stability classes are used. Most commonly, the atmosphere is classified from Stability Class A (very unstable) to Stability Class F (very stable) (Table 3-1).

The horizontal and vertical movements of the atmosphere (turbulence) have great influence on the dispersion of the chlorine plume. In fact, in mathematical equations describing the dispersion of the plume, its spread is directly related to the stability classes. If the release lasts for an extended period of time, the change in wind direction also needs to be considered due to the possible new direction the plume might travel (Figure 3-5). Wind direction generally becomes less predictable at low wind speeds. A wind speed of zero cannot be calculated in most models.

3.4 SOURCES OF ATMOSPHERIC DATA

For modeling purposes, historic weather data can be taken from an on-site weather station or from the closest station of the National Weather Service. Prior to preparing an agency mandated study using data from an on-site station, it would be prudent to verify whether the reviewing regulatory agency has adopted any instrument and testing standards. This data can be entered into a model manually or imported as an electronic file. Electronic weather data are available from the EPA Office of Air Quality Planning and Standards (OAQPS) and from the National Weather Service. Electronic data often require preprocessing before they are in a form usable by a given model. Weather data may also be available from commercial sources.

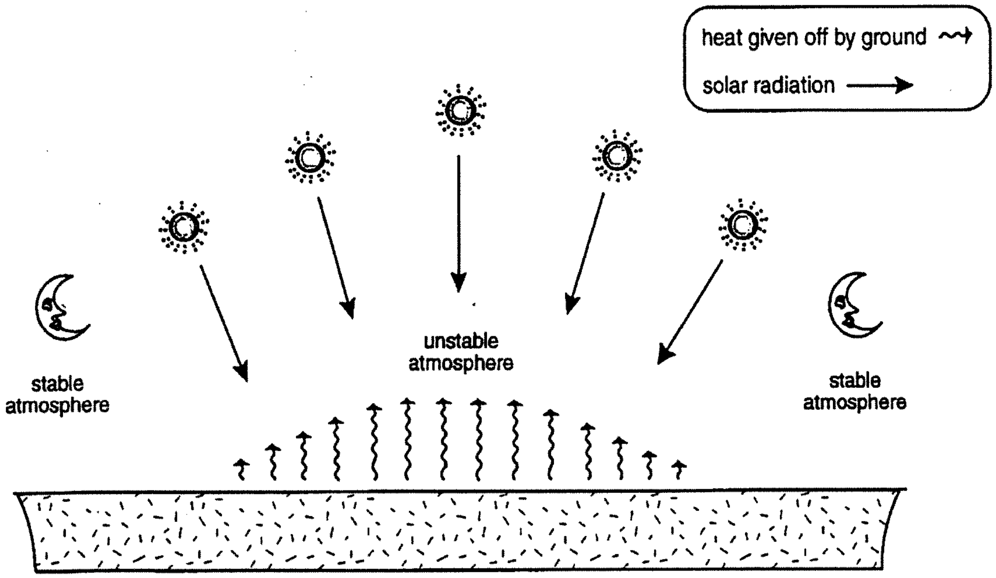


Figure 3.4 - Effect of Changing Solar Radiation and Temperatures at Different Times of the Day

Table 3-1. Pasquill-Turner Approach for Determining Atmospheric Stability in Rural Terrain.

Atmospheric Stability Categories

Surface Wind Speed (elevation of 10 meters) (m/s)	Day			Night	
	Incoming Solar Radiation			Thinly Overcast or	
	Strong	Moderate	Slight	> ½ Cloud Cover	< ½ Cloud Cover
<2	A	A – B	B		
2 – 3	A-B	B	C	E	F
3 – 5	B	B – C	C	D	E
5 – 6	C	C – D	D	D	D
>6	C	D	D	D	D

Note:

“Strong” incoming solar radiation corresponds to a solar altitude of > 60° with clear skies.

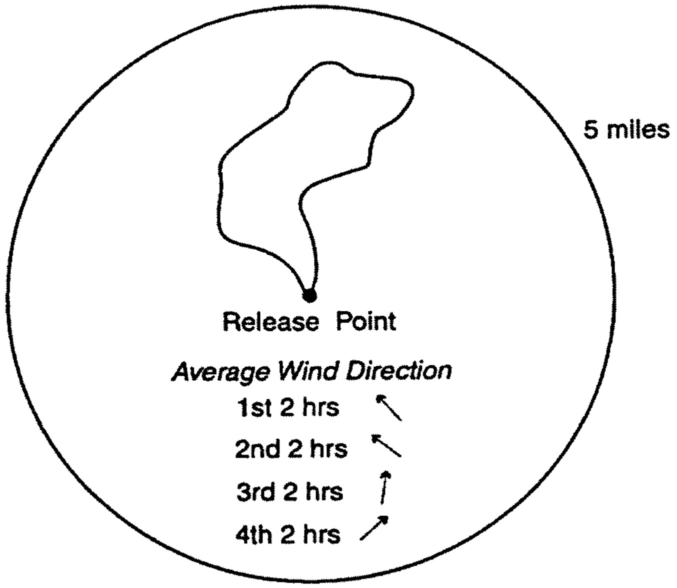
“Slight” incoming solar radiation corresponds to a solar altitude of 15° to 35° with clear skies.

The degree of cloudiness strongly influences the incoming solar radiation.

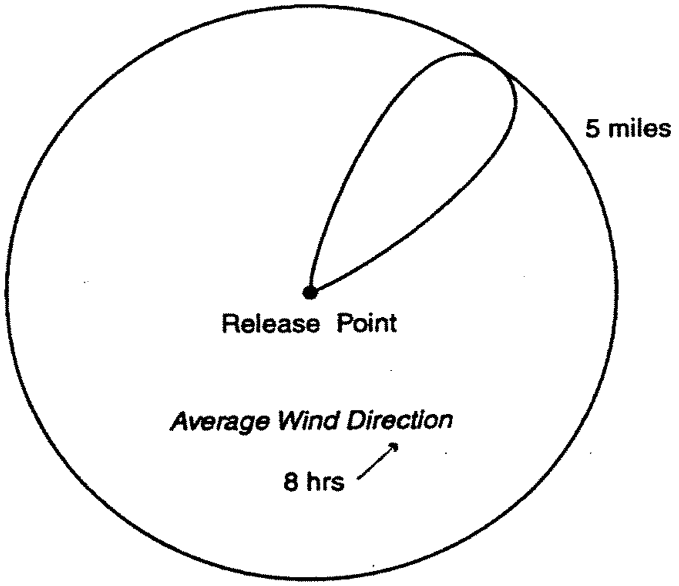
Neutral category D can be assumed for overcast conditions day or night, regardless of wind speed. “Night” refers to a period from 1 hour before sunset to 1 hour after sunrise.

*This categorization scheme applies only to rural areas (i.e., areas consisting of flat, vegetated terrain.) Stability categories for urban areas are generally one or two categories more unstable than stability categories estimated for a rural area using the Pasquill-Turner approach.

Source: *Reference 5.1.5*



(a) Vapor Cloud Movement During an 8-Hour Period with a Wind Persistence Time of 2 Hours



(b) Vapor Cloud Movement During an 8-Hour Period with a Wind Persistence Time of 8 Hours

Figure 3.5 - Examples of Atmospheric Dispersion of Vapor Clouds with Different Wind Persistence Times

4. CHLORINE RELEASE SCENARIOS

Each of the following examples gives an estimate for the area affected by a chlorine release under a given scenario. The scenarios were selected to give a wide range of potential release quantities and conditions. Also included are four (4) examples developed to demonstrate worst-case conditions as defined by the Environmental Protection Agency (*5.1.3* and *5.1.4*). Appendix A gives additional information explaining the computer model utilized to make the estimates. The footprints depict downstream distances at which chlorine concentration exceeds 20 parts per million (ppm) and 3 ppm. These values represent the American Industrial Hygiene Association (AIHA) Emergency Response Planning Guidelines ERPG-3 value (20 ppm) and ERPG-2 value (3 ppm) (*5.1.2*). These values were chosen because of their applicability to emergency response planning within LEPCs and industry and have been accepted by EPA.

In addition to the footprint type of outputs, two additional outputs are included. The second output shows the maximum (or peak) chlorine concentration at approximately 25, 50, 75, and 95% of the 3 ppm cloud distance versus time. This output provides information on the time required for the cloud to reach specific downwind distances.

The third output shows the maximum or peak concentration of chlorine at a specific distance downwind from the source. While the footprint output is both common and useful, it does not allow for a determination of how high the concentration of chlorine might be within the overall cloud. This new output will allow the reader to determine the maximum distance that a cloud will travel at chlorine concentrations other than 3 or 20 ppm.

Section 4.3 provides additional information concerning how to interpret the output graphs.

4.1 WORST-CASE SCENARIO ASSUMPTIONS

These are release scenarios involving standard chlorine containers utilizing the methods prescribed by EPA in its RMP Offsite Consequence Analysis Guidance (*5.1.3*). All of the worst-case scenarios depicted in this pamphlet involve transportation containers. These have been selected because they represent various size containers in common use. Facilities must individually determine whether the use of any of these scenarios satisfies the requirements of EPA's Risk Management Rule (*5.1.4*). Inputs common to these worst-case scenarios are as follows:

- The ambient relative humidity is 50%
- The ambient temperature is 77°F (25°C)
- Liquid chlorine is at 77°F and 100 psig before the release
- Surface roughness is 3.94 inches (0.1 meters). Such a surface roughness corresponds to a relatively flat, grassy, rural setting. A release in hilly terrain, forested area, and urban environment or over water may have significantly different terrain results.

- The wind speed is 3.36 miles/hour (1.5 meters/sec). The reference height for measuring the wind speed is 32.8 feet (10 meters).
- The contents of the container are released instantaneously and evaporated at a constant rate over a ten-minute period
- The atmospheric stability is class F
- The release occurs at ground level
- Solar radiation is assumed at 0 Btu/hr/ft^2
- Averaging time is 10 minutes
- Receptor height is 0 feet (ground level)

It should be noted that the EPA guidance allows different assumptions to be used for some of these parameters (*5.1.3*)

4.2 ALTERNATE SCENARIO ASSUMPTIONS

These are release scenarios involving equipment in use at chlorine production and/or use facilities. Facilities must individually determine whether the use of any of these scenarios satisfies the requirements of EPA's Risk Management Rule (*5.1.4*). Inputs common to these worst-case scenarios are listed below. Both the 3 ppm and 20 ppm footprints utilize the same conditions of 1.5 m/s, no cloud cover, and F stability, for the worst-case scenarios. As with the worst-case scenarios listed above, EPA guidance allows different assumptions to be used for many of these parameters when appropriate.

- The ambient relative humidity is 50%
- The ambient temperature is 77°F (25°C)
- Liquid or gaseous chlorine is at 77°F (25°C) and 100 psig before the release
- Surface roughness is 3.94 inches (0.1 meters). Such surface roughness corresponds to a relatively flat, grassy, rural setting. A release in hilly terrain, forested area, urban environment or over water may have significantly different dispersion results.
- The wind speed is either 7.72 miles/hour (3 m/s) or 3.36 miles/hour (1.5 meters/sec). The reference height for measuring the wind speed is 32.8 feet (10 meters).
- Minimum pool depth is 0.394 inches (1 centimeter)
- The maximum pool area is determined by the model (10,000 meter^2)
- The pool temperature is allowed to drop

- The initial substrate temperature is 77°F (25°C)
- Averaging time used is as follows: If the release duration is greater than 10 minutes, one hour averaging time is used. Otherwise, a 10 minute averaging time is used.
- Receptor height is 0 feet (ground level)
- The model determines whether there is aerosol formation
- If aerosol has formed, it is assumed to evaporate at the source

Changes in the ambient temperature or relative humidity assumptions will have little effect on the dispersion. Changes in the assumptions about the temperature and pressure of the chlorine prior to the release could significantly affect the dispersion. As stated in Section 1.9, the user of this pamphlet should consult with a person skilled in the modeling of heavy gases if different assumptions are used.

4.3 UNDERSTANDING THE OUTPUTS

Outputs for the worst-case scenarios are depicted only for stability class F. Outputs for alternate scenarios are depicted for stability classes B, D, and F. This approach is thought to cover most of the atmospheric conditions addressed in Section 3.3.

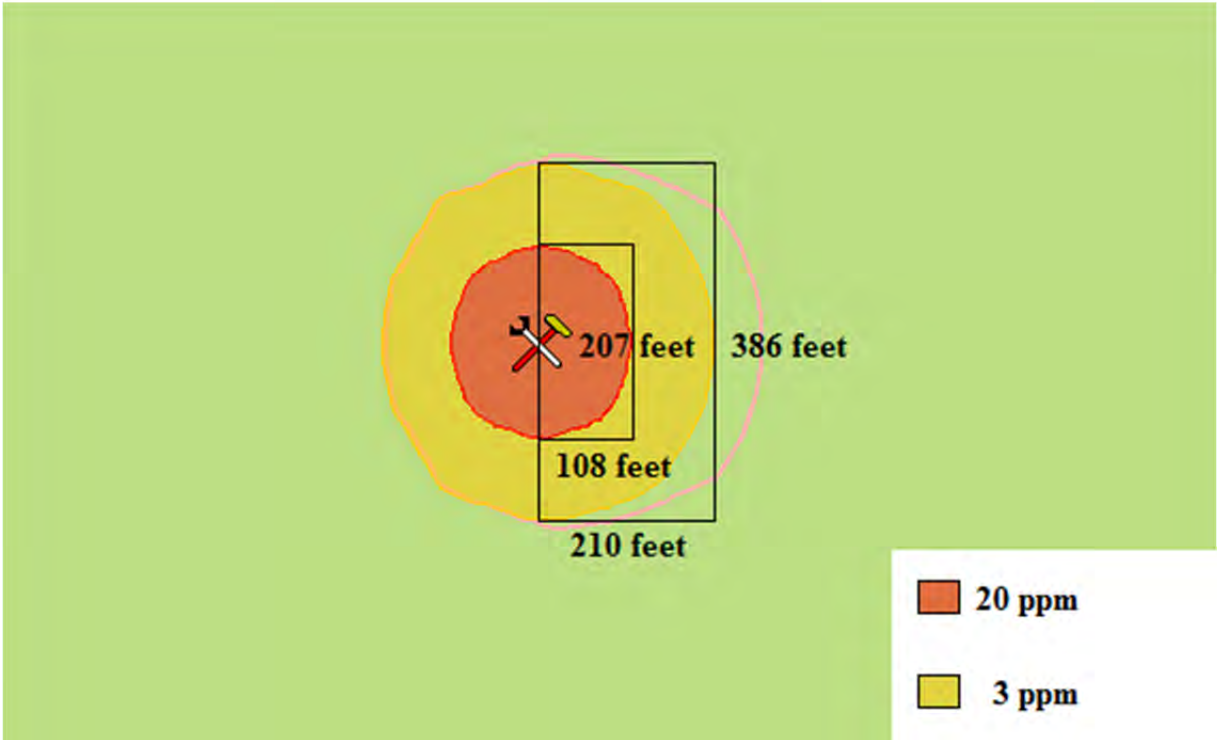
Appendix B provides a detailed explanation of how to interpret each of the outputs.

- The graphs were derived by considering an approximately 5 degree average wind direction fluctuation. If during the release the wind direction shifts considerably, the area impacted by the plume will be accordingly wider.
- Care should be taken when interpolating results from a graph. Concentration is not linear with distance. The user is further cautioned that the second output for each scenario, maximum concentration of chlorine at a specific distance downwind from the source, is presented as a semi-log graph. As needed, refer to Appendix B for an explanation on how to use this type of graph.

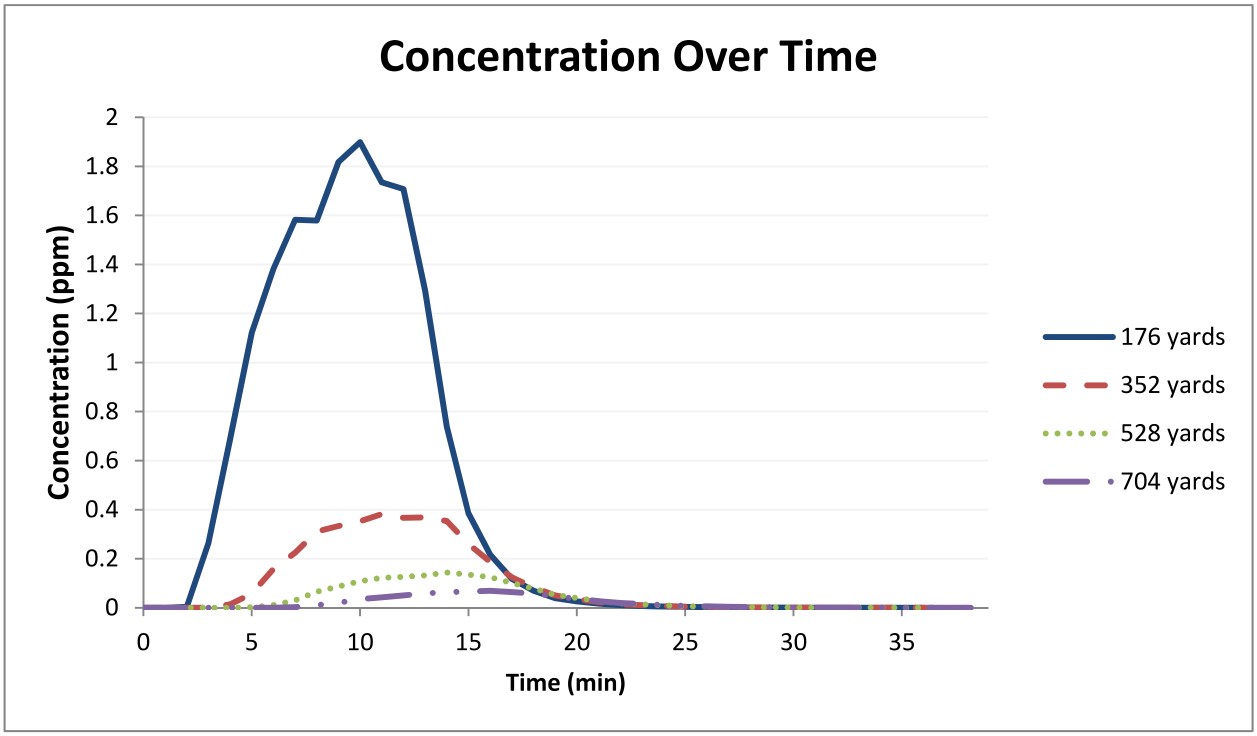
4.4 WORST-CASE (CATASTROPHIC) SCENARIOS

4.4.1 150-lb. Cylinder

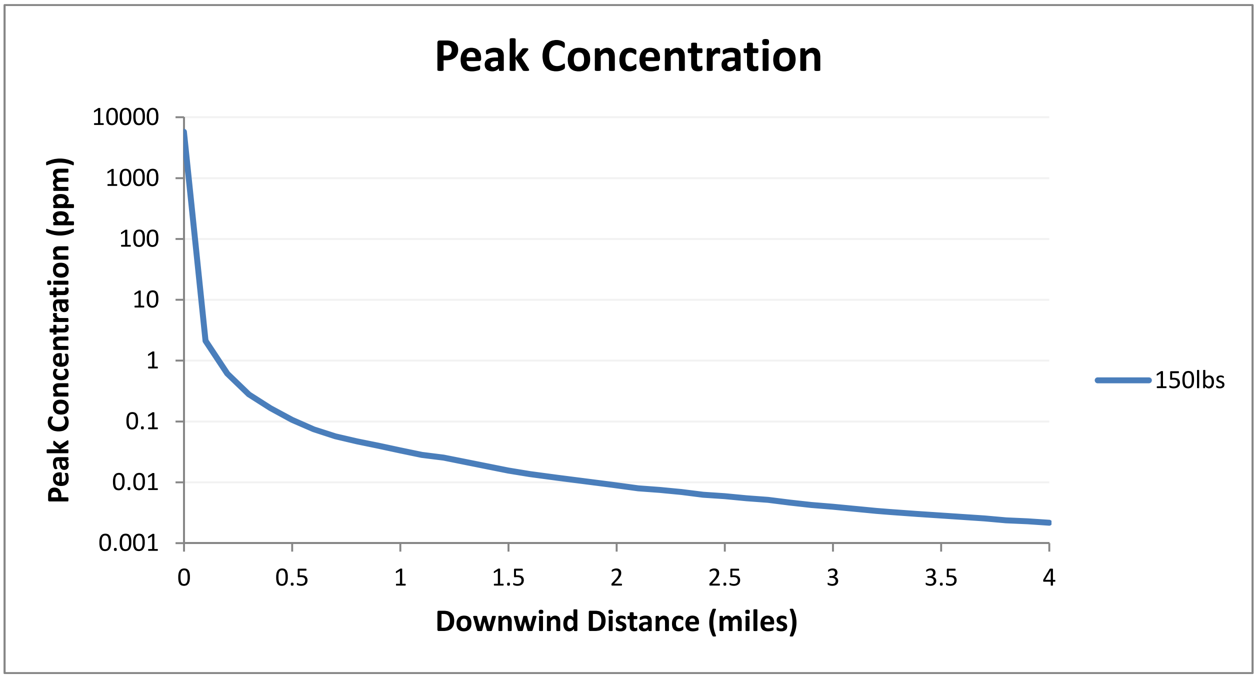
- Total mass release = 150 pounds
- 10 minute release
- 0.25 pounds/second steady state release
- Release occurs on concrete
- Wind Speed = 1.5 m/s @ 3 ppm
- Wind Speed = 1.5 m/s @ 20 ppm
- Maximum downwind distance = 210 ft.
- Maximum width = 386 ft.
- Maximum downwind distance = 108 ft.
- Maximum width = 207 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:

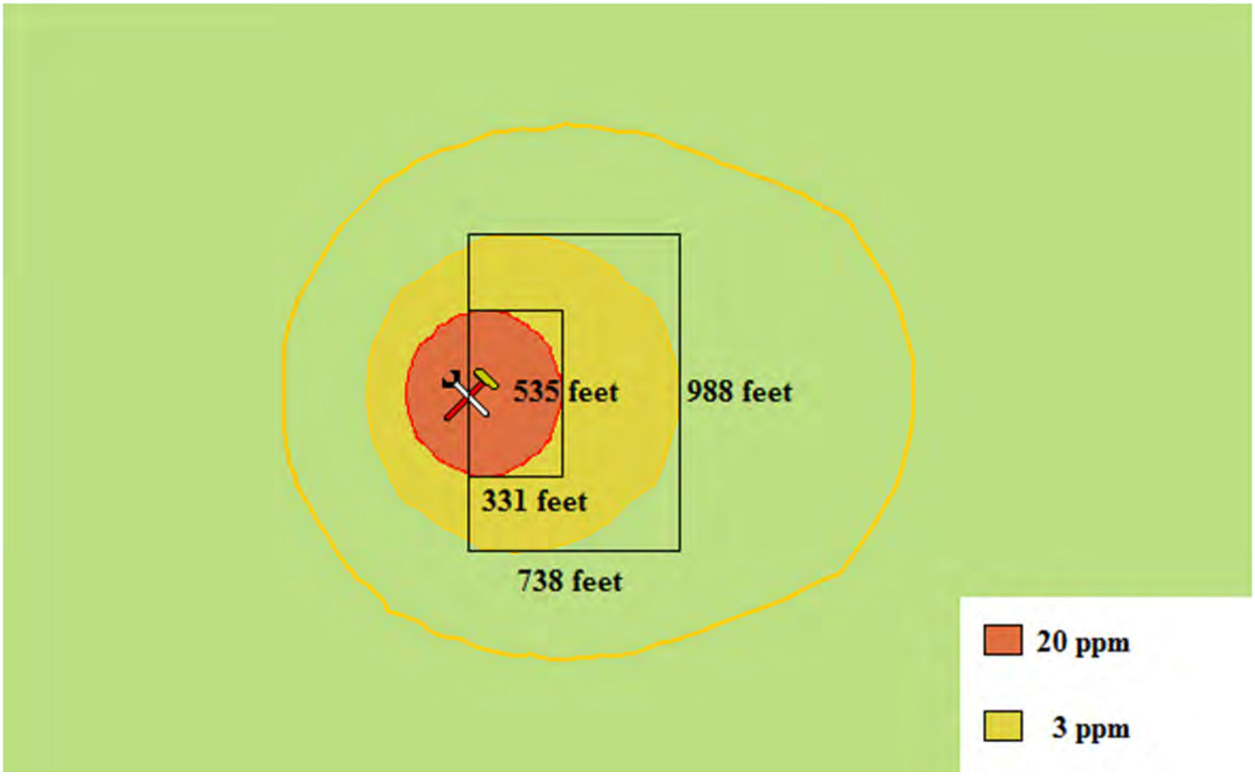


Peak Concentration as a Function of Distance:

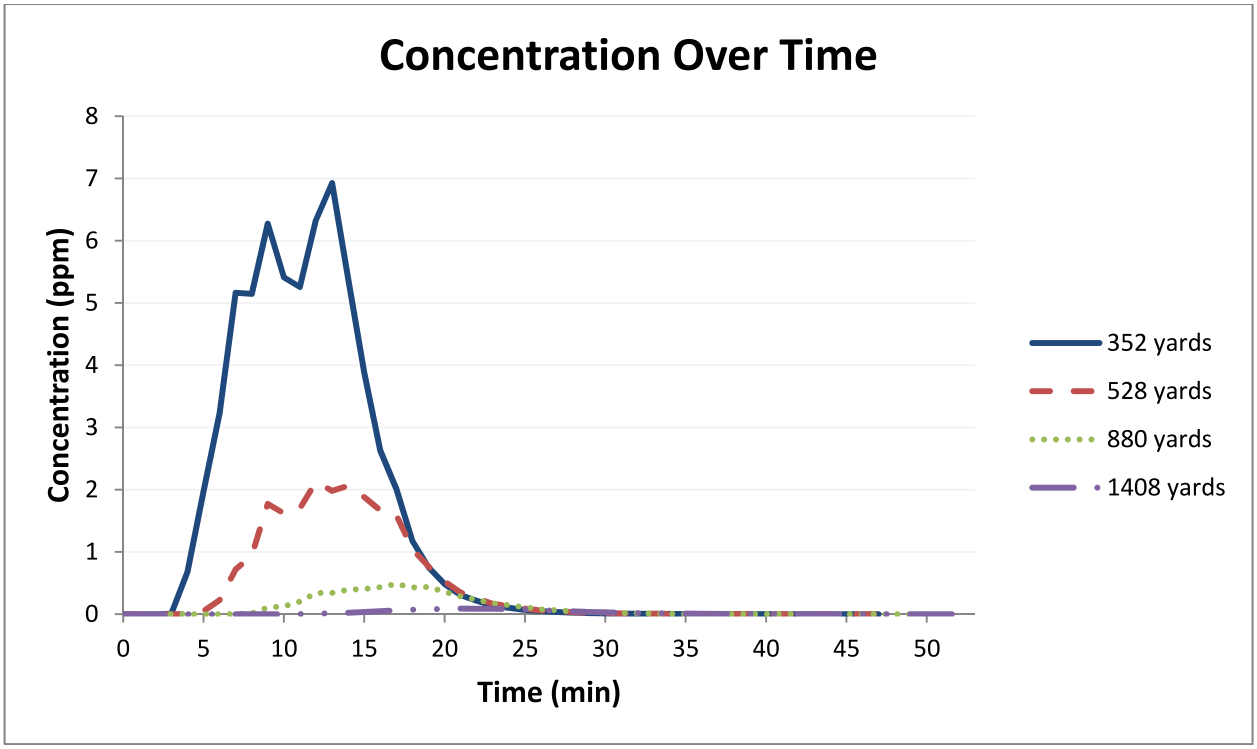


4.4.2 1-Ton Container

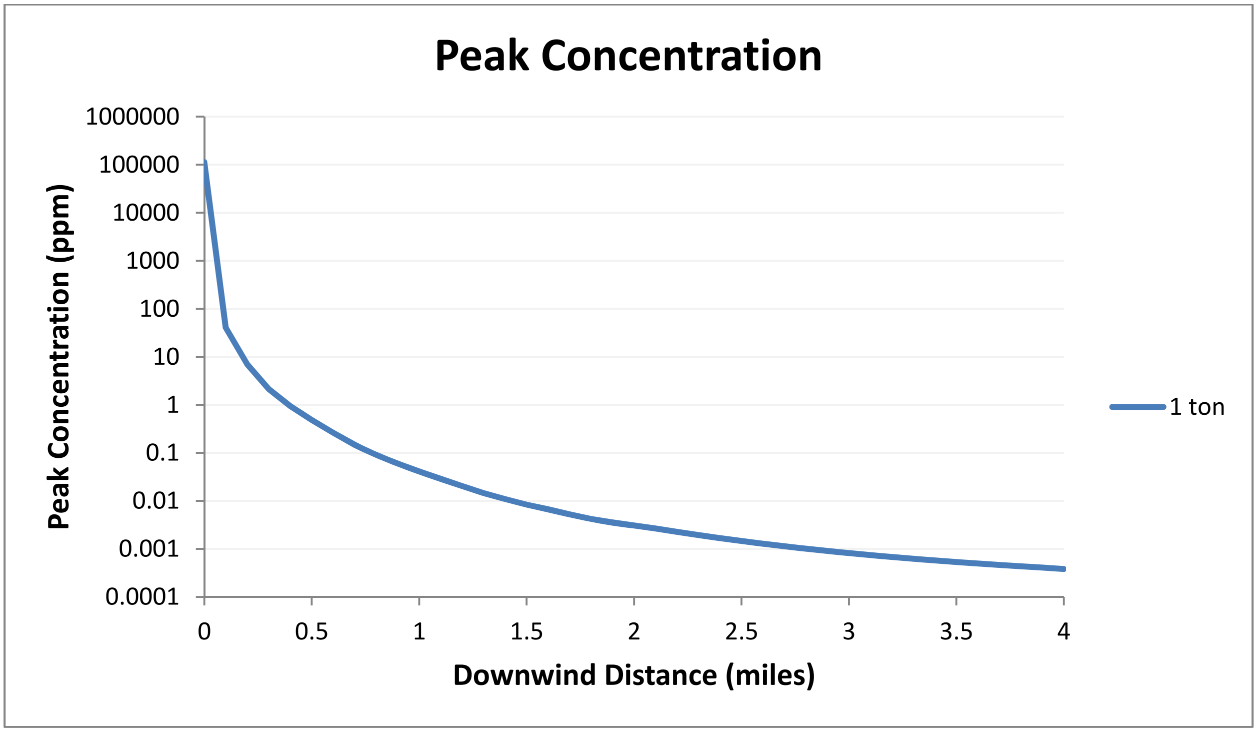
- Total mass release = 2,000 lbs.
- Duration of release = 10 minutes
- Release state = gas
- Release rate: 3.33 lbs./second
- Release occurs on concrete
- Wind Speed = 1.5 m/s @ 3ppm
- Wind Speed = 1.5 m/s @ 20ppm
- Maximum downwind distance = 738 ft.
- Maximum width = 988 ft.
- Maximum downwind distance = 331 ft.
- Maximum width = 535 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:

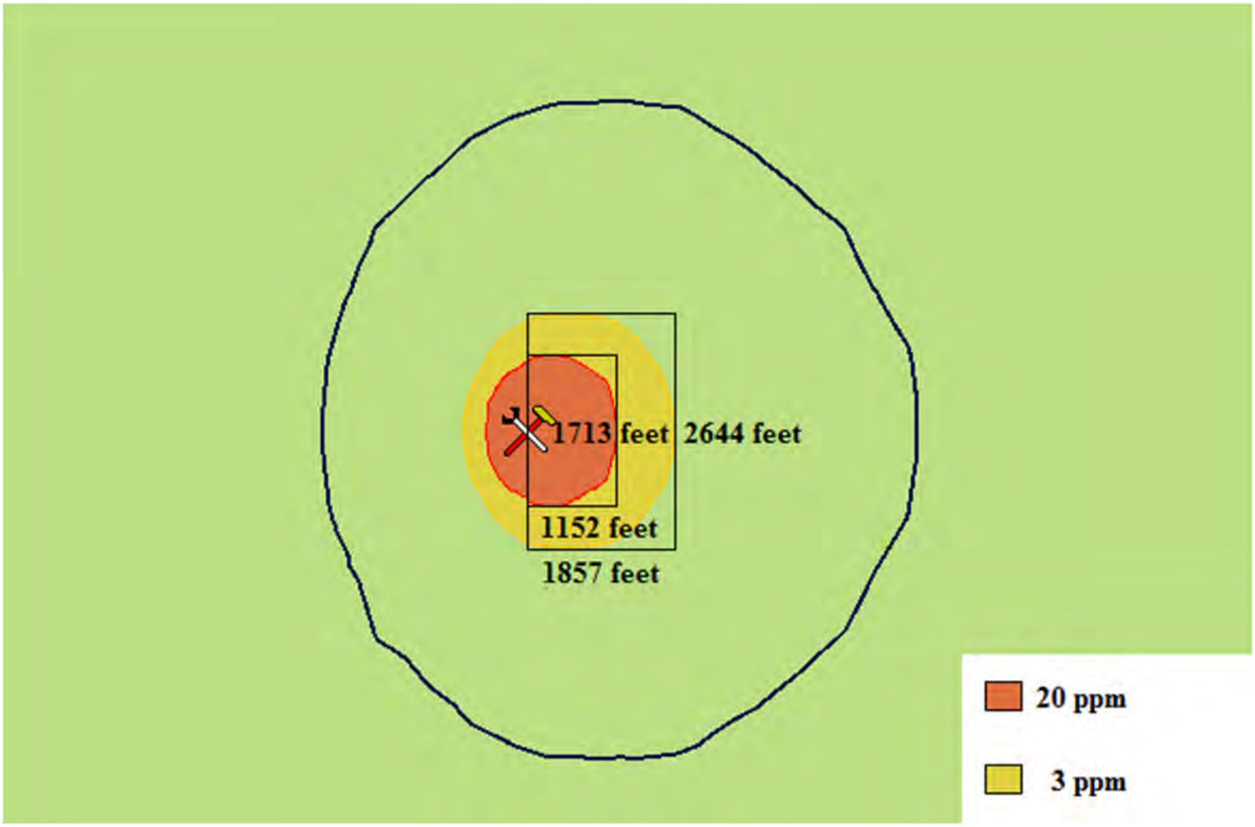


Peak Concentration as a Function of Distance:

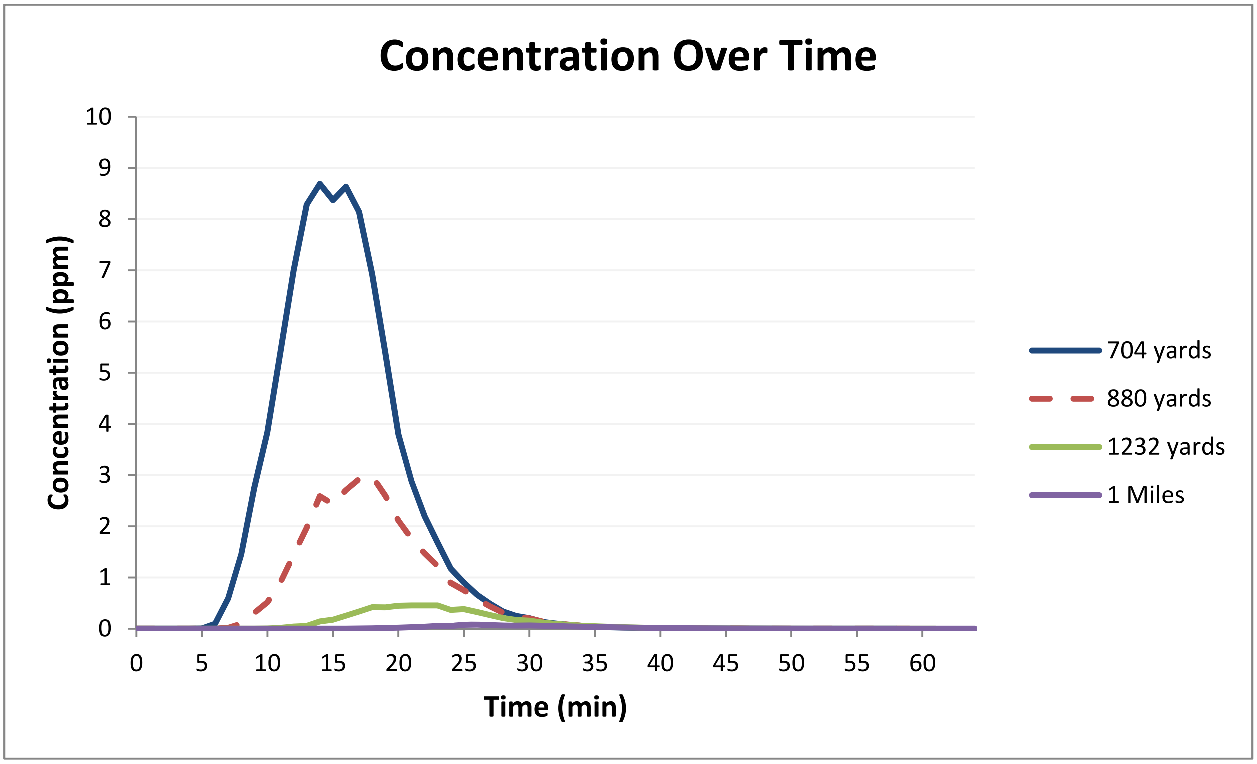


4.4.3 17-Ton Highway Cargo Tank

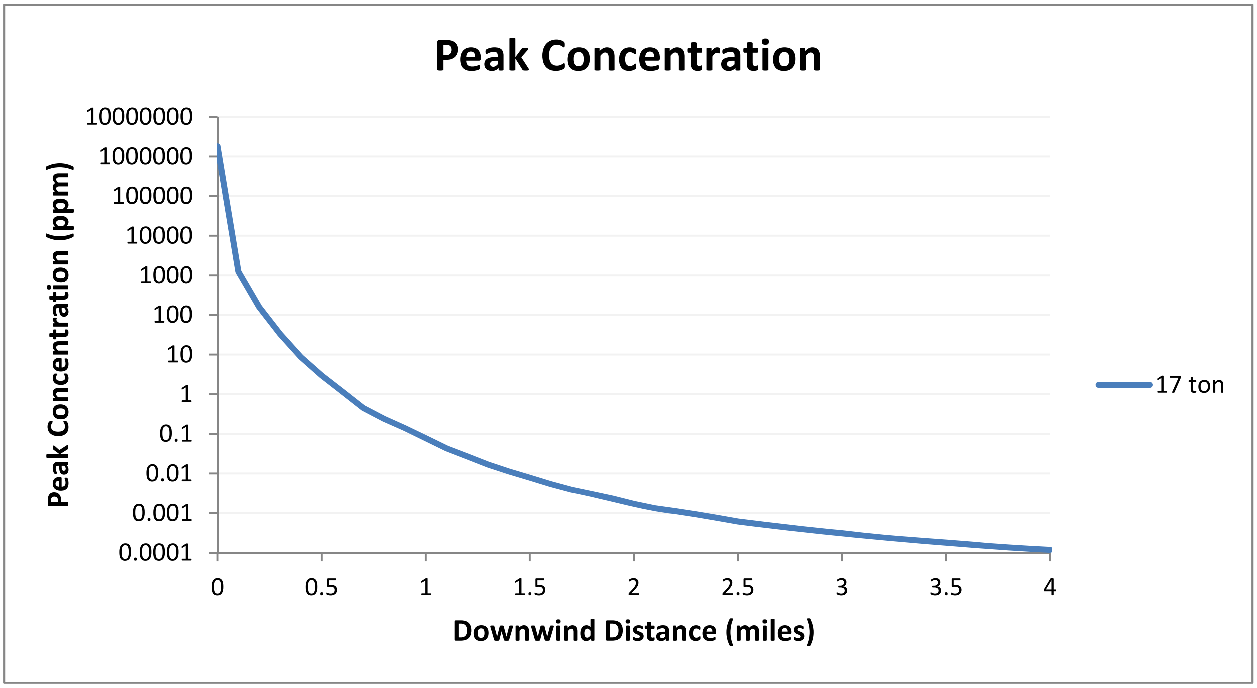
- Total mass release = 34,000 lbs.
- Duration of release = 10 minutes
- Release state = gas
- Release rate: 56.67 lbs./second
- Release occurs on concrete
- Wind Speed = 1.5 m/s @ 3 ppm
- Wind Speed = 1.5 m/s @ 20 ppm
- Maximum downwind distance = 1857 ft.
- Maximum width = 2644 ft.
- Maximum downwind distance = 1152 ft.
- Maximum width = 1713 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:

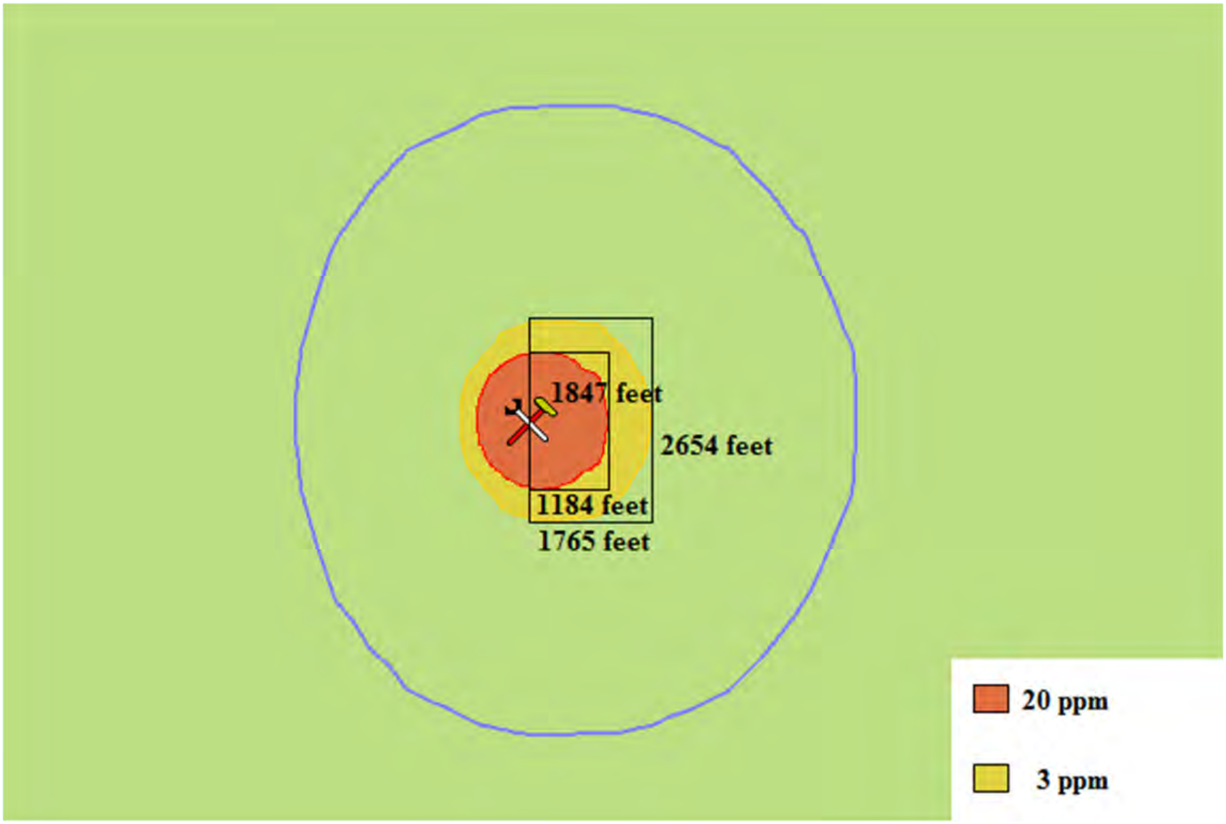


Peak Concentration as a Function of Distance:

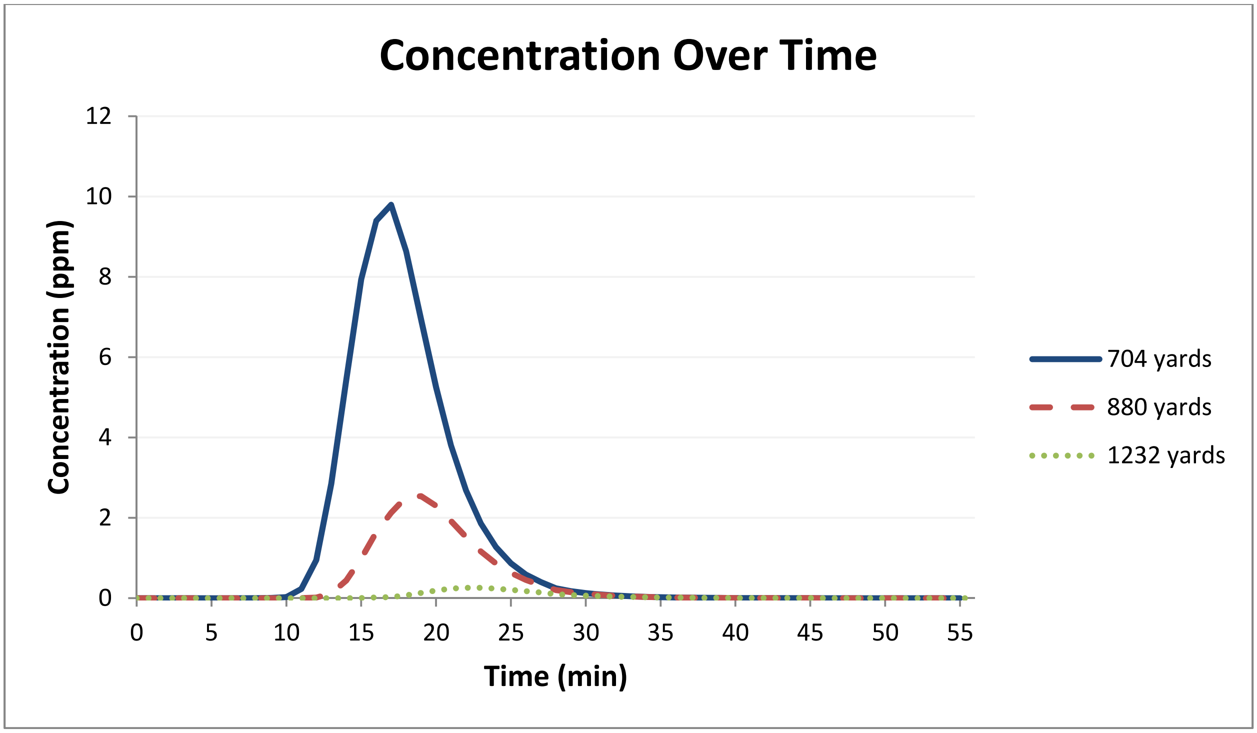


4.4.4 90-Ton Rail Car

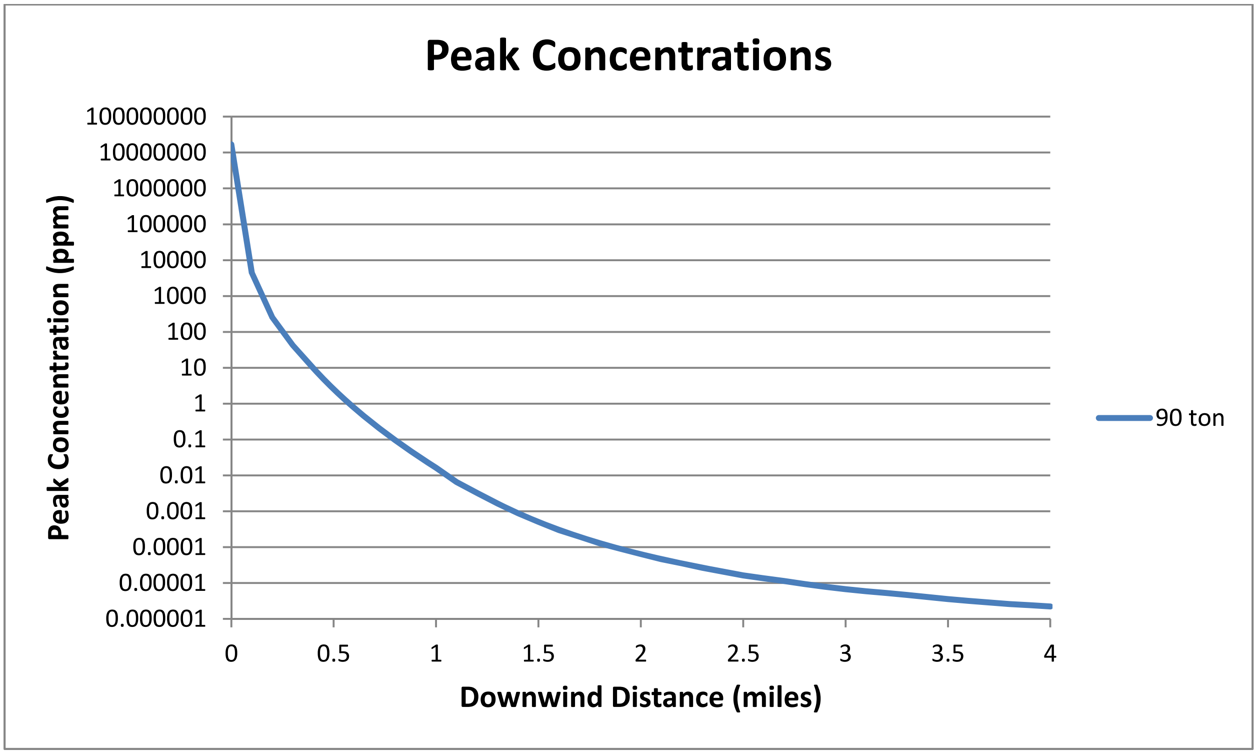
- Total mass release = 180,000 lbs.
- Duration of release = 10 minutes
- Release state = gas
- Release rate:300 lbs./second
- Release occurs on concrete
- Wind Speed = 1.5 m/s @ 3 ppm
- Wind Speed = 1.5 m/s @ 20 ppm
- Maximum downwind distance = 1765 ft.
- Maximum width = 2654 ft.
- Maximum downwind distance = 1184 ft.
- Maximum width = 1847 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



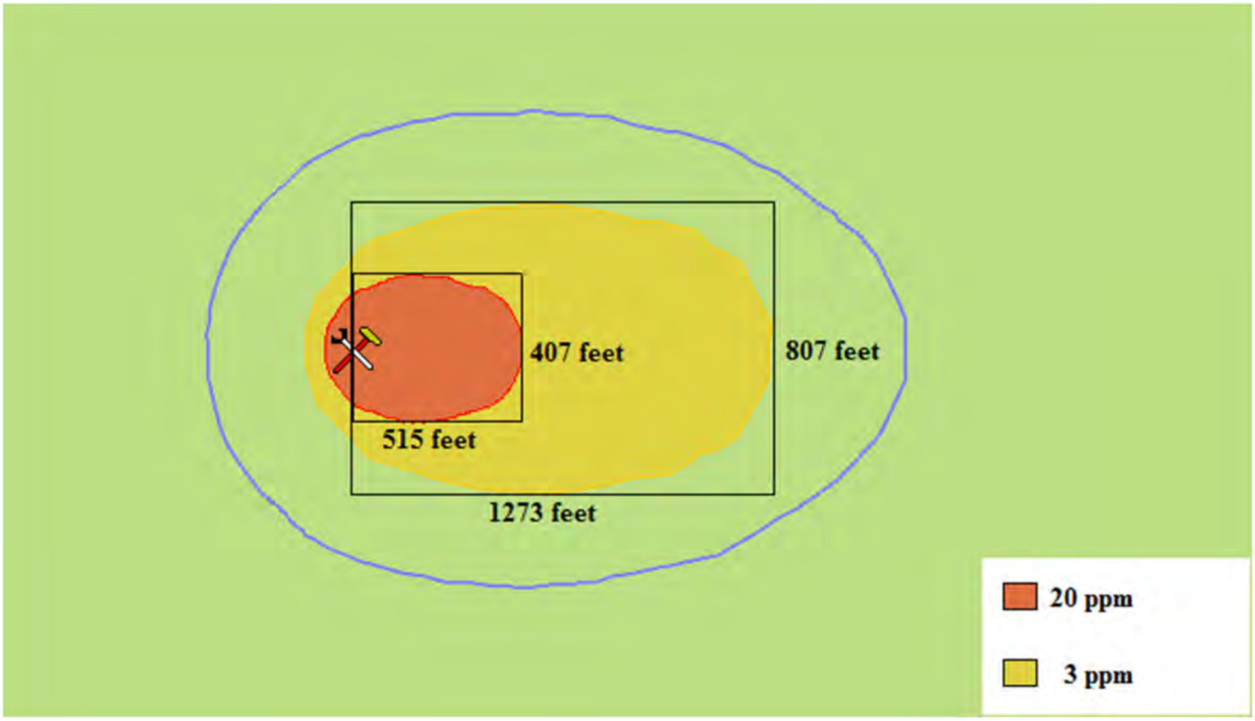
Peak Concentration as a Function of Distance:



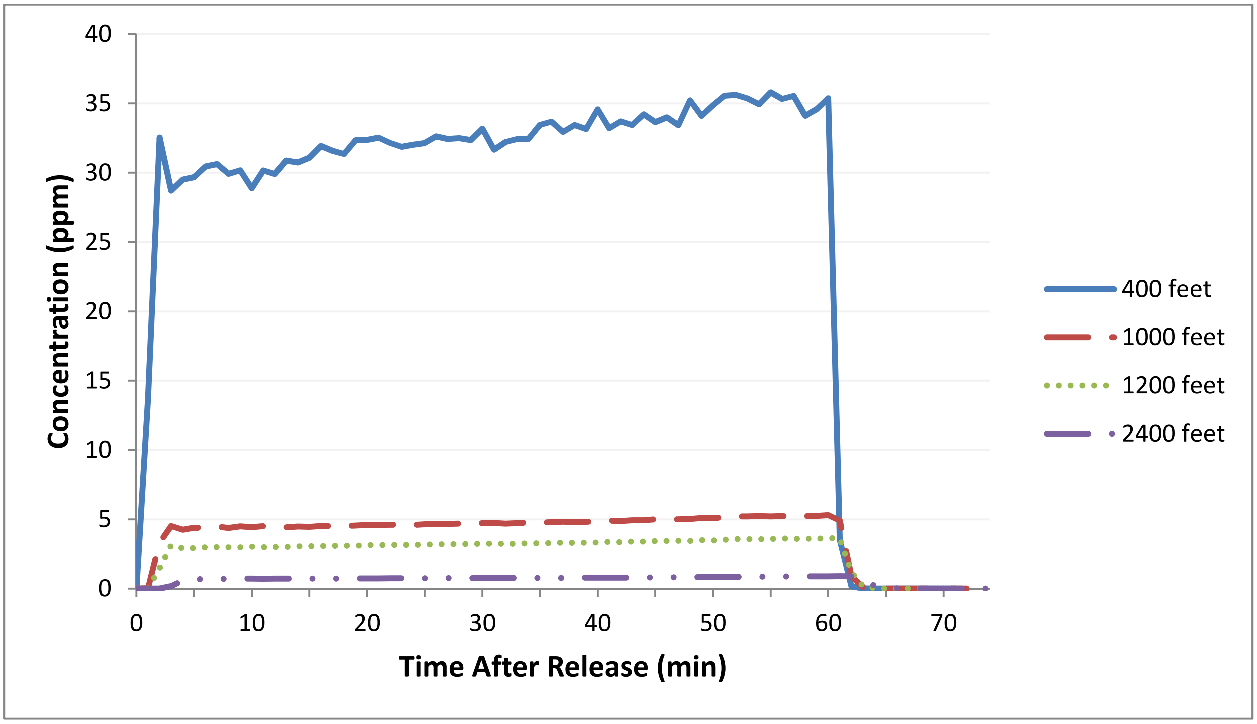
4.4.5 1-Inch Pipe Failure (gas)

A 1-inch schedule 80 pipe is sheared off. An infinite supply is assumed, and mitigation is assumed to occur after one hour.

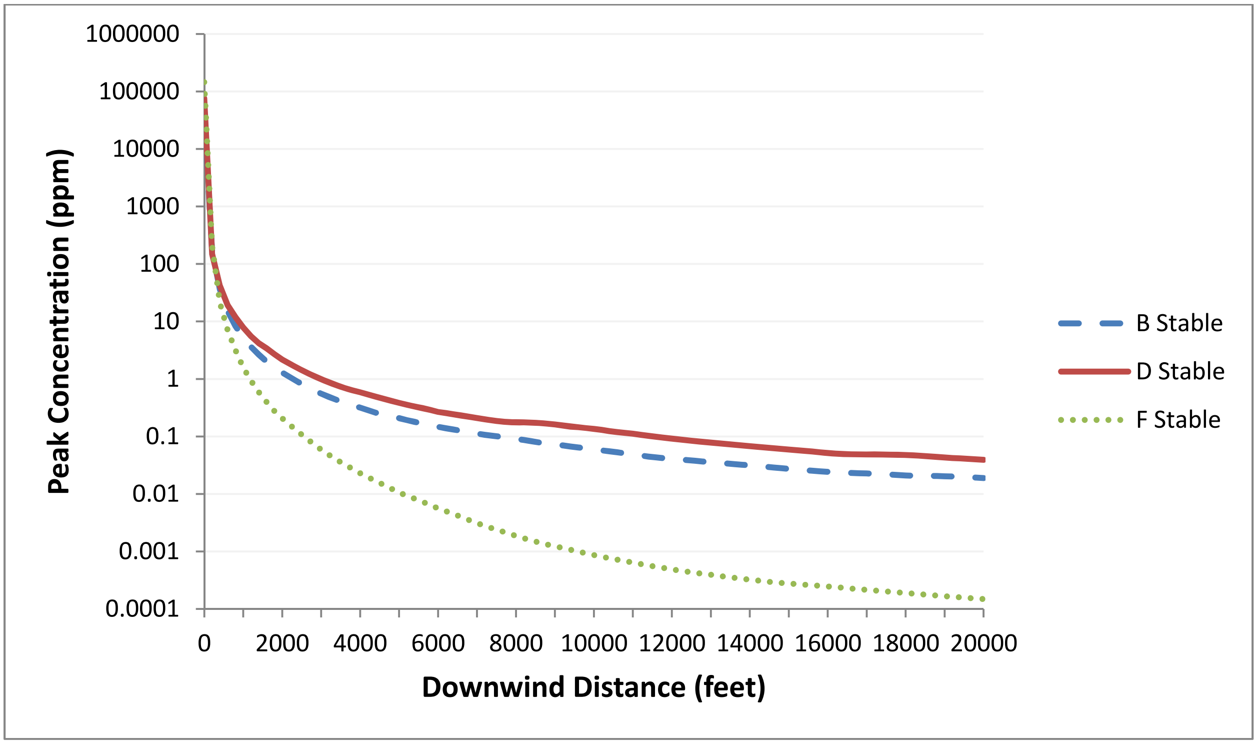
- Container type: pipe
- Release mechanism: failure
- Release state: gas
- Release rate: 137 lbs./minute
- Contents mass: 8,208 lbs.
- Duration of release: 60 minutes
- Hole elevation: 15 ft.
- Opening diameter: 1 inch
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 1273 ft.
- Maximum width = 807 ft.
- Maximum downwind distance = 515 ft.
- Maximum width = 407 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



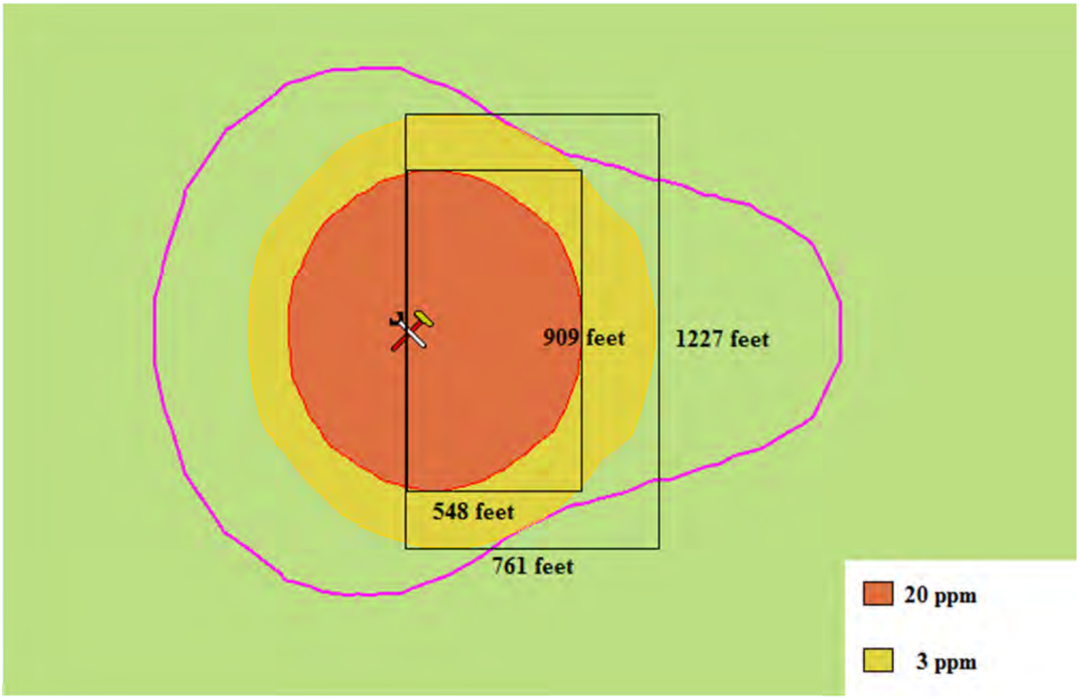
Peak Concentration as a Function of Distance:



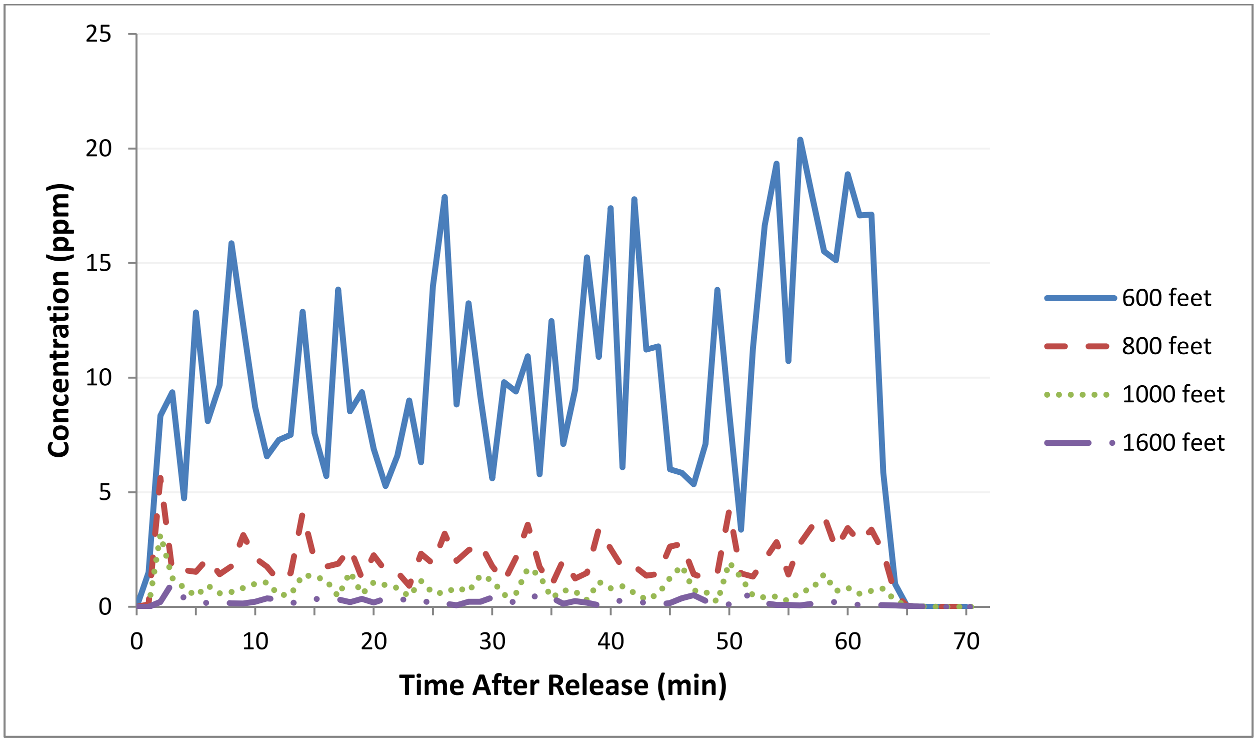
4.4.6 1-Inch Pipe Failure (liquid)

A 1-inch schedule 80 pipe is sheared off. An infinite supply is assumed, and the source is assumed to be stopped after 1 hour. Evaporation of the liquid pool is assumed to continue.

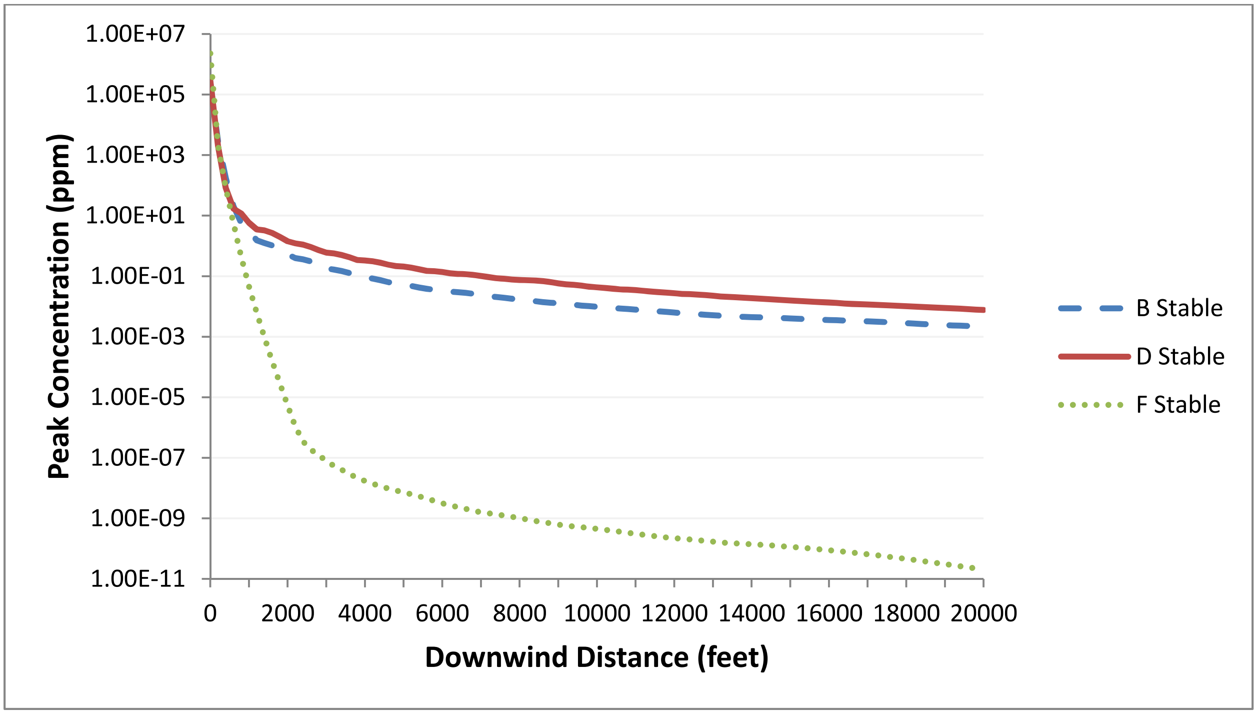
- Container type: pipe
- Release mechanism: failure
- Release state: liquid
- Release rate: 240 lbs./minute
- Contents mass: 14,400 lbs.
- Time for pool to evaporate: 110-160 minutes
- Duration of release: 110-160 minutes
- Hole elevation: 15 ft.
- Opening diameter: 1 inch
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 761 ft.
- Maximum width = 1227 ft.
- Maximum downwind distance = 548 ft.
- Maximum width = 909 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



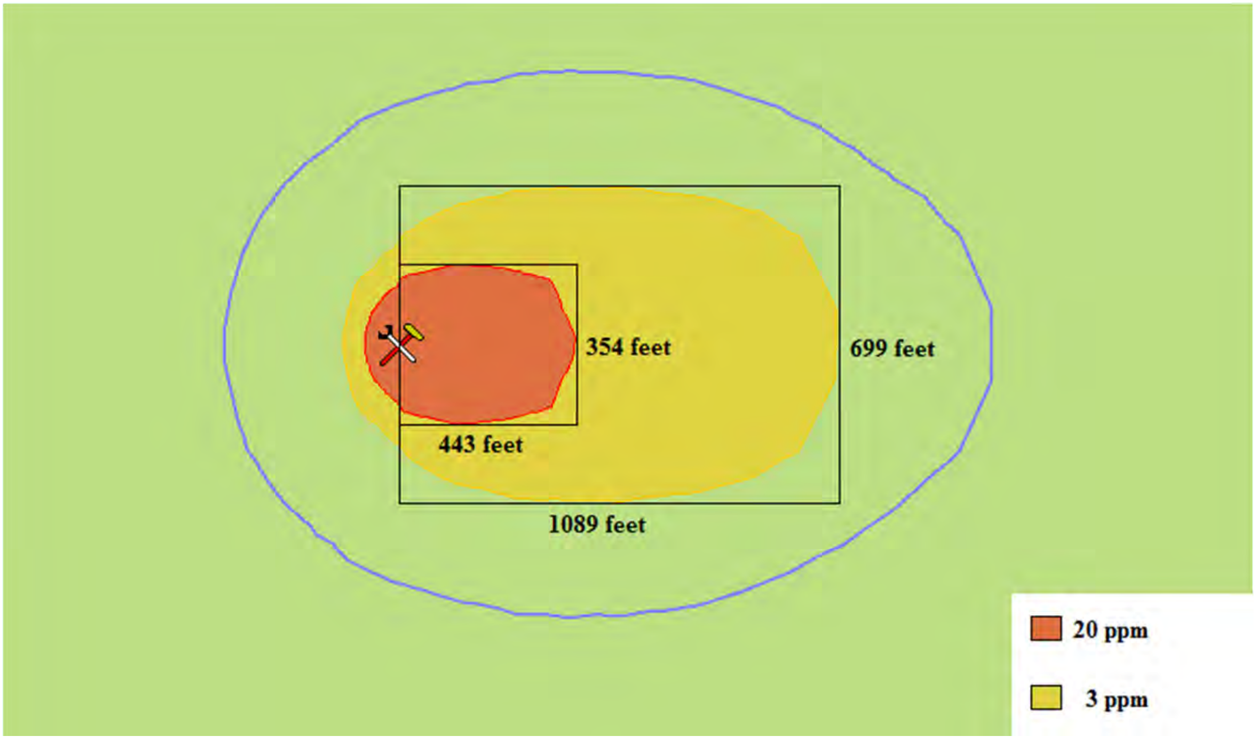
Peak Concentration as a Function of Distance:



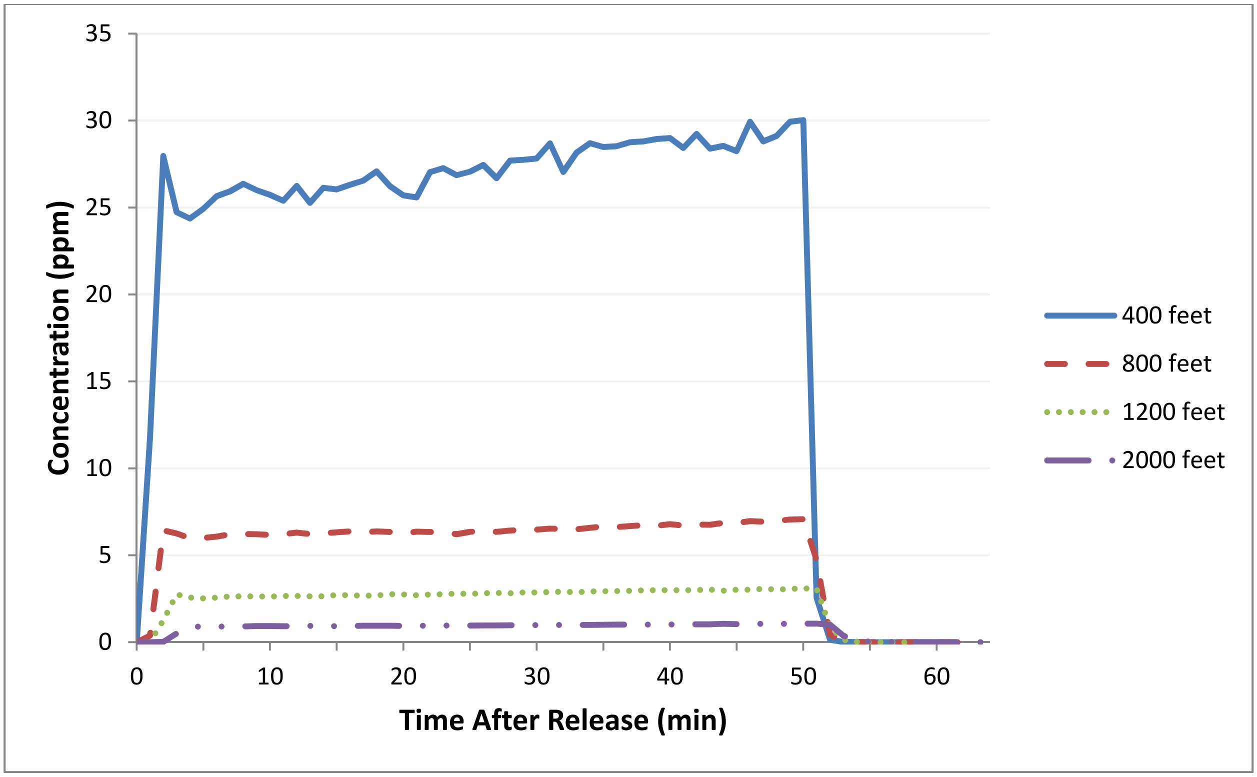
4.4.7 1-Ton Manifold

Four 1-ton containers are connected to a 1-inch schedule 80 pipe manifold, and the manifold is sheared off.

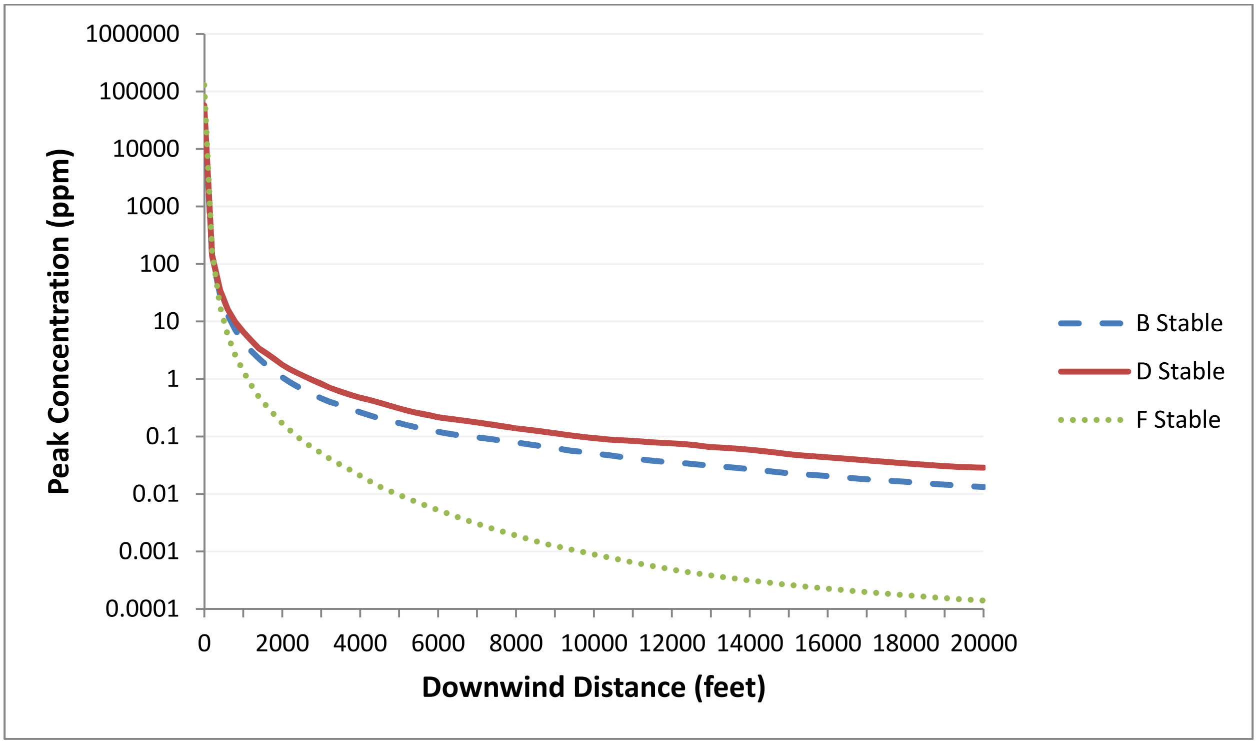
- Release mechanism: Line Failure
- Release state: Gas
- Release rate: 120 lbs./minute
- Contents mass: 8,000 lbs.
- Duration of release: 40-50 minutes (modeled as 50)
- Time to empty the containers: 40-50 minutes
- Hole elevation: 3 ft.
- Opening diameter: The inside pipe diameter is 1 inch. However, the 5/16 inch diameter valve opening on each cylinder is the limiting condition
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 1089 ft.
- Maximum width = 699 ft.
- Maximum downwind distance = 443 ft.
- Maximum width = 354 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



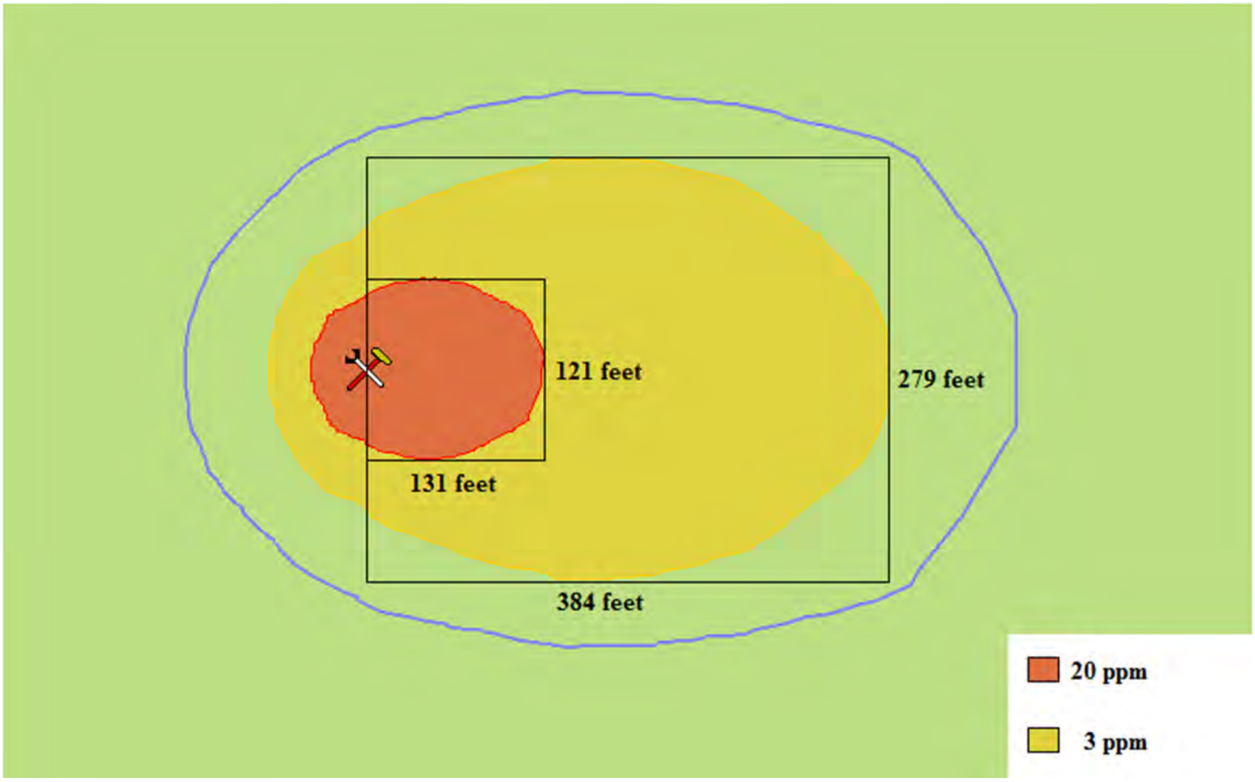
Peak Concentration as a Function of Distance:



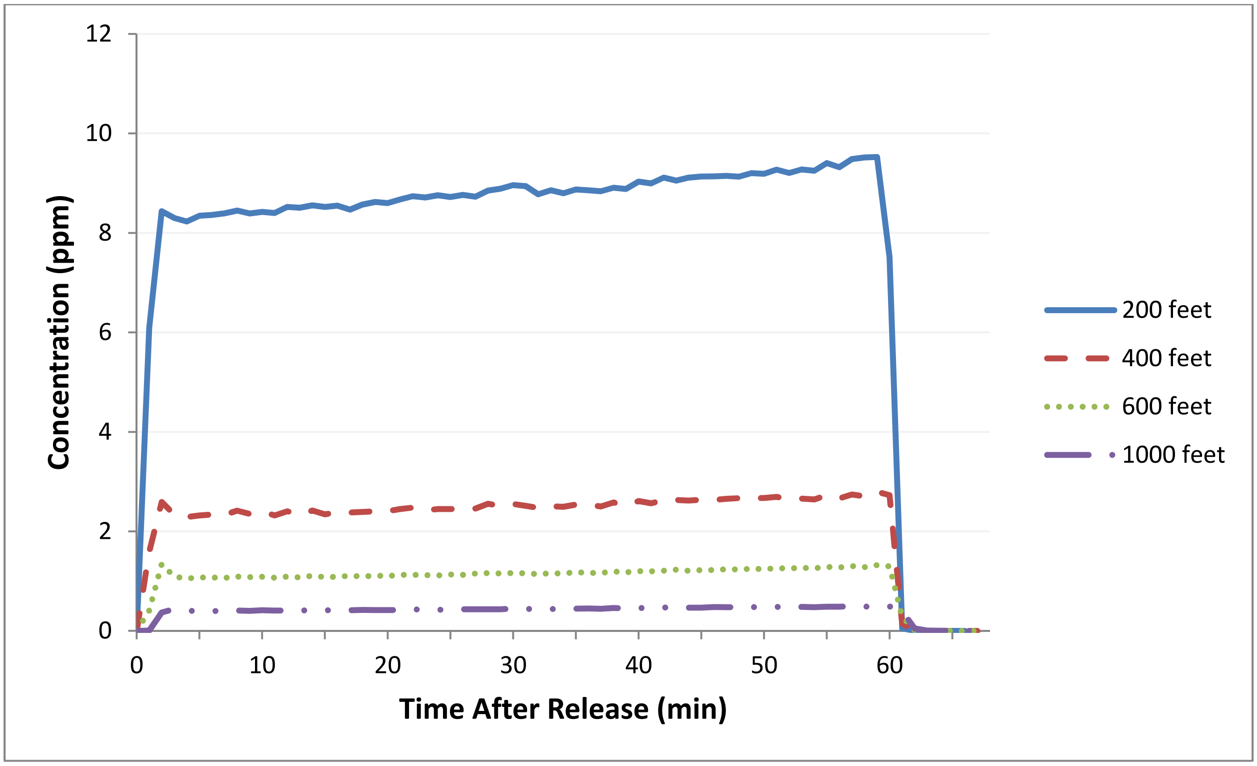
4.4.8 1-Ton Valve Failure (gas)

1-Ton Container gas valve remains open. Mitigation is assumed to occur in one hour.

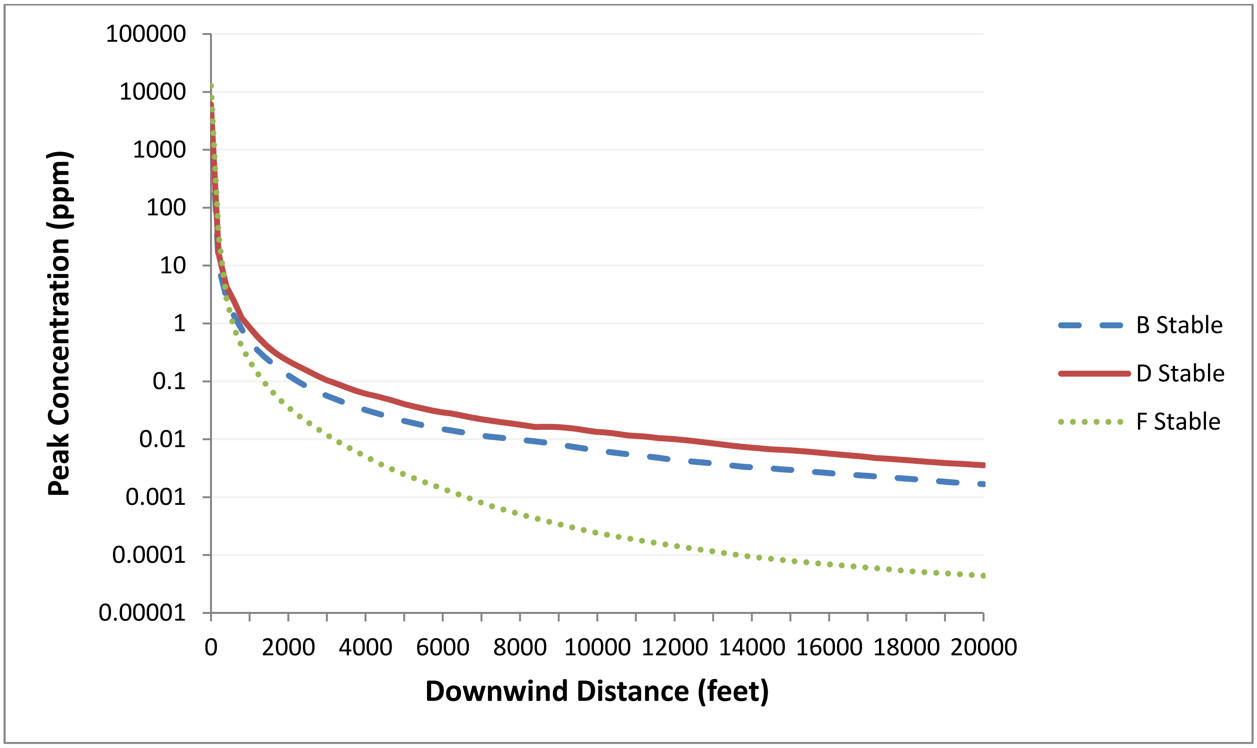
- Release mechanism: Valve Failure
- Release state: Gas
- Release rate: 12.7 lbs./minute
- Contents mass: 2,000 lbs.
- Duration of release: 60 minutes
- Time to empty the containers: 106 minutes
- Hole elevation: 1.5 ft.
- Opening diameter: 5/16 inch
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 384 ft.
- Maximum width = 279 ft.
- Maximum downwind distance = 131 ft.
- Maximum width = 121 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



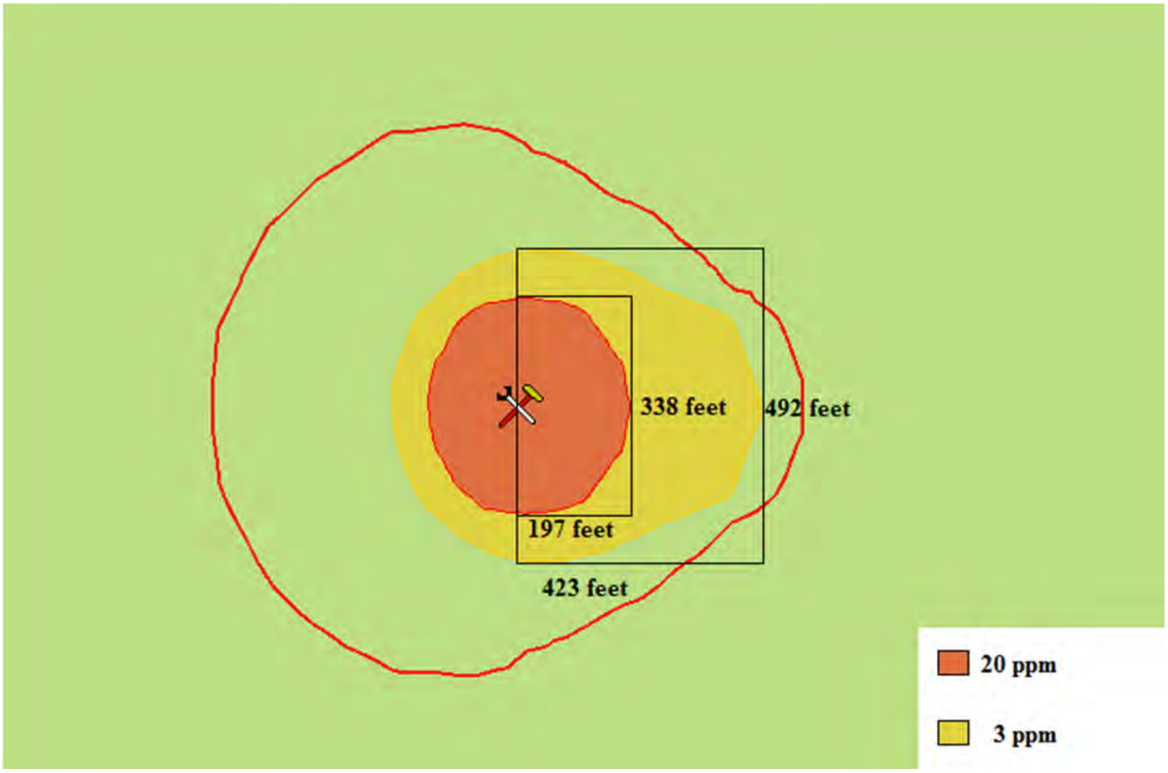
Peak Concentration as a Function of Distance:



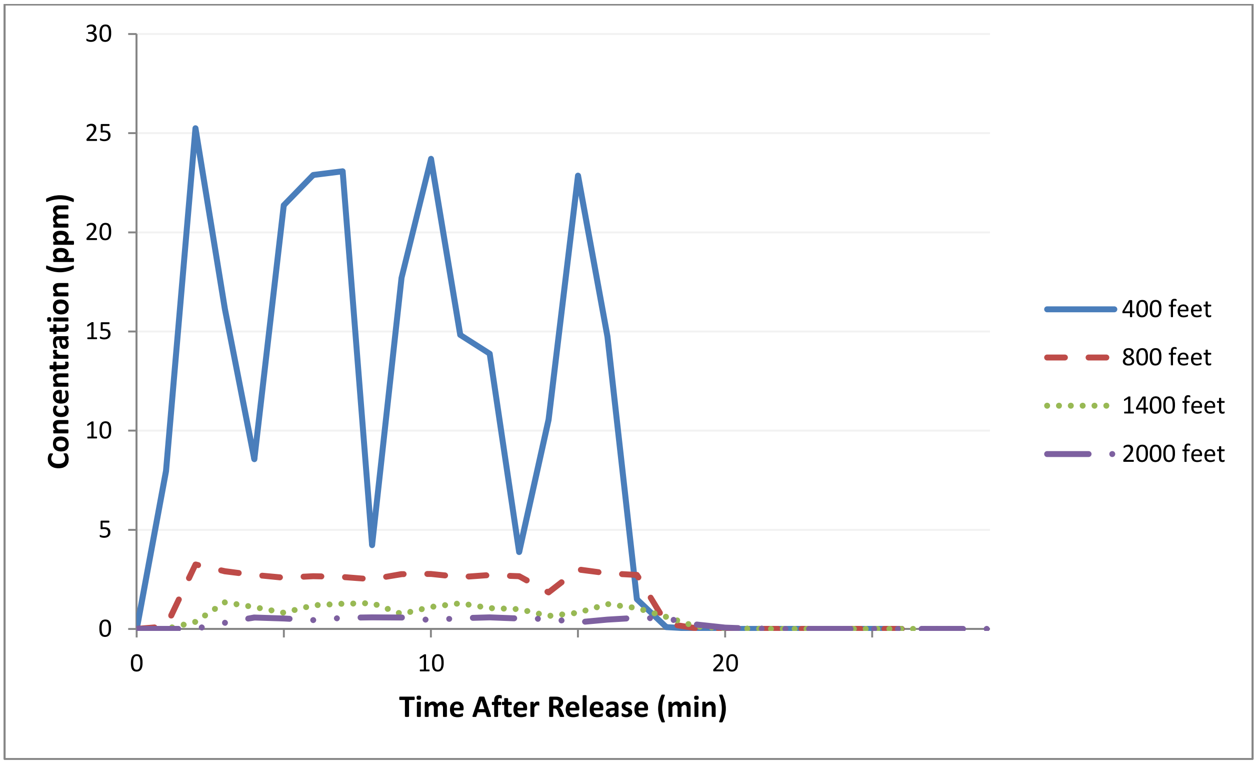
4.4.9 1-Ton Valve Failure (liquid)

1-Ton Container liquid valve remains open.

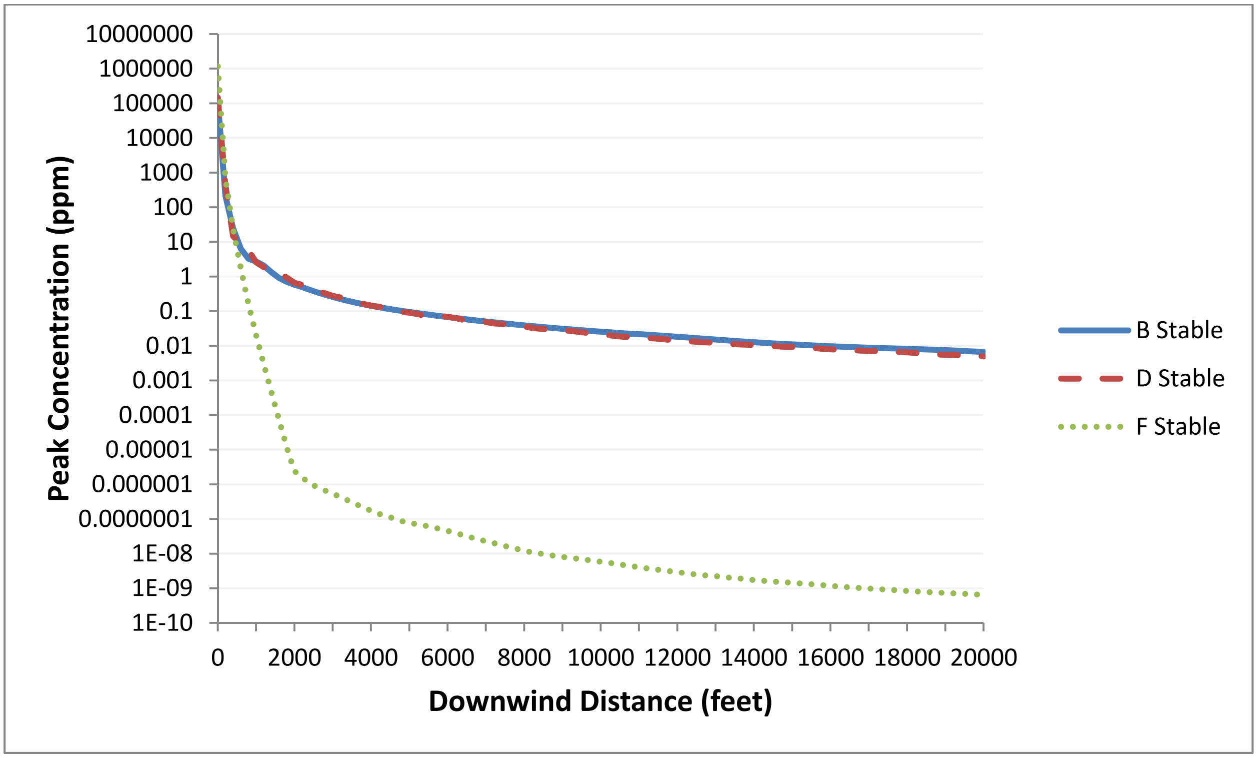
- Release mechanism: Valve Failure
- Release state: Liquid
- Release rate: 191 lbs./minute
- Contents mass: 2,000 lbs.
- Time to evaporate: 1-2 hours
- Duration of release: 1-2 minutes
- Time to empty the containers: 16 minutes
- Hole elevation: 3 ft.
- Opening diameter: 5/16 inch
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 423 ft.
- Maximum width = 492 ft.
- Maximum downwind distance = 197 ft.
- Maximum width = 338 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



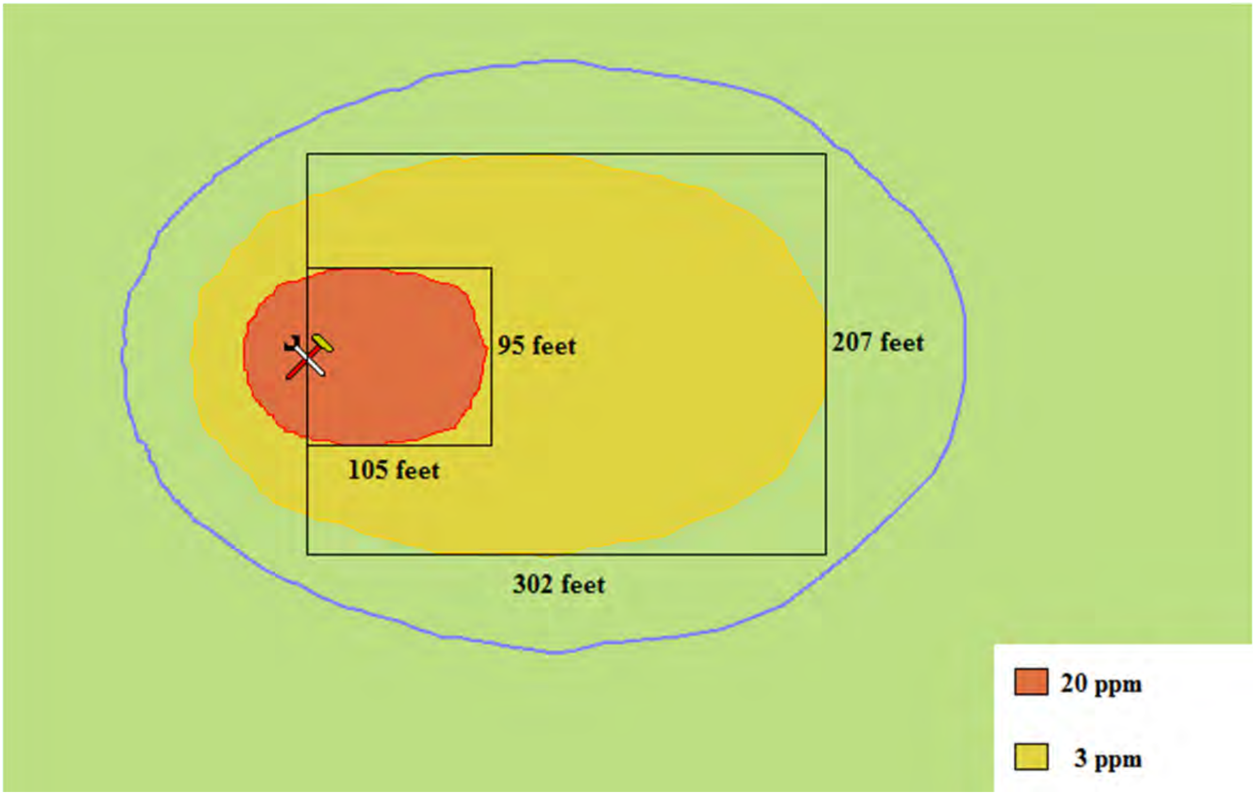
Peak Concentration as a Function of Distance:



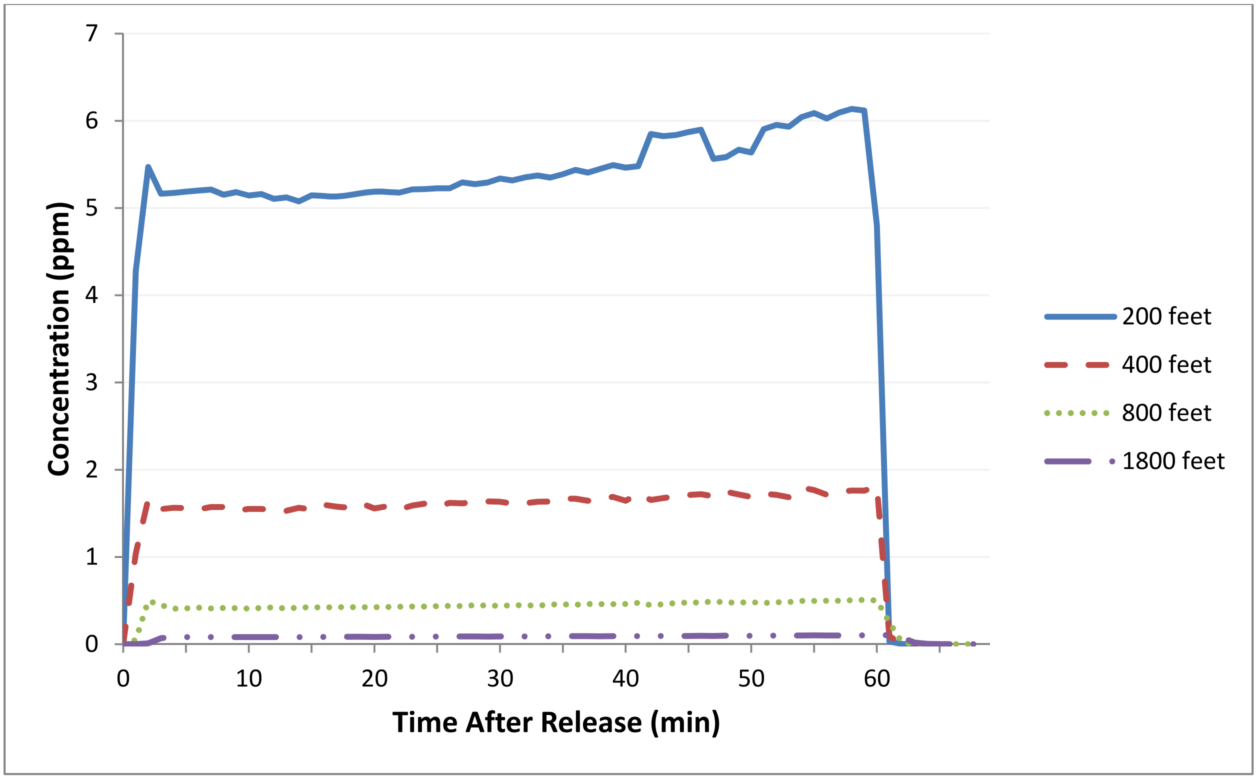
4.4.10 ¼-Inch Tube Failure (gas)

A ¼-inch, type K copper tubing is sheared off. There is an Infinite supply of chlorine and mitigation is assumed to occur in one hour.

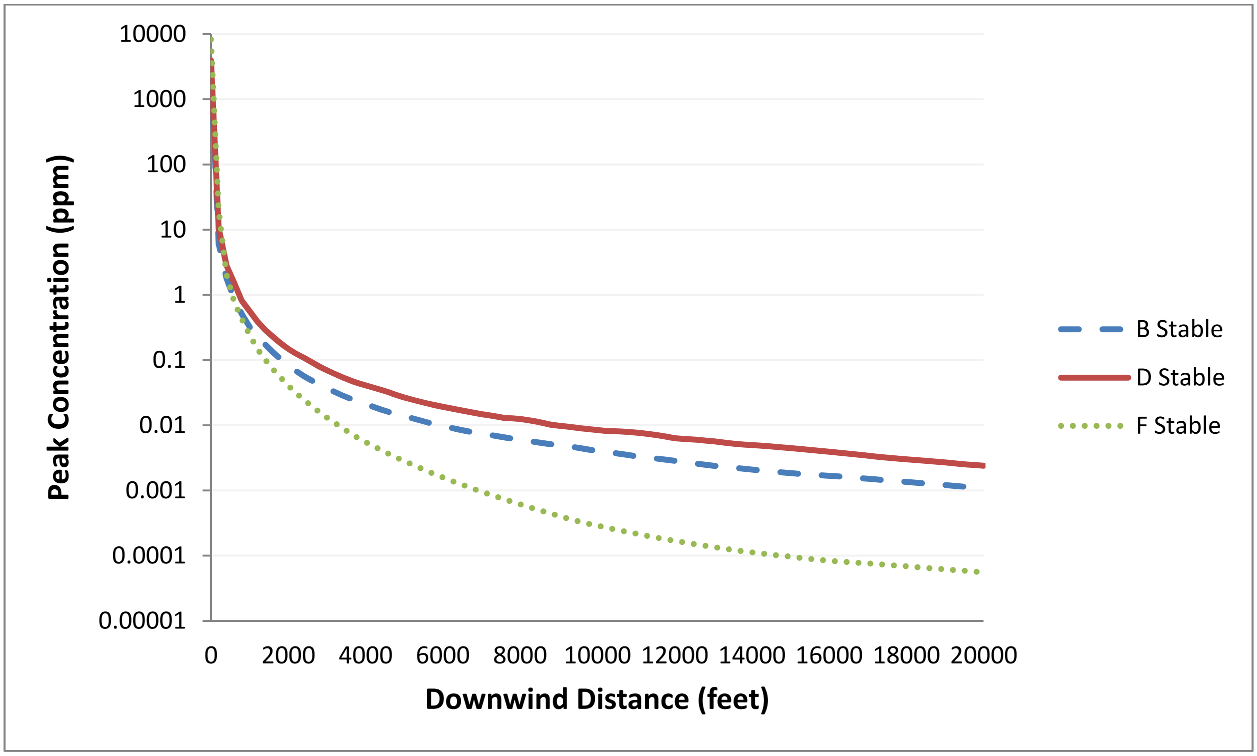
- Container type: tubing
- Release mechanism: failure
- Release state: gas
- Release rate: 8.3 lbs./minute
- Contents mass: 500 lbs.
- Duration of release: 60 minutes
- Hole elevation: 3 ft.
- Opening diameter: ¼ inch
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 302 ft.
- Maximum width = 207 ft.
- Maximum downwind distance = 105 ft.
- Maximum width = 95 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



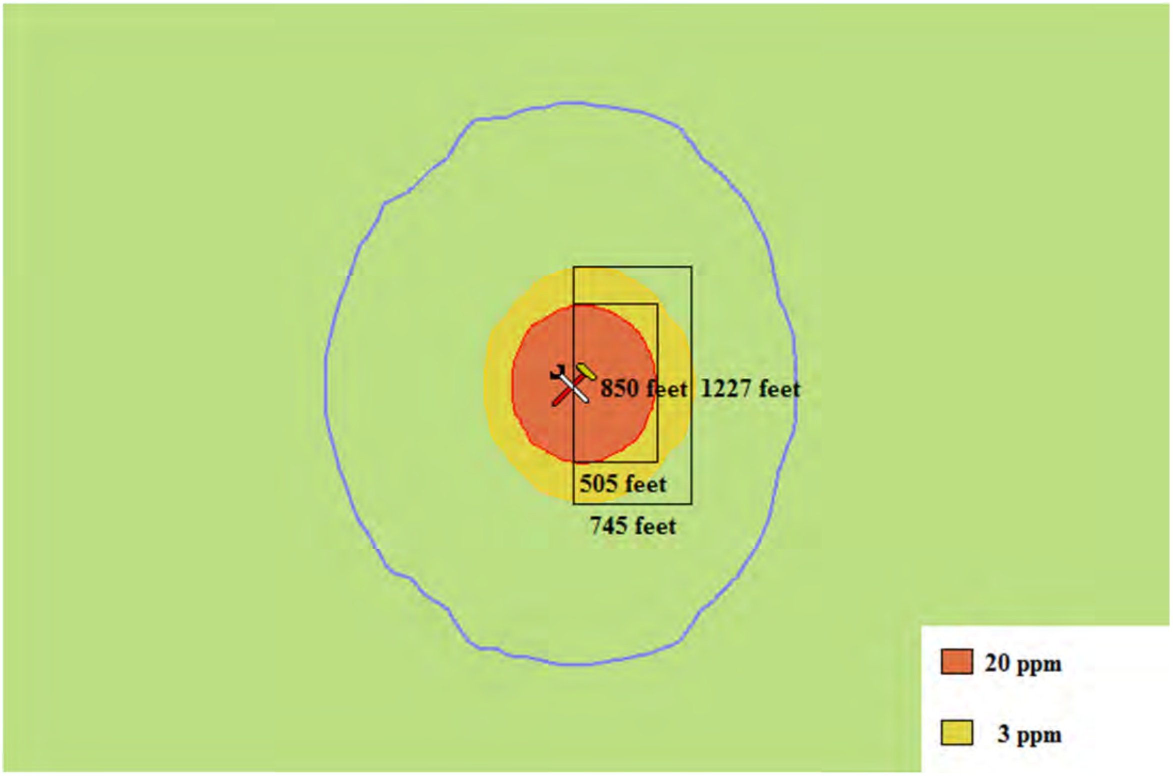
Peak Concentration as a Function of Distance:



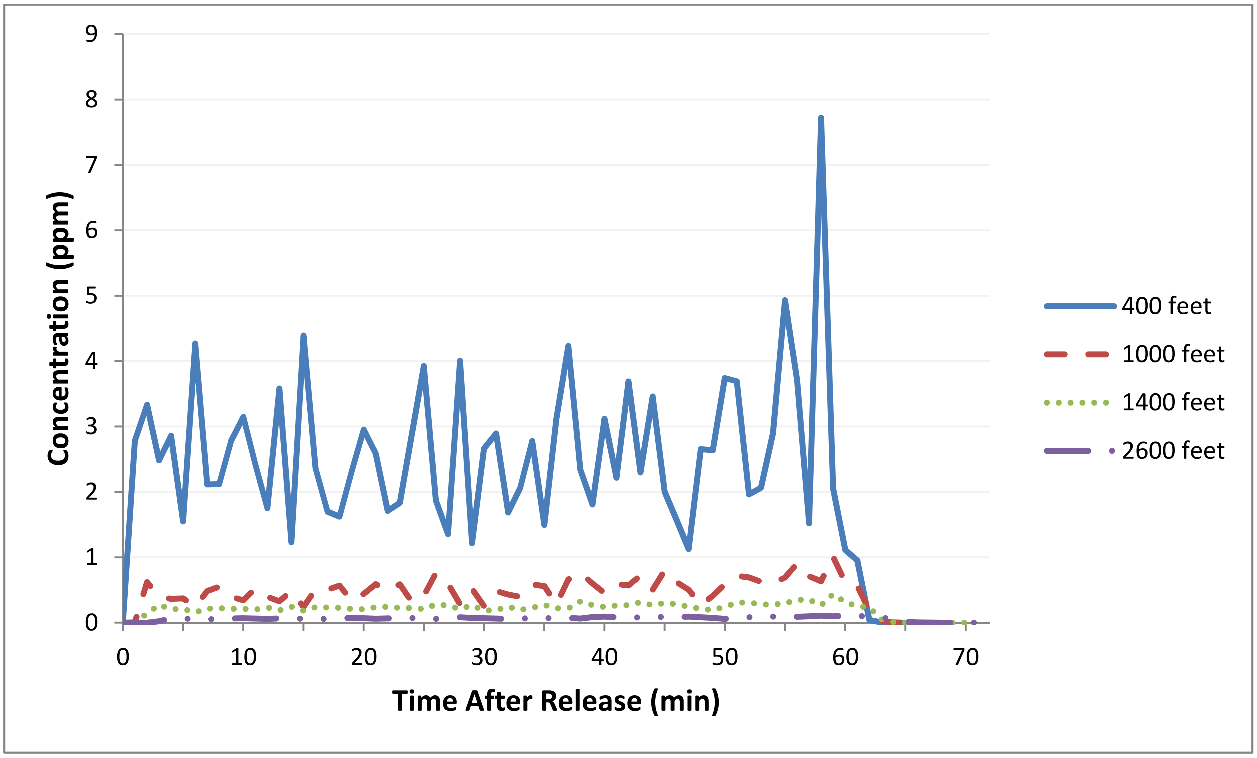
4.4.11 ¼-Inch Tube Failure (liquid)

A ¼-inch, type K copper tubing is sheared off with an infinite supply of chlorine. Source is assumed to be stopped in one hour. Evaporation of pool is assumed to continue.

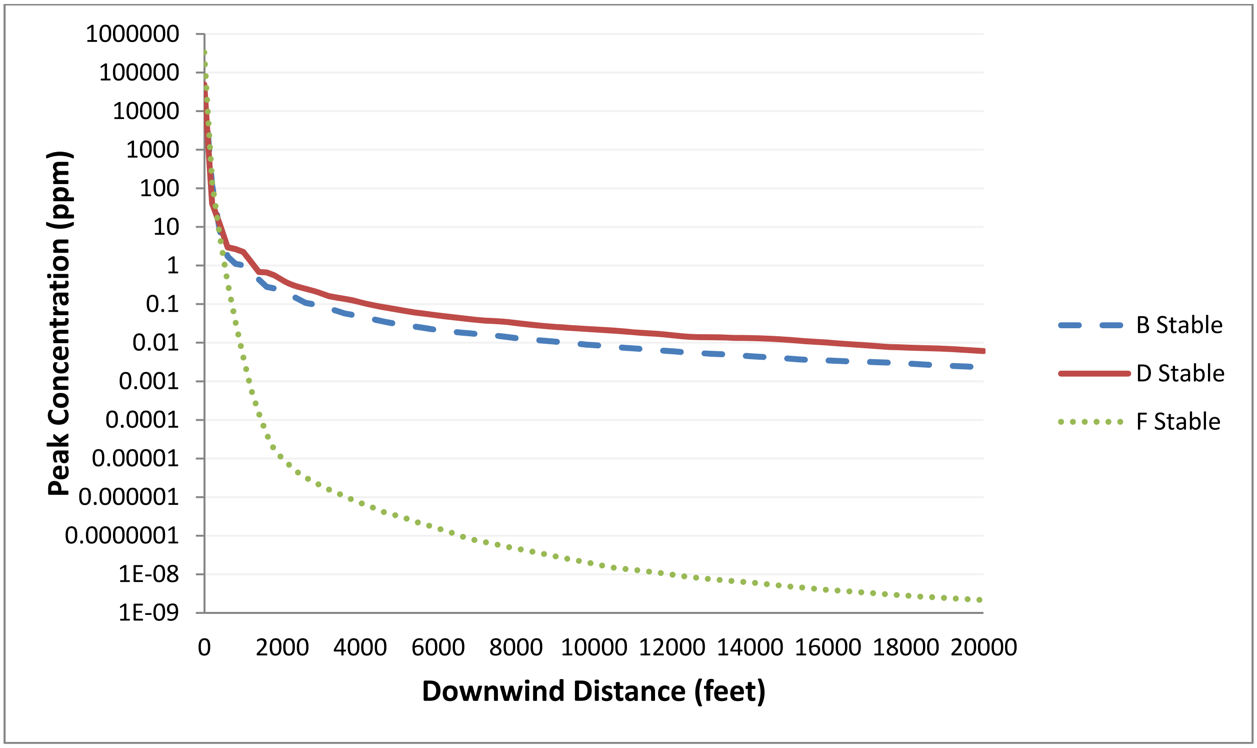
- Container type: tubing
- Release mechanism: failure
- Release state: liquid
- Release rate: 36.6 lbs./minute
- Contents mass: 2,200 lbs.
- Time for pool to evaporate: 110-150 minutes
- Duration of release: 110-150 minutes
- Hole elevation: 3 ft.
- Opening diameter: ¼ inch
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 745 ft.
- Maximum width = 1227 ft.
- Maximum downwind distance = 505 ft.
- Maximum width = 850 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



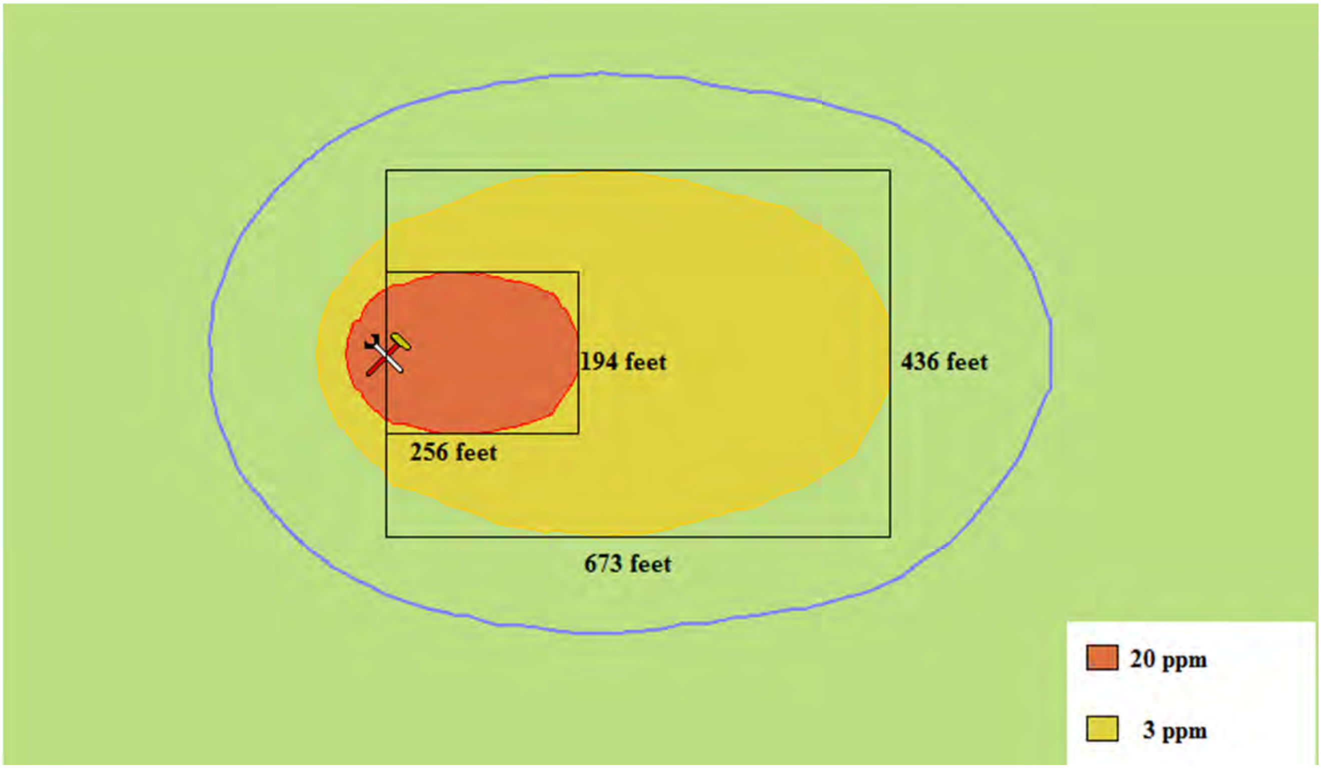
Peak Concentration as a Function of Distance:



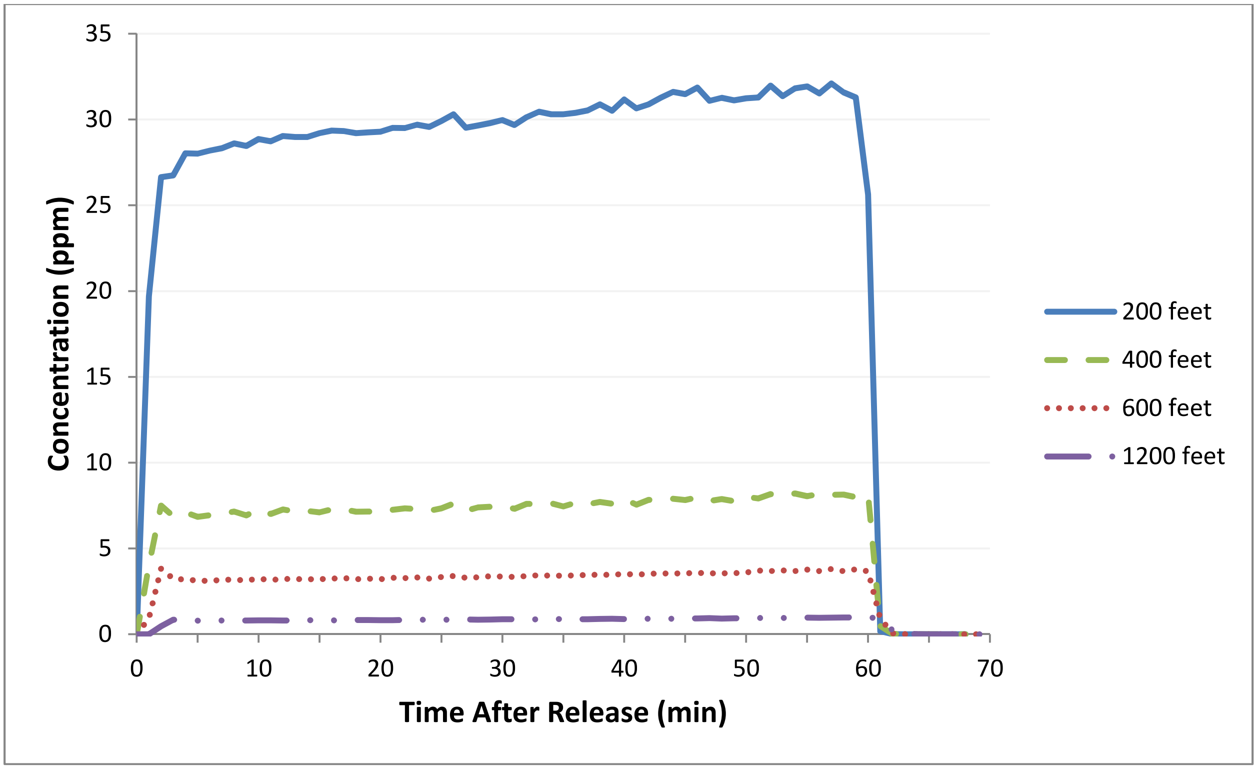
4.4.12 ½-Inch Tube Failure (gas)

A ½-inch, type K copper tubing is sheared off with an infinite supply of chlorine. Mitigation is assumed to occur in one hour.

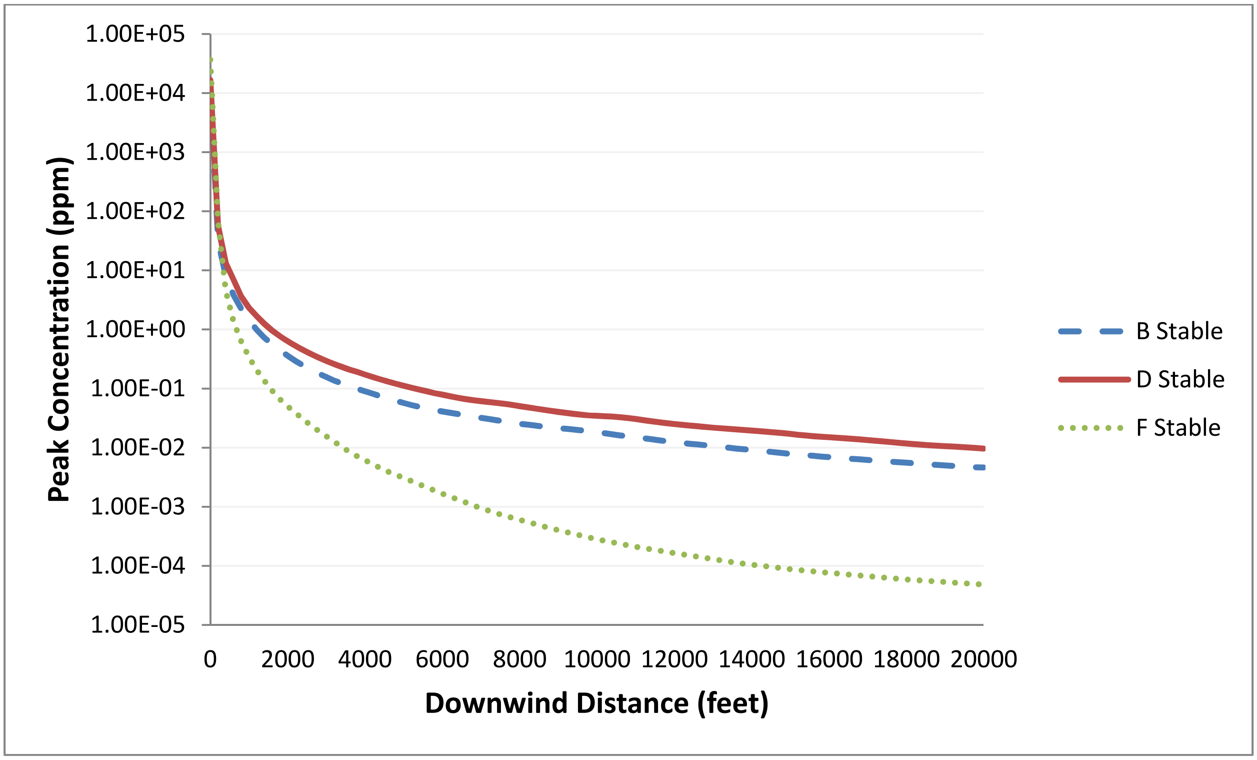
- Container type: tubing
- Release mechanism: failure
- Release state: gas
- Release rate: 36.0 lbs./minute
- Contents mass: 2,160 lbs.
- Duration of release: 60 minutes
- Hole elevation: 3 ft.
- Opening diameter: ½ inch
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 673 ft.
- Maximum width = 436 ft.
- Maximum downwind distance = 256 ft.
- Maximum width = 194 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



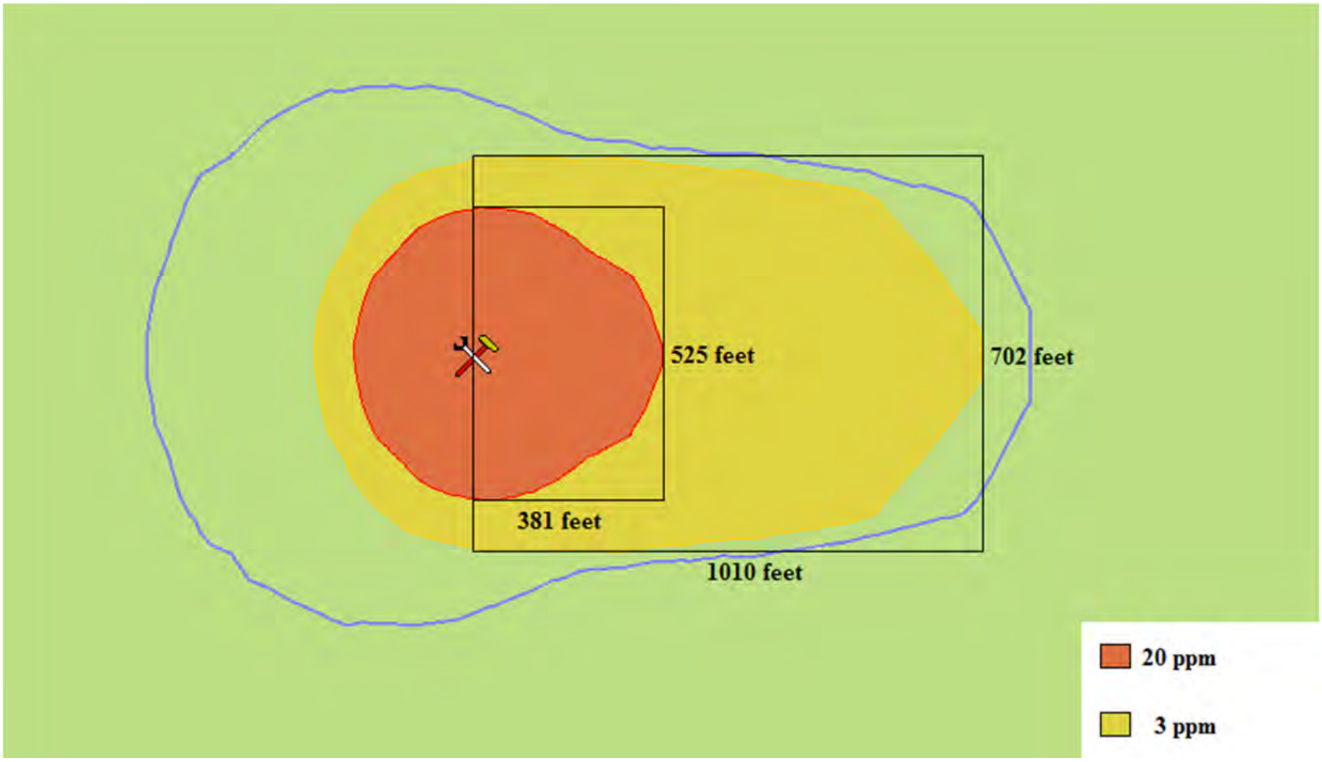
Peak Concentration as a Function of Distance:



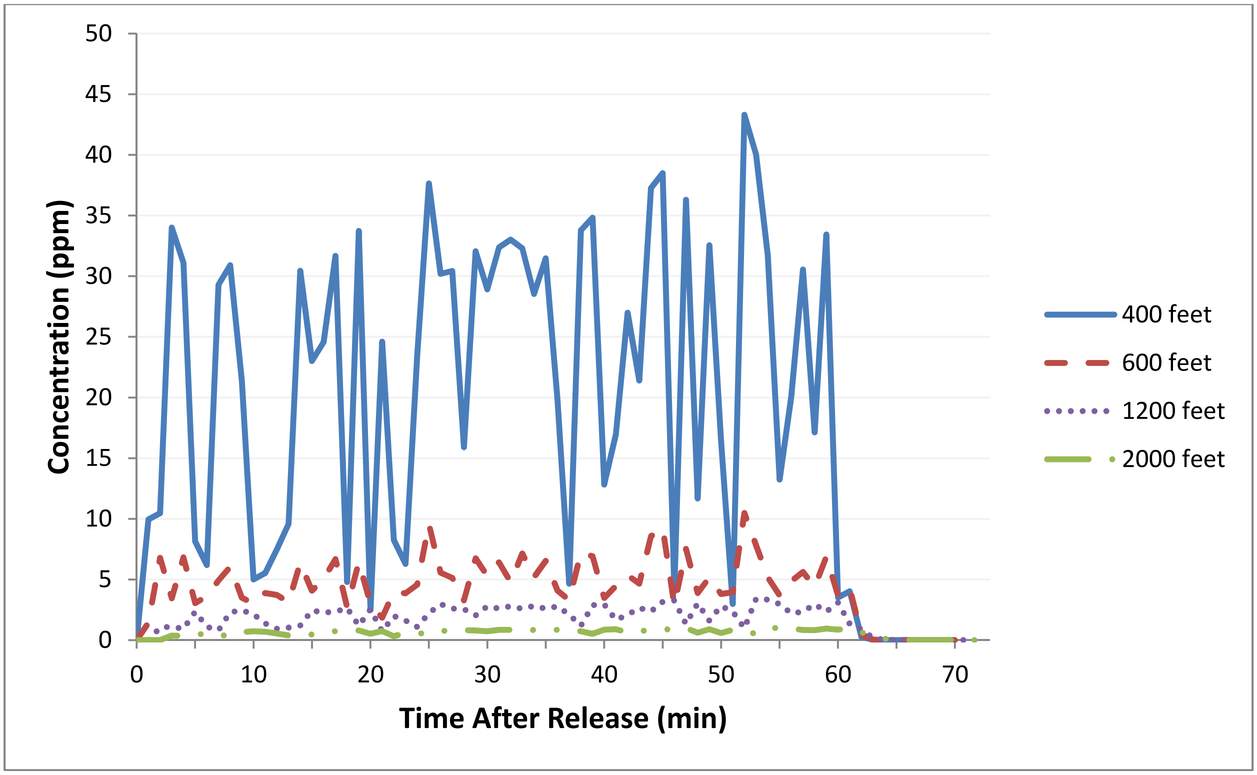
4.4.13 ½-Inch Tube Failure (liquid)

A ½-inch, type K copper tubing is sheared off. There is an infinite supply of chlorine and the mitigation is assumed to occur in one hour. Evaporation of pool is assumed to continue.

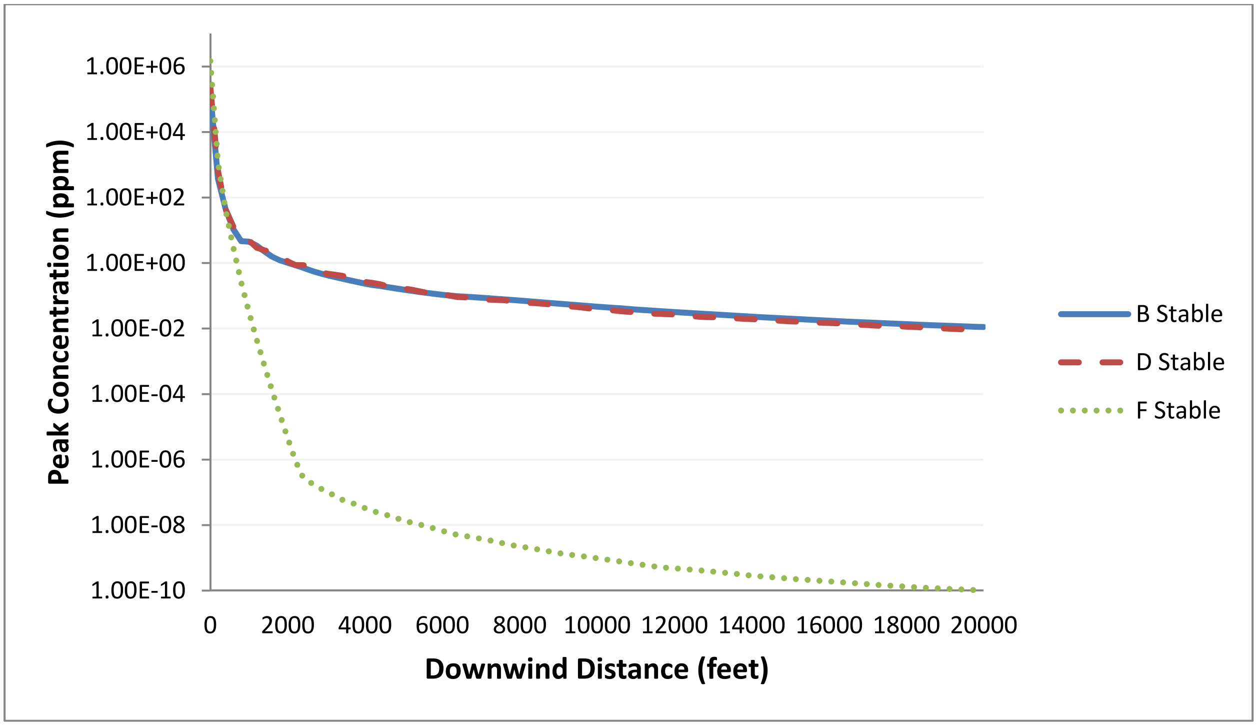
- Container type: tubing
- Release mechanism: failure
- Release state: liquid
- Release rate: 158 lbs./minute
- Contents mass: 9,500 lbs.
- Time for pool to evaporate: 110-170 minutes
- Duration of release: 110-170 minutes
- Hole elevation: 3 ft.
- Opening diameter: ½ inch
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 1010 ft.
- Maximum width = 702 ft.
- Maximum downwind distance = 381 ft.
- Maximum width = 525 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



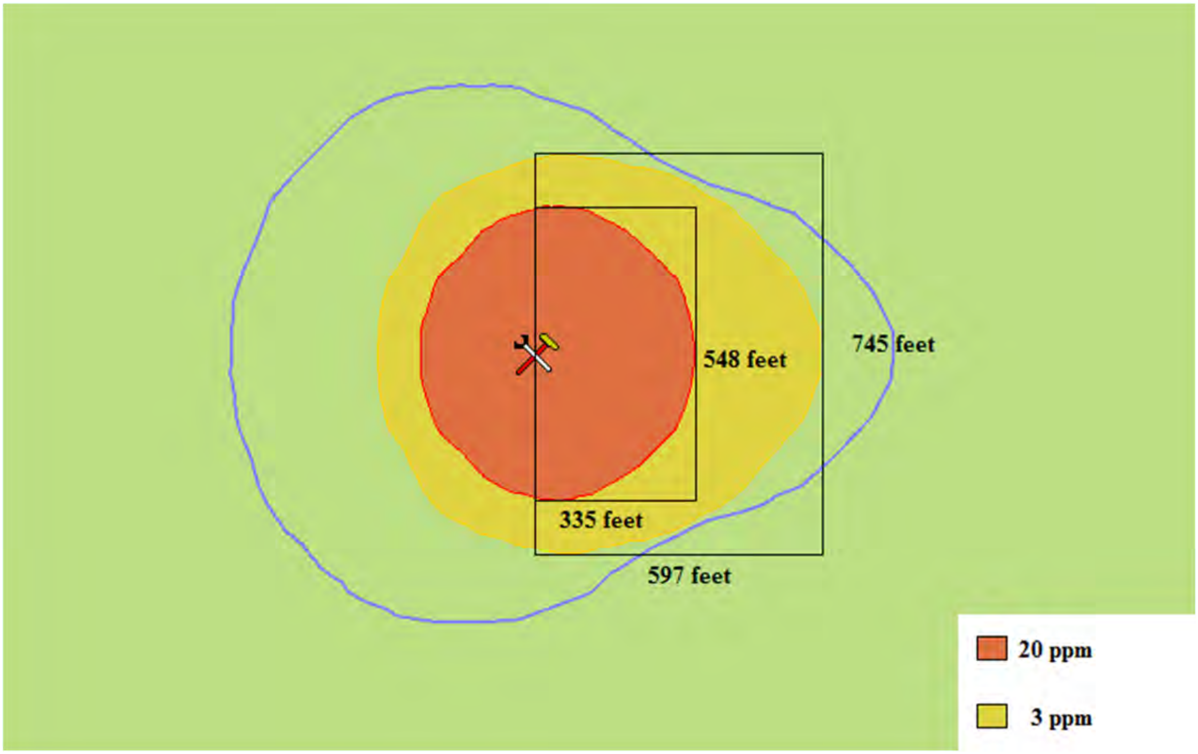
Peak Concentration as a Function of Distance:



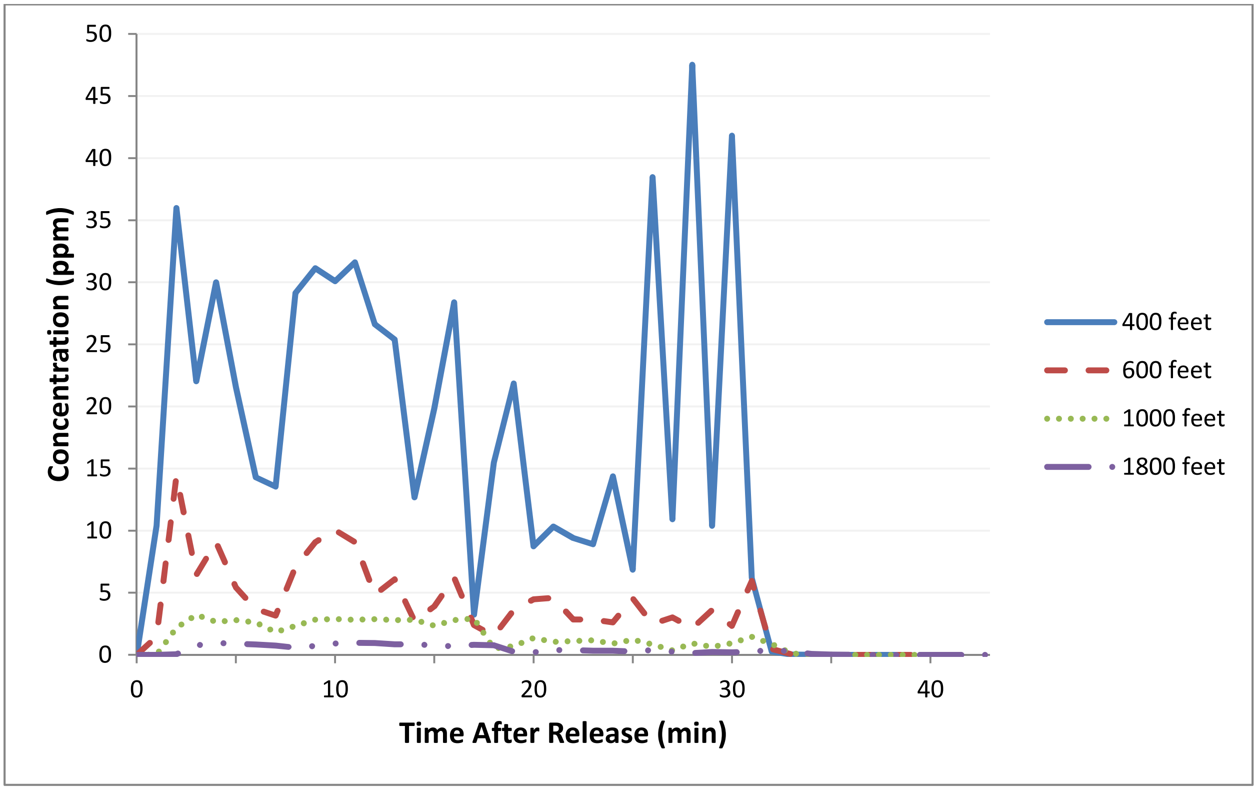
4.4.14 90 Ton Relief Valve

A rail tank car is overfilled with chlorine; the pressure rises and the relief valve opens; in reality, the relief valve will open and close repeatedly; the frequency of opening is dependent on heat transferred to the car from the environment; for modeling purposes, it is assumed the relief valve remains open for 30 minutes.

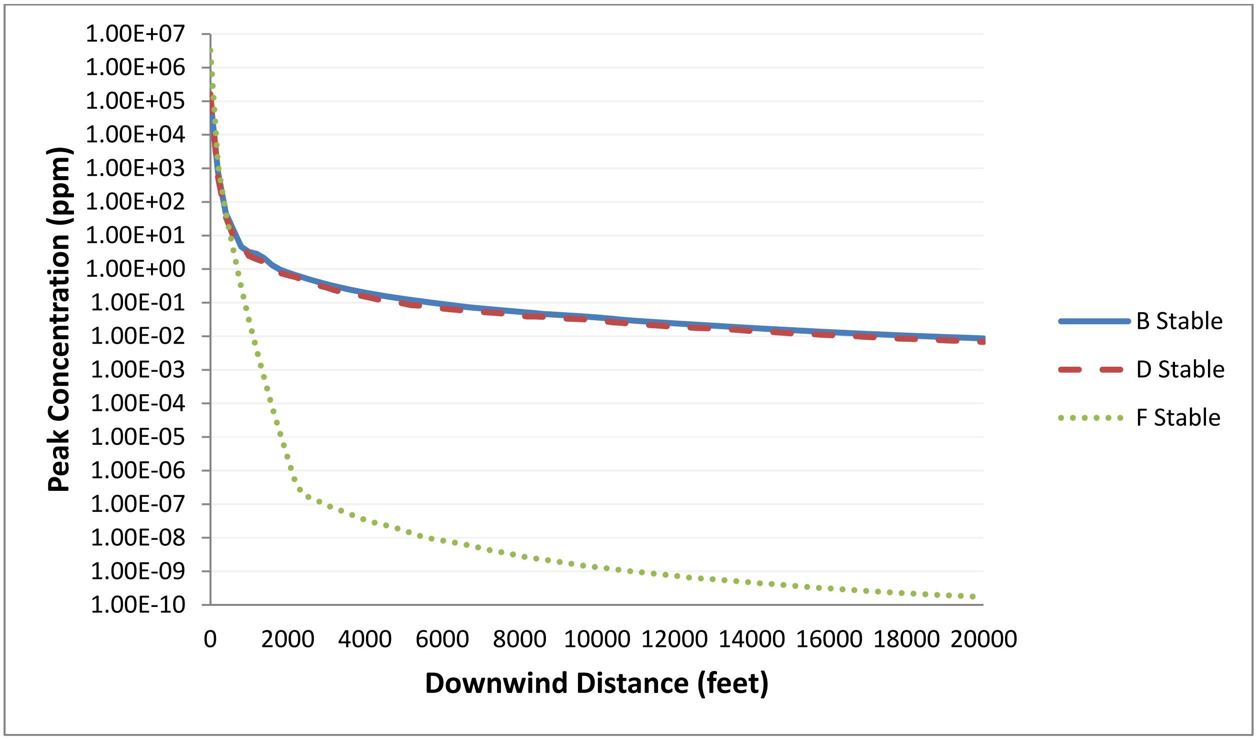
- Container type: railroad tank car
- Release mechanism: over pressure
- Release state: liquid/gas
- Release rate: 141 lbs./minute
- Contents mass: 101 tons
- Time for pool to evaporate: 60-75 minutes
- Total amount of Cl_2 released = approximately 4,000 lbs.
- Duration of release: 30 minutes
- Hole elevation: 135 ft.
- Opening diameter: 1.04 inches
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 597 ft.
- Maximum width = 745 ft.
- Maximum downwind distance = 335 ft.
- Maximum width = 548 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



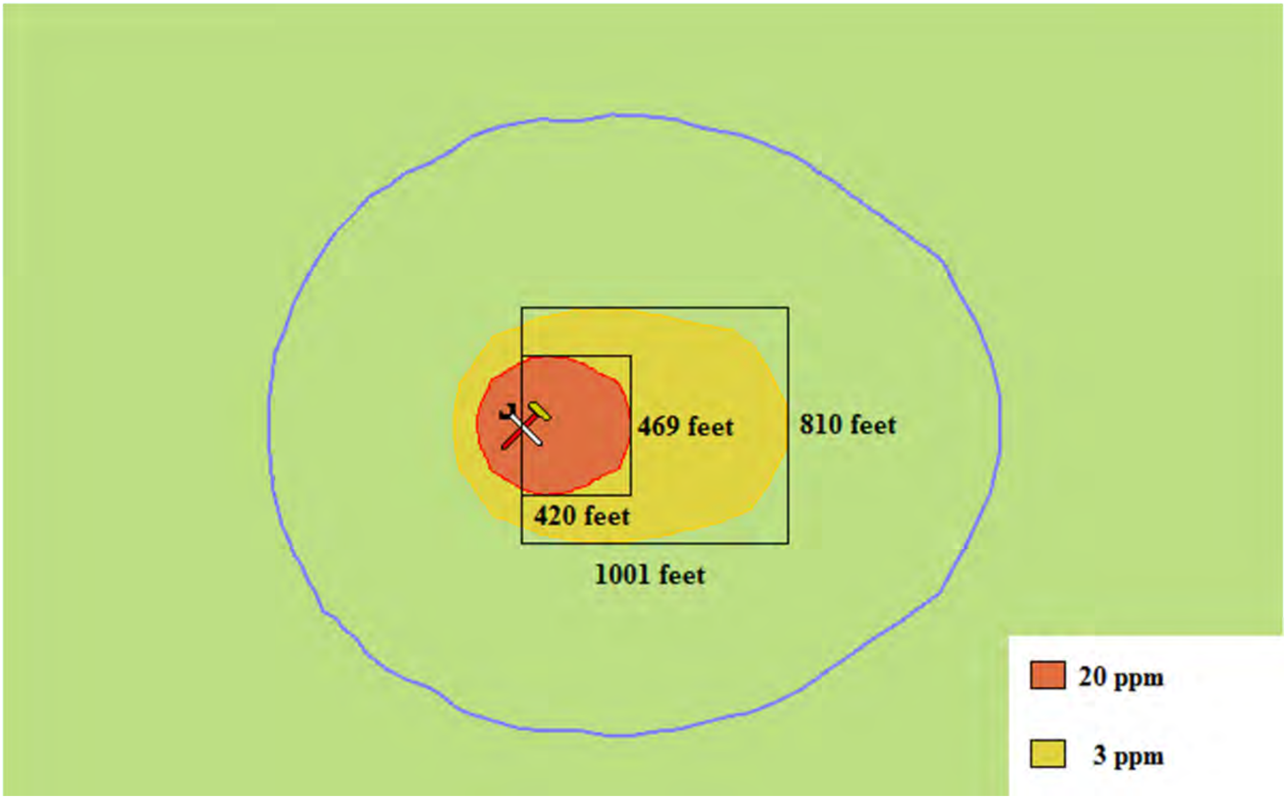
Peak Concentration as a Function of Distance:



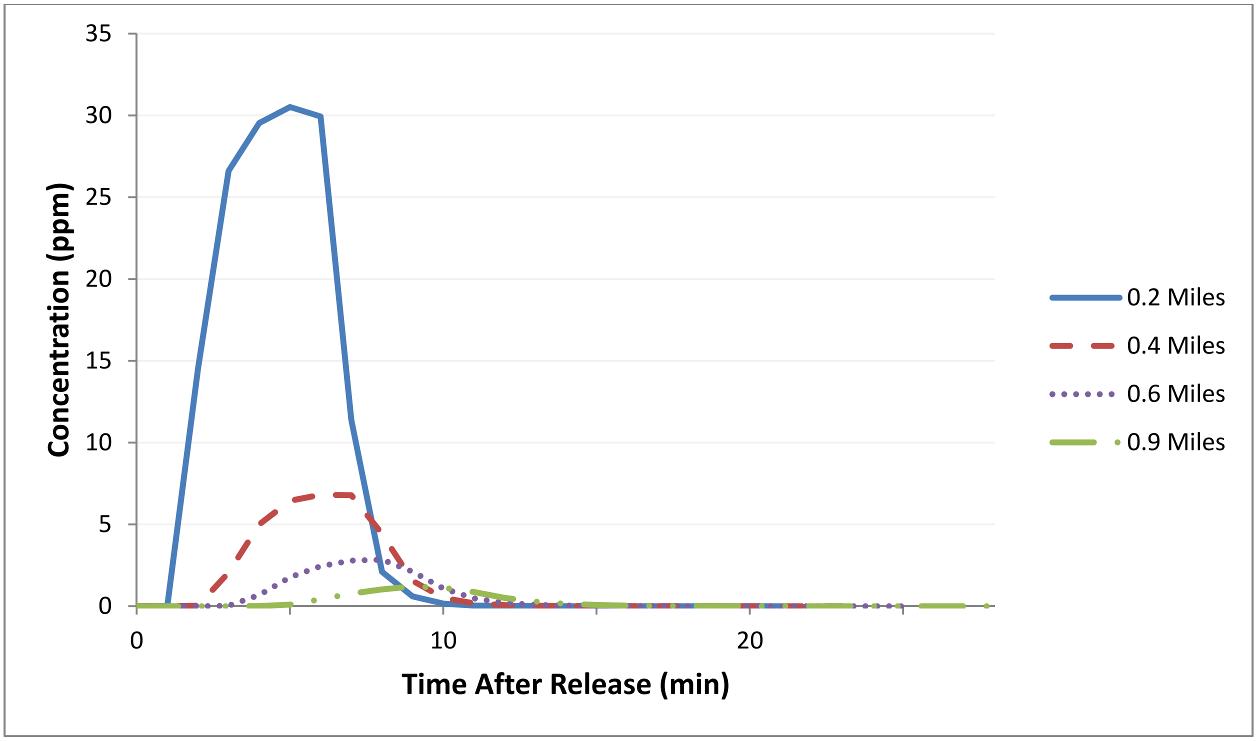
4.4.15 Acid Reaction

31.5% hydrochloric acid is introduced into a 5,000-gallon tank of 15% sodium hypochlorite. It is assumed that complete decomposition takes place and releases 6,250 lbs. of chlorine at a constant rate over 5 minutes.

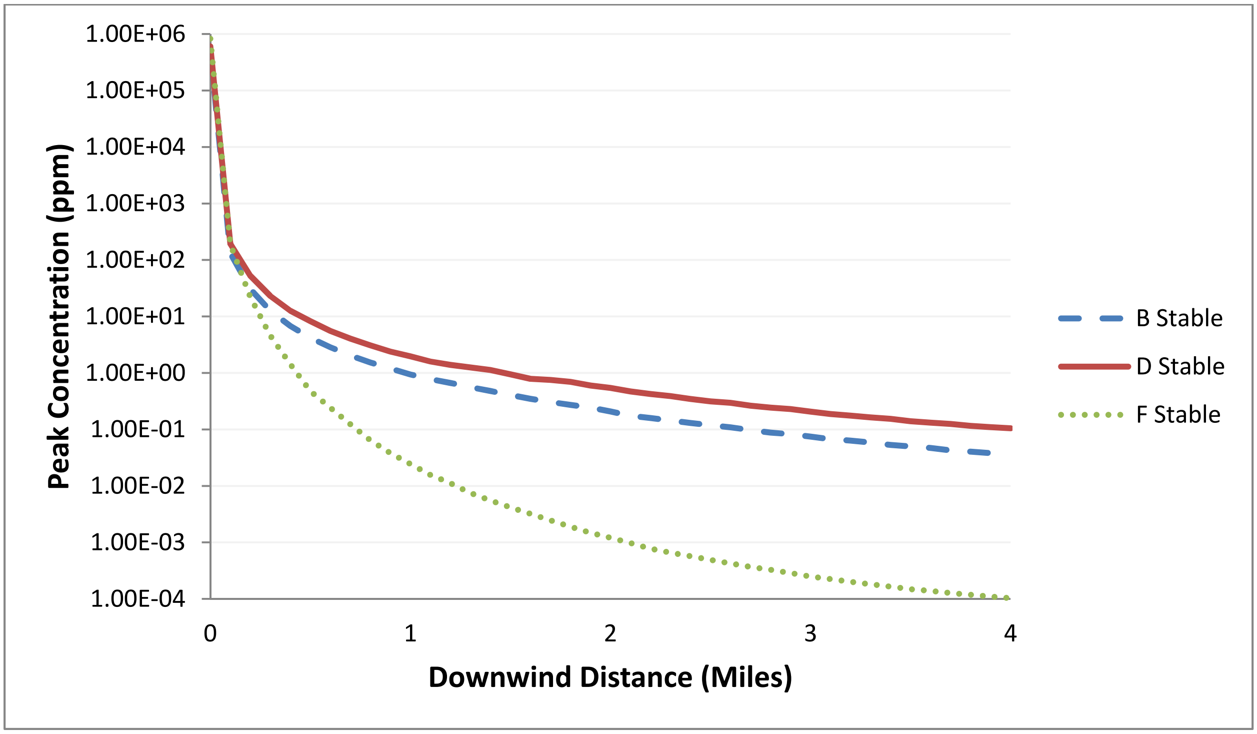
- Container type: vessel
- Release mechanism: chemical reaction
- Release state: gas
- Release rate: 1,250 lbs./minute
- Contents mass: 6,250 lbs.
- Duration of release: 5 minutes
- Elevation of release: 0 feet
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 1001 ft.
- Maximum width = 810 ft.
- Maximum downwind distance = 420 ft.
- Maximum width = 469 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



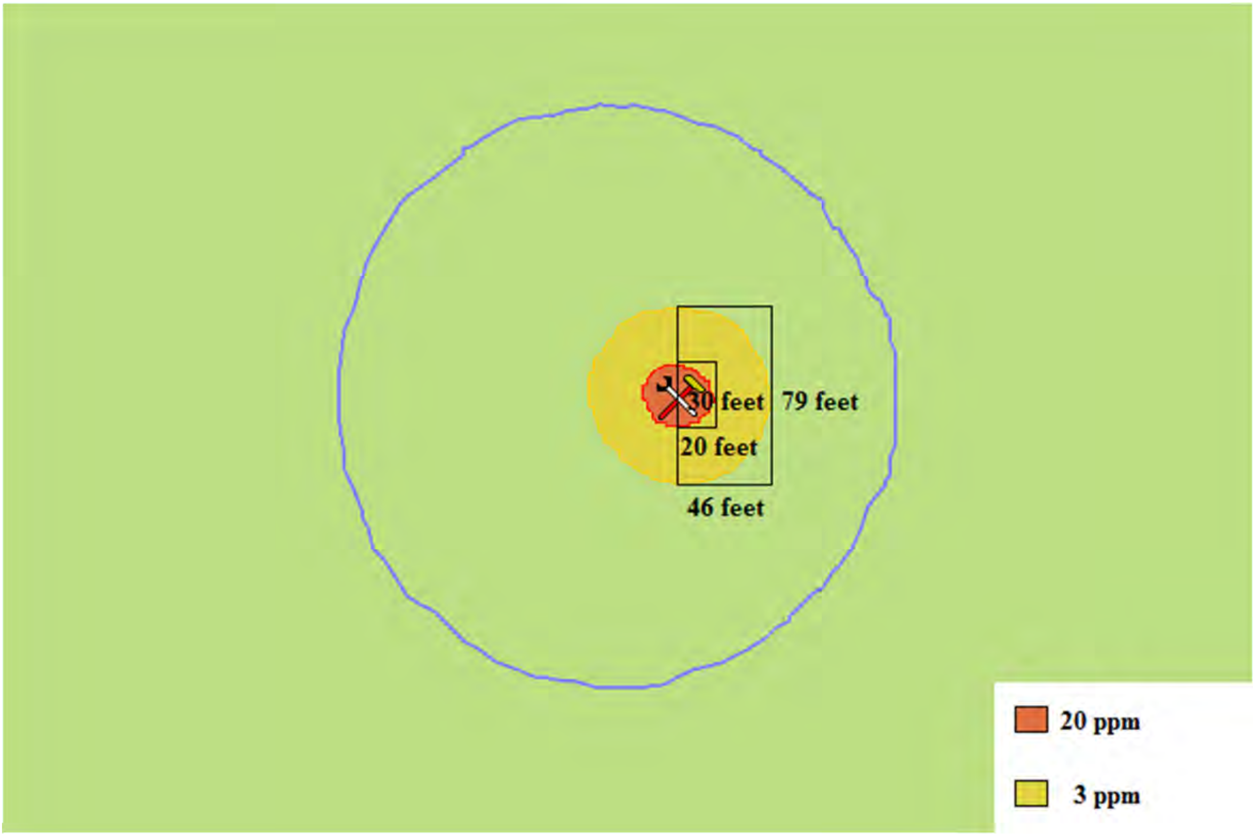
Peak Concentration as a Function of Distance:



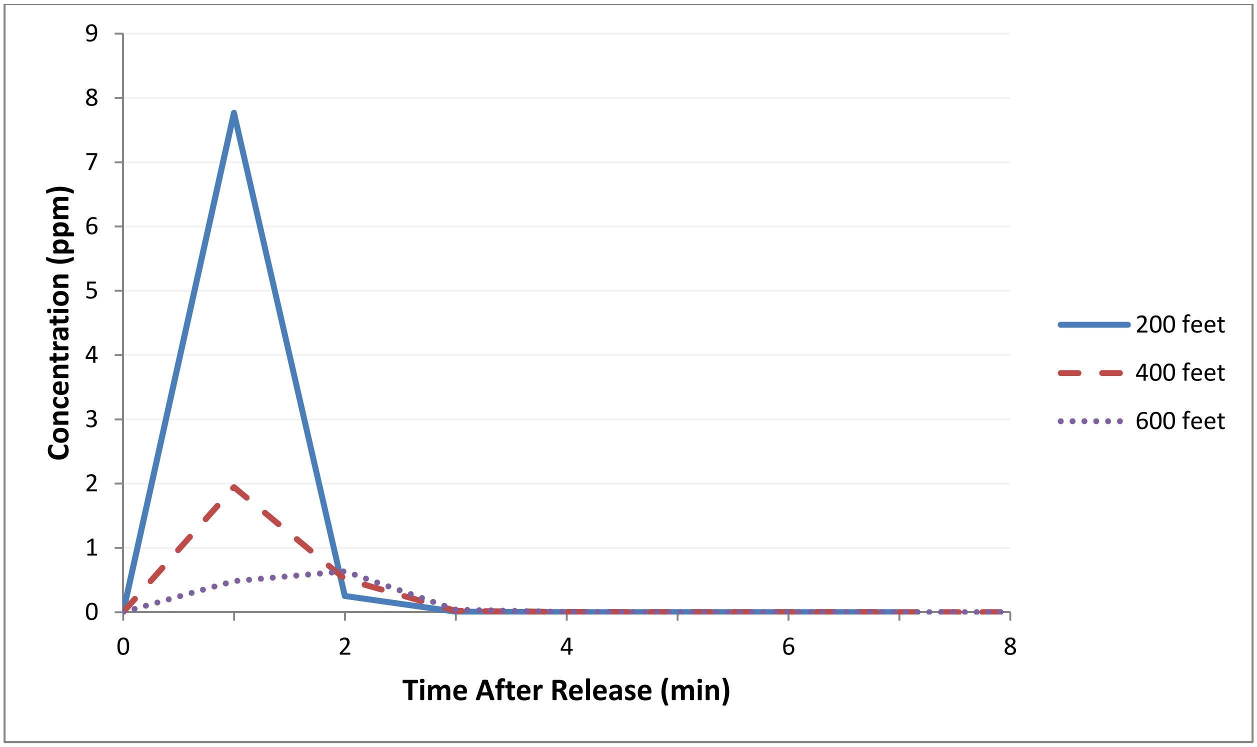
4.4.16 Calcium Hypochlorite - Decomposition

A reaction of 100 lbs. of 65% calcium hypochlorite (65% available chlorine) occurs at a swimming pool. An assumption is made that 25% of the available chlorine or 16.25 lbs. are released at a constant rate in 1 minute.

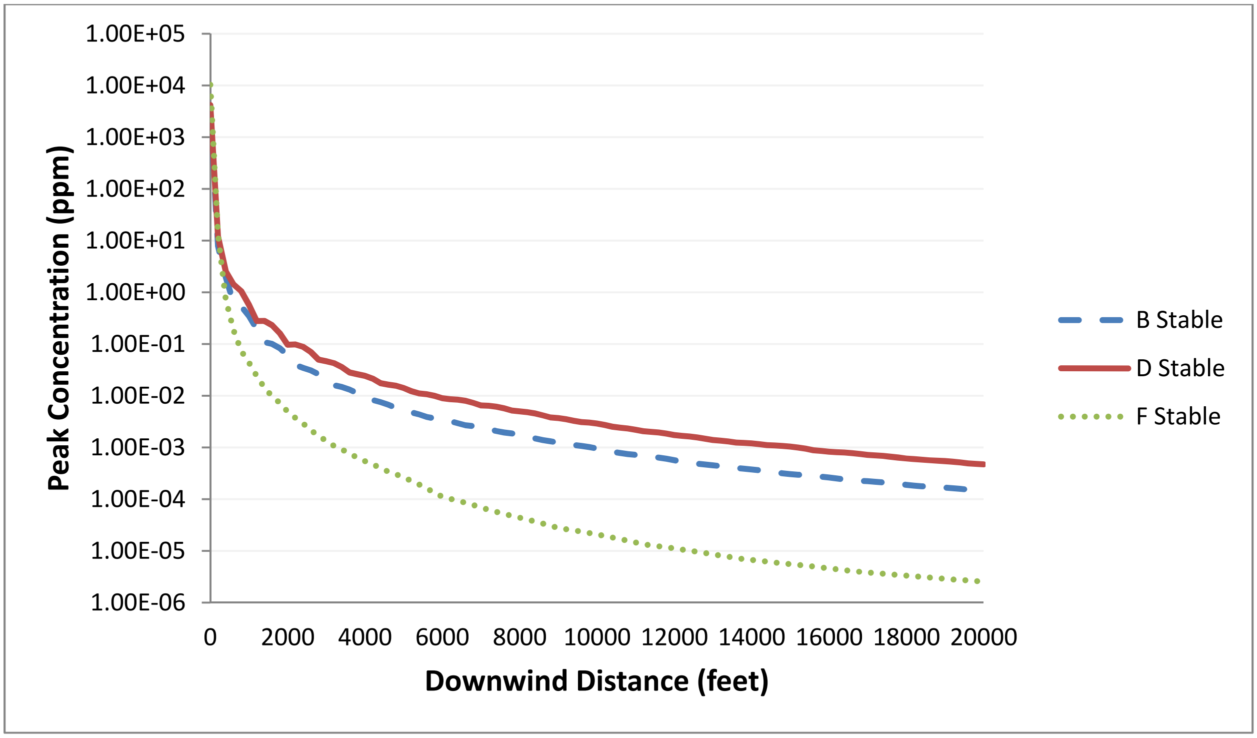
- Container type: vessel
- Release mechanism: chemical reaction
- Release state: gas
- Release rate: 16.25 lbs./minute
- Duration of release: 1 minutes
- Elevation of release: 0 feet
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 46 ft.
- Maximum width = 79 ft.
- Maximum downwind distance = 20 ft.
- Maximum width = 30 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



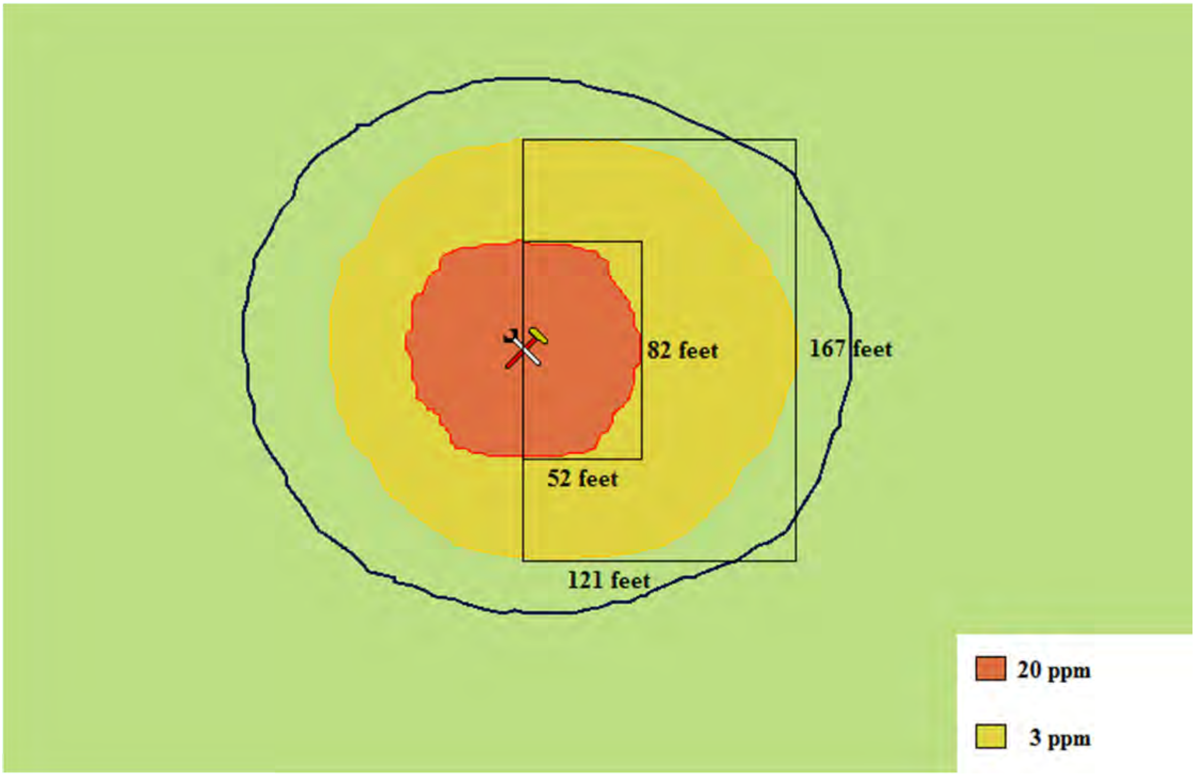
Peak Concentration as a Function of Distance:



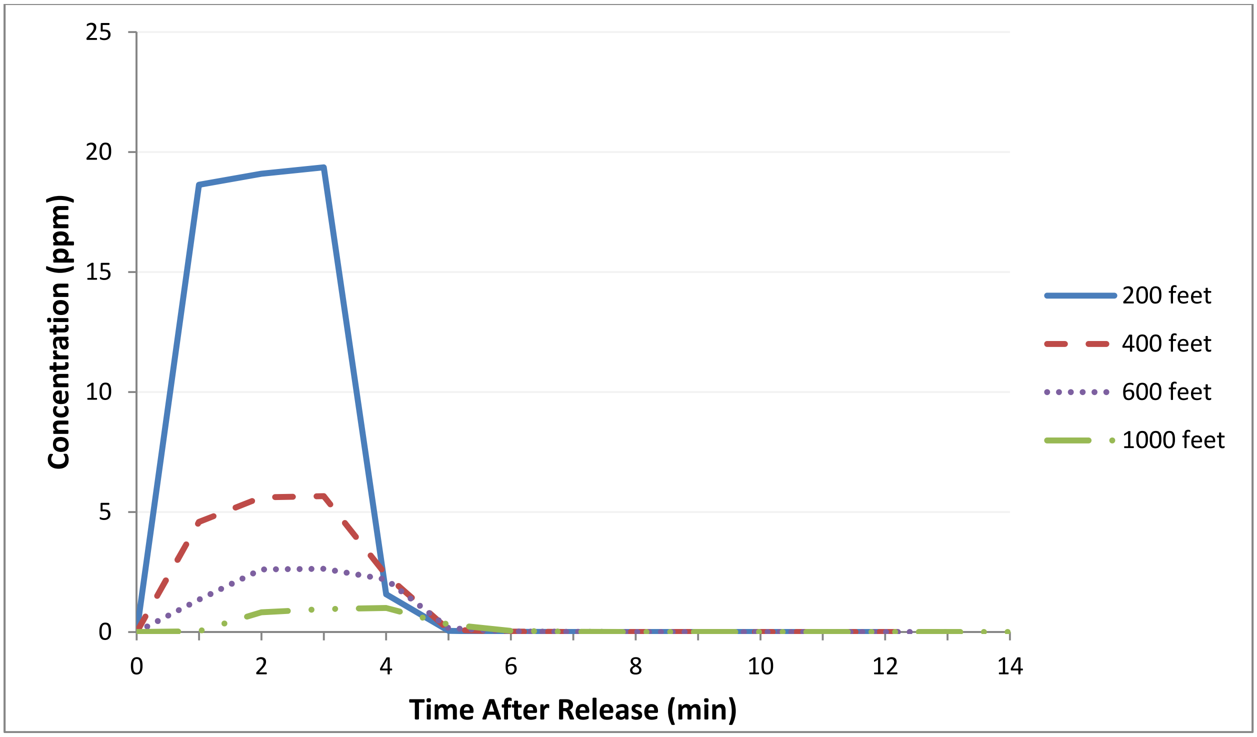
4.4.17 150 lb. Valve Failure

Release from a 150-lbs. cylinder valve failure.

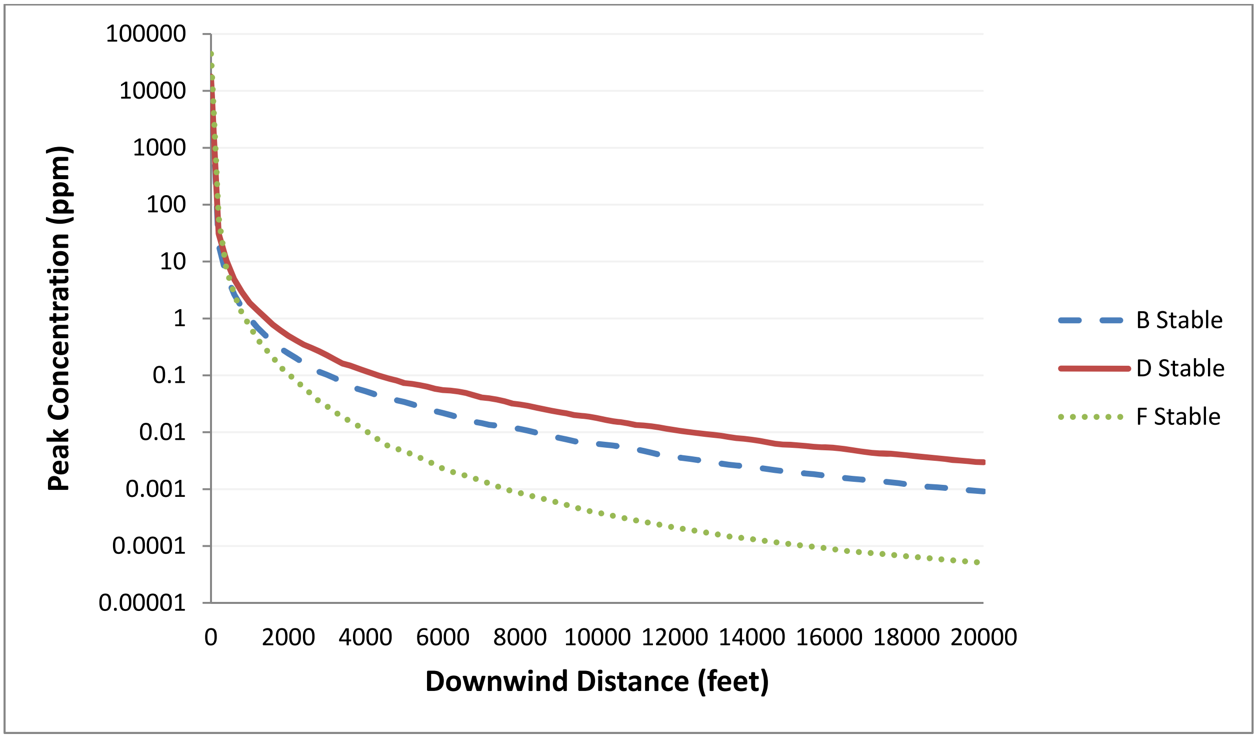
- Container type: 150-lbs. cylinder
- Release mechanism: valve failure
- Release state: liquid and gas
- Release rate: 68.4 lbs./minute
- Time for pool to evaporate: 52-87 minutes
- Duration of release: 52.87 minutes
- Time to empty the container: 3.2 minutes
- Hole elevation: 0 feet
- Valve opening diameter: 3/16 in.
- Contents mass: 150 lbs.
- Wind Speed = 3 m/s @ 3 ppm
- Wind Speed = 3 m/s @ 20 ppm
- Maximum downwind distance = 121 ft.
- Maximum width = 167 ft.
- Maximum downwind distance = 52 ft.
- Maximum width = 82 ft.



Peak Concentration as a Function of Time at Various Downwind Distances:



Peak Concentration as a Function of Distance:



5. REFERENCES

5.1 OTHER REFERENCES

5.1.1 Understanding Atmospheric Dispersion of Accidental Releases; Center for Chemical Process Safety, American Institute of Chemical Engineers: New York, 2003.

5.1.2 Emergency Response Planning Guidelines, Chlorine; American Industrial Hygiene Association: Fairfax, VA, updated periodically.

5.1.3 Risk Management Program Rule (RMP) Offsite Consequence Analysis Guidance; U.S. Environmental Protection Agency: Washington, DC. The RMP was revised in March 2009 and is accessible at the following link: http://www.epa.gov/oem/docs/chem/oca-chps.pdf.

5.1.4 Accidental Release Prevention Requirements: Risk Management Programs Under the Clean Air Act, Section 112(r)(7).

5.1.5 Turner, D. B. Workbook of Atmospheric Dispersion Estimates: An Introduction to Dispersion Modeling, ed. 2; Lewis: Ann Arbor, 1994.

5.1.6 PROJECT JACK RABBIT: FIELD TESTS – CSAC 11-006; Prepared by Shannon B. Fox, Ph.D., Chemical Security Analysis Center, Science & Technology Directorate, U.S. Department of Homeland Security Aberdeen Proving Ground, MD and Donald Storwold, Meteorology Division, West Dessert Test Center, Dugway Proving Ground, UT.

5.1.7 Deposition of Cl_2 on Soils During Outdoor Releases; Journal of Hazardous Materials, 252-253 (2013) 107-114; Published by Elsevier B.V.

APPENDIX A – HPAC MODEL EXPLANATION

The model used to analyze the scenarios in this pamphlet is the Hazard Prediction and Analysis Capability (HPAC) 5.0 model. This appendix summarizes some of the key concepts employed in this model.

HPAC 5.0 is a hazard prediction modeling system developed by the U.S. Department of Defense, Defense Threat Reduction Agency (DTRA), which distributes it freely to U.S. Government agencies and their contractors but not to commercial interests. HPAC contains 13 incident source models including chemical/biological weapons incident, missile intercept, nuclear weapon strike, nuclear weapon single event, radiological weapons incident, nuclear effects incident, chemical or biological facility incident, industrial facility incident (IFac), industrial transportation incident (ITrans), nuclear facility incident, nuclear weapon incident, smoke incident, and analytical (user-defined) release. For the modeling performed in Pamphlet 74, the analytical source module was used to define the chlorine release source, with the release volumes manually input for each scenario.

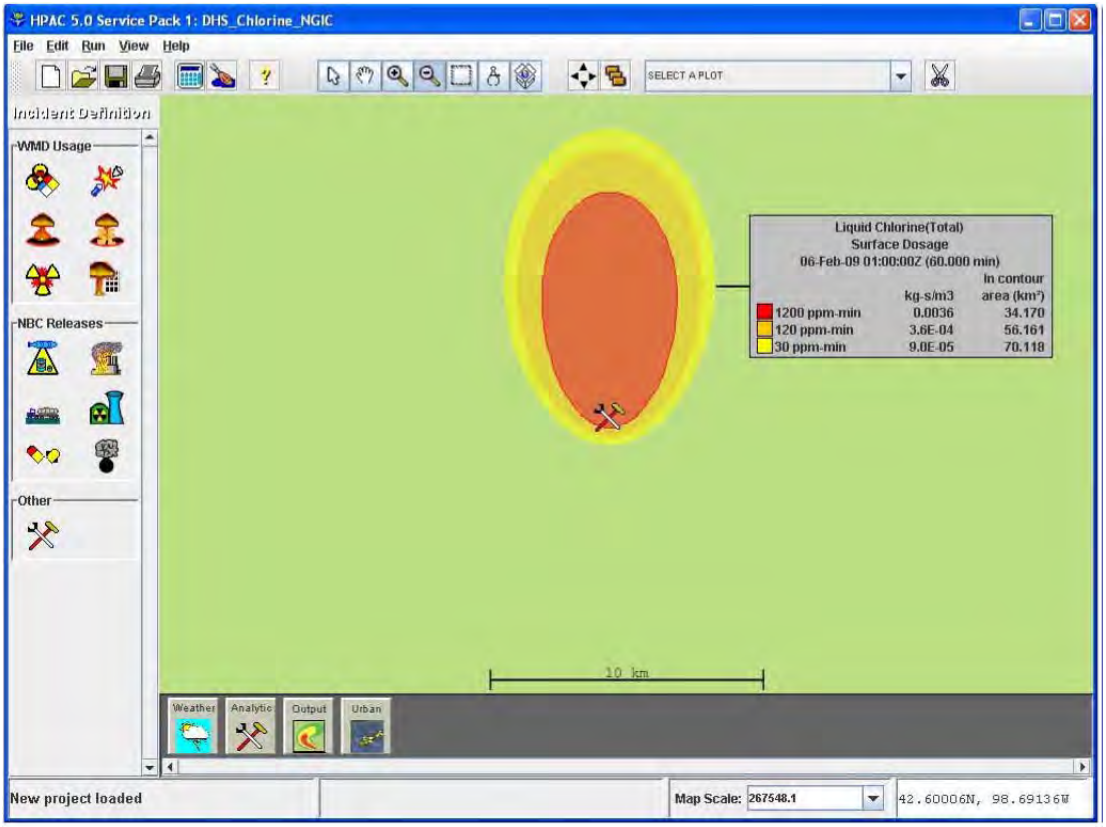
HPAC contains a wide array of options for representing predictions graphically and in text form and supports the output of concentration time histories at a large number of user-defined locations. HPAC is distributed with a 1-km resolution population database and can calculate affected populations. It can also output casualty tables with the best estimate, worst-case estimate, and 10-percent risk estimate of casualties for selected chemical and biological warfare agents. HPAC includes 1-km resolution terrain and land cover data that describe three-dimensional topographic variations and account for agent absorption characteristics and surface albedo. The HPAC output from the scenarios presented in Pamphlet 74 do not include casualty estimates due to sensitivity concerns, however the expected concentrations, dosages, and ranges predicted for each scenario are presented.

HPAC employs the SCIPUFF model for atmospheric transport and dispersion modeling. SCIPUFF is a Lagrangian puff dispersion model that uses a collection of Gaussian puffs to represent an arbitrary three-dimensional concentration field. The model incorporates an algorithm for splitting and merging puffs and accounts for wind shear effects. Turbulent diffusion is modeled based on second-order turbulence closure theory, which relates the dispersion rate to velocity fluctuation statistics. In addition to calculating average concentration values, the model provides a prediction of the statistical variance in the concentration field resulting from random fluctuations in the wind field.

The variance can be used to estimate a probability distribution for the predicted value. The SCIPUFF model calculates dense gas dynamics which is important and relevant for chlorine releases, and uses an algorithm that computes effects such as settling and spreading of the plume laterally as a result of interaction of the plume with the ground surface. The dense gas model also considers collapse of dense gas clouds (slumping) and suppression of vertical diffusion resulting from stable buoyancy distribution.

A variety of weather inputs can be used with HPAC, and the options include single wind vector or vertical wind profile inputs, time-varying meteorology, imported or user-created weather files, and data imported from the remote Meteorological Data Service (MDS) operated by DTRA. The model can accommodate surface observations (usually made hourly), upper air observations (typically made every 12 hours), and numerical weather predictions. HPAC contains two meteorological preprocessors: SWIFT and MC-SCIPUFF. The preprocessors calculate a wind field by interpolating the meteorological data while referencing the project terrain file. They support the input of wind observations from multiple meteorological sites during the same scenario. SWIFT is the default wind model but cannot be used when a dimension of the project domain exceeds 1,000 km. The models are mass consistent, which ensures that air flows around or over but never through terrain features.

HPAC has a graphical user interface (GUI) that assists in setting up runs and visualizing their output. An example of the HPAC 5.0 GUI is provided in Figure A1. An HPAC project is created by selecting an incident source model and positioning the source, then defining weather and selecting terrain, urban, and other modeling options. Typical run times range from a few minutes to 15 minutes.



Liquid Chlorine(Total)
Surface Dosage
06-Feb-09 01:00:00Z (60.000 min)

	kg-s/m3	In contour area (km²)
🟥 1200 ppm-min	0.0036	34.170
🟧 120 ppm-min	3.6E-04	56.161
🟨 30 ppm-min	9.0E-05	70.118

Figure A1 - HPAC Graphical User Interface showing the use of the analytical source module.

The function within HPAC called the analytical source module was used to manually specify the release conditions in each of the scenarios modeled. In Figure A1, an example of the scenario output contour plots is also shown. The tools icon in the middle is the icon that the analytical source module uses to represent the release location. The analytical source module includes the ability to model continuous releases at a constant rate, instantaneous releases, liquid pools, moving sources, and stack releases. For the scenarios presented in Pamphlet 74, the characteristic parameters of each incident were manually entered into the analytical source module to achieve the desired release rate, duration, orientation, and other input variables. HPAC does not presently account for chemical reactions explicitly, but it can remove material from the plume at a steady rate. New findings from the analysis of chlorine releases in the Jack Rabbit I project were used to define source input parameters and also include the removal of chlorine through reactivity with the soil. *(5.1.6 and 5.1.7)*

APPENDIX B - UNDERSTANDING DISPERSION MODELING RESULTS

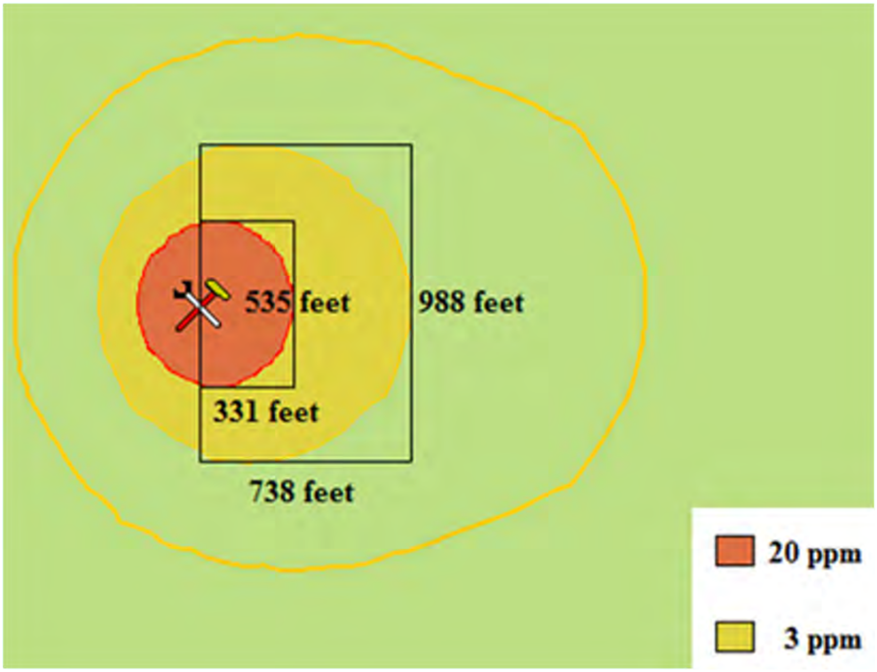
The results of dispersion modeling for release scenarios are often presented graphically (concentration vs. distance, concentration vs. time, etc.). When there is a chlorine release from a given “source” (e.g., chlorine cylinder, rail tank car, etc.), emergency response personnel need to know the concentration (typically expressed in parts per million or ppm) of chlorine in the atmosphere at various “receptor” sites (e.g., locations of homes, businesses, etc.).

The results of any given release scenario may be graphically presented in several different ways. The particular graphical format(s) selected for use will depend on the questions that need to be answered.

In order to facilitate the user’s selection and use of the appropriate information, sample graphical outputs are presented with some explanatory notes.

Note - all the examples described are actual outputs of Scenario 4.4.2. (1 ton release)

B.1 FOOTPRINTS



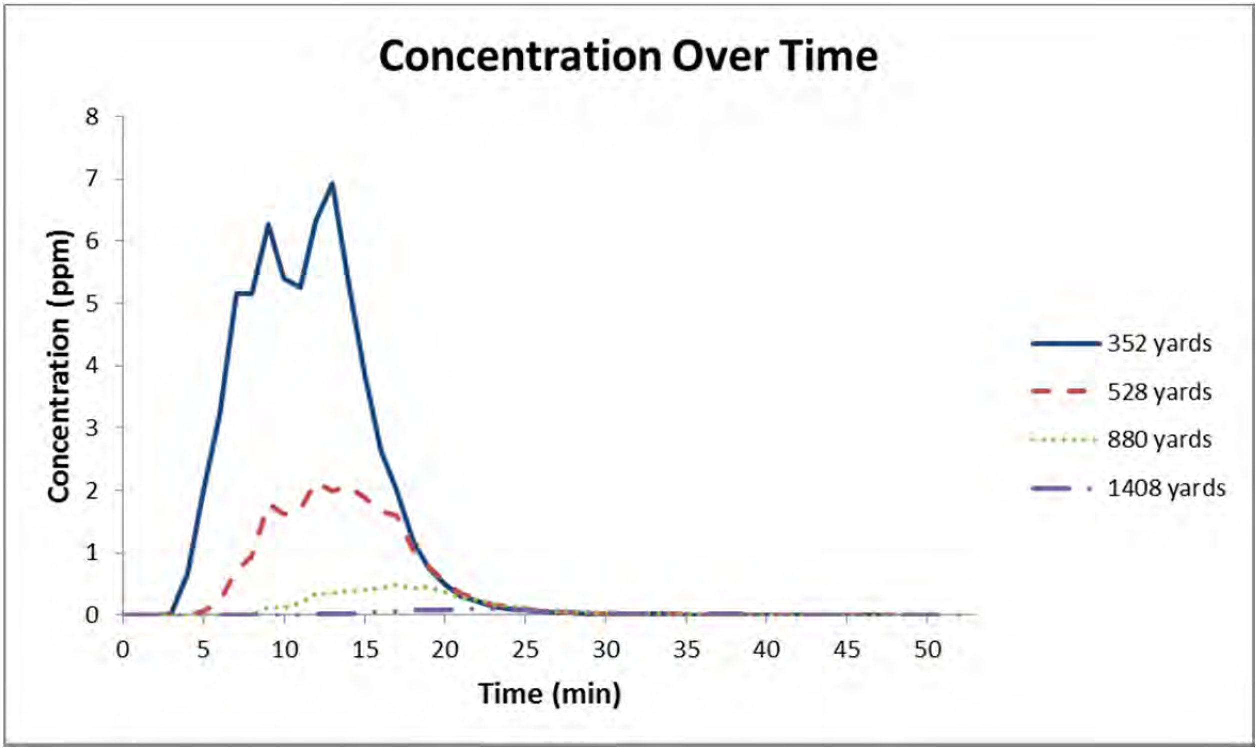
When viewing a footprint, one should think of being in the air looking down on the release area. In most cases, the X- and Y- axes are not drawn to the same scale. This footprint shows the area downwind from the point of release where the chlorine concentration will reach or exceed the specified levels of concern (3 ppm and 20 ppm) at the time of maximum impact as determined by a model. The footprint thus represents the maximum area that a given concentration of chlorine will reach or exceed after a release. At a given time after a release the affected area may be less than that shown by the footprint, but at no time after a release is it expected that the release will exceed the area depicted by the footprint. However, each footprint is based on specific assumptions which, if changed, would change the dimensions of the footprint.

In this footprint, the outer shaded area represents the maximum area where chlorine concentrations are expected to peak at between 3 and 20 ppm. The inner unshaded area represents the maximum area where the chlorine concentration exceeds or reaches 20 ppm. The inner area does not designate a maximum chlorine concentration. Theoretically, at the very point of the release the chlorine concentration would reach 100%.

This footprint shows the maximum downwind distance from the release that the concentration exceeds or equals 20 ppm is approximately 331 ft. Crosswind from the release, the maximum distance that the concentration exceeds or equals 20 ppm is about 535 ft. on each crosswind side of the release.

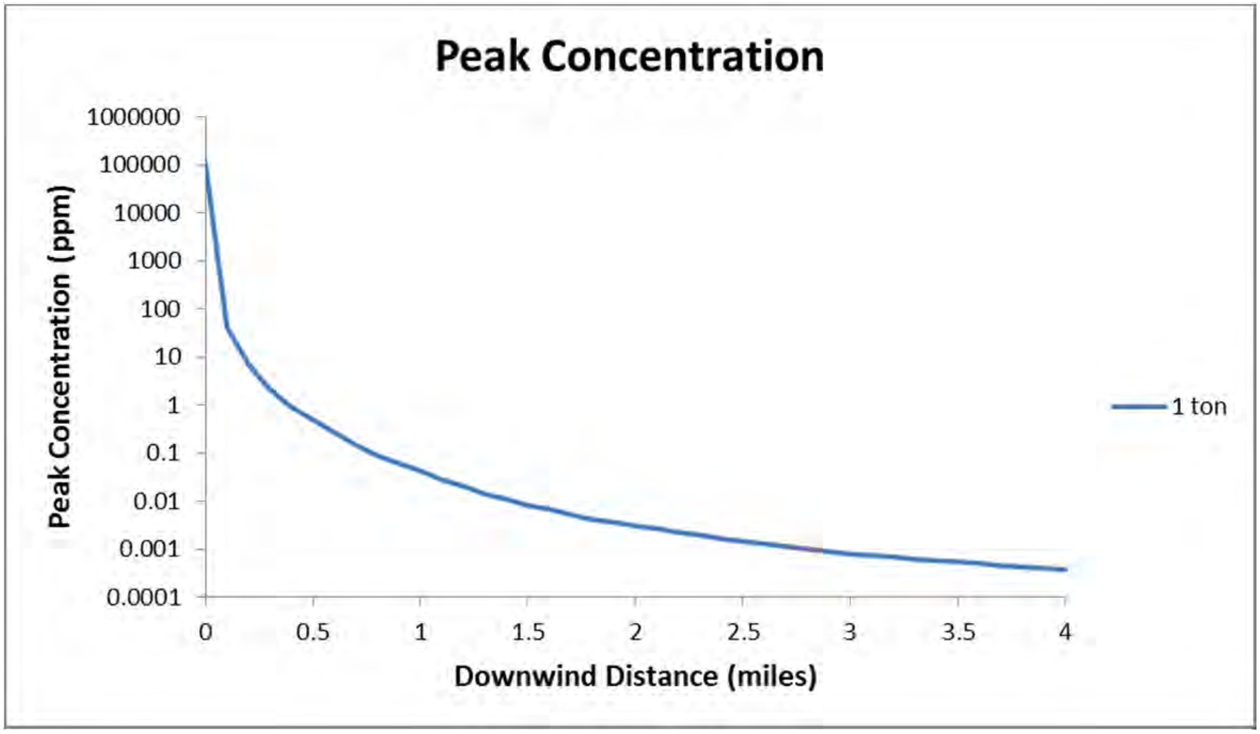
This footprint shows the maximum downwind distance from the release that the concentration exceeds or equals 3 ppm is approximately 738 ft. Crosswind from the release, the maximum distance that the concentration exceeds or equals 3 ppm is about 988 ft. on each crosswind side of the release.

B.2 PEAK (MAXIMUM) CONCENTRATIONS AS A FUNCTION OF TIME AT VARIOUS DOWNWIND DISTANCES



This graphical output shows the peak (maximum) concentration at approximately 25, 50, 75, and 95% of the maximum 3 ppm cloud distance as a function of time. In looking at the output depicted above, it can be seen that at 352 yards downwind from the source, the chlorine concentration will peak at about 7 ppm. At 528 yards downwind from the source, it will peak at about 1.7 ppm. This output also provides an estimate of the time after the release that a point downwind will be affected. If one is concerned about a point 352 yards downwind, the output indicates that the area will begin to be affected about 3-5 minutes after the release. About 20 minutes later, the 352 yards point will no longer be affected. At 880 yards downwind, the point will begin to see the effects of the release about 10 minutes after it occurs. It will also last for about 15 minutes.

B.3 PEAK CONCENTRATION AS A FUNCTION OF DISTANCE



This graphical output shows the maximum or peak concentration at a specific distance downwind from the point of release. For example, if one wanted to know the maximum distance that the concentration would reach 1 ppm the graph shows this distance is about ½ mile. If one wanted to know the maximum distance that the chlorine concentration would reach 20 ppm, the graph shows that this distance is about 0.06 miles or 331 ft. This distance should agree with the 20 ppm distance as shown by the footprint.

Note: The Y - axis is a log scale.

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