United States
Environmental Protection
Agency

Office of Solid Waste
and
Emergency Response

EPA 550-B-99-009
March 2009
www.epa.gov/emergencies

RISK MANAGEMENT PROGRAM GUIDANCE FOR OFFSITE CONSEQUENCE ANALYSIS

Office of Emergency Management

This document provides guidance to the owner or operator of processes covered by the Chemical Accident Prevention Program rule in the analysis of offsite consequences of accidental releases of substances regulated under section 112(r) of the Clean Air Act. This document does not substitute for EPA's regulations, nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, States, or the regulated community, and may not apply to a particular situation based upon the circumstances. This guidance does not constitute final agency action, and EPA may change it in the future, as appropriate.

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LIST OF EXHIBITS

TABLE OF POTENTIALLY REGULATED ENTITIES

This table is not intended to be exhaustive, but rather provides a guide for readers regarding entities likely to be regulated under 40 CFR part 68. This table lists the types of entities that EPA is now aware could potentially be regulated by this rule (see Appendix B of the "General Guidance for Risk Management Programs" for a more detailed list of potentially affected NAICS codes). Other types of entities not listed in this table could also be affected. To determine whether your facility is covered by the risk management program rules in part 68, you should carefully examine the applicability criteria discussed in Chapter 1 of the General Guidance and in 40 CFR 68.10. If you have questions regarding the applicability of this rule to a particular entity, call the EPCRA/CAA Hotline at (800) 424-9346 (TDD: (800) 553-7672).

Category	**NAICS Codes**	**SIC Codes**	**Examples of Potentially Regulated Entities**
Chemical manufacturers	325	28	Petrochemicals Industrial gas Alkalies and chlorine Industrial inorganics Industrial organics Plastics and resins Agricultural chemicals Soap, cleaning compounds Explosives Miscellaneous chemical manufacturing
Petroleum refineries	32411	2911	Petroleum refineries
Pulp and paper	322	26	Paper mills Pulp mills Paper products
Food processors	311	20	Dairy products Fruits and vegetables Meat products Seafood products
Polyurethane foam	32615	3086	Plastic foam products
Non-metallic mineral products	327	32	Glass and glass products Other non-metallic mineral products
Metal products	331 332	33 34	Primary metal manufacturing Fabricated metal products

Category	NAICS Codes	SIC Codes	Examples of Potentially Regulated Entities
Machinery manufacturing	333	35	Industrial machinery Farm machinery Other machinery
Computer and electronic equipment	334	36	Electronic equipment Semiconductors
Electric equipment	335	36	Lighting Appliance manufacturing Battery manufacturing
Transportation equipment	336	37	Motor vehicles and parts Aircraft
Food distributors	4224 4228	514 518	Frozen and refrigerated foods Beer and wines
Chemical distributors	42269	5169	Chemical wholesalers
Farm supplies	42291	5191	Agricultural retailers and wholesalers
Propane dealers	454312	5171 5984	Propane retailers and wholesalers
Warehouses	4931	422	Refrigerated warehouses Warehouse storing chemicals
Water treatment	22131	4941	Drinking water treatment systems
Wastewater treatment	22132 56221	4952 4933	Sewerage systems Wastewater treatment Waste treatment
Electric utilities	22111	4911	Electric power generation
Propane users			Manufacturing facilities Large institutions Commercial facilities
Federal facilities			Military installations Department of Energy installations

Roadmap to Offsite Consequence Analysis Guidance by Type of Chemical

Type of Chemical and Release Scenario	Applicable Sections and Appendices
Toxic Gas	
Worst-Case Scenario	
1) Define Worst Case	Section 2.1
2) Select Scenario	Sections 2.2 and 2.3
3) Calculate Release Rates	
Unmitigated	Section 3.1.1
Passive Mitigation	Section 3.1.2
Refrigerated	Section 3.1.3
4) Find Toxic Endpoint	Appendix B (Exhibit B-1)
5) Determine Reference Table and Distance	Section 3.1.3, 3.2.3
Dense or Neutrally Buoyant Plume	Chapter 4 and Appendix B (Exhibit B-1)
Chemical-Specific Tables (ammonia, chlorine, sulfur dioxide)	Chapter 4
Urban or Rural	Section 2.1 and Chapter 4
Release Duration	Section 2.1
Alternative Scenario	
1) Define Alternative Scenario	Chapter 6
2) Select Scenario	Chapter 6
3) Calculate Release Rates	
Unmitigated (from tanks and pipes)	Section 7.1.1
Active or Passive Mitigation	Section 7.1.2
4) Find Toxic Endpoint	Appendix B (Exhibit B-1)
5) Determine Reference Table and Distance	
Dense or Neutrally Buoyant Plume	Chapter 8 and Appendix B (Exhibit B-1)
Chemical-Specific Tables (ammonia, chlorine, sulfur dioxide)	Chapter 8
Urban or Rural	Section 2.1 and Chapter 8
Release Duration	Section 7.1

Roadmap to Offsite Consequence Analysis Guidance by Type of Chemical (continued)

Type of Chemical and Release Scenario	Applicable Sections and Appendices
Toxic Liquid	
Worst-Case Scenario	
1) Define Worst Case	Section 2.1
2) Select Scenario	Sections 2.2 and 2.3
3) Calculate Release Rates	
Releases from Pipes	Section 3.2.1
Unmitigated Pool Evaporation	Section 3.2.2
Passive Mitigation (dikes, buildings)	Section 3.2.3
Release at Ambient Temperature	Section 3.2.2, 3.2.3
Release at Elevated Temperature	Section 3.2.2, 3.2.3
Releases of Mixtures	Section 3.2.4 and Appendix B (Section B.2)
Temperature Corrections for Liquids at 25-50 °C	Section 3.2.5 and Appendix B (Exhibit B-4)
Releases of Solutions	Section 3.3 and Appendix B (Exhibit B-3)
4) Find Toxic Endpoint	
For Liquids/Mixtures	Appendix B (Exhibit B-2)
For Solutions	Appendix B (Exhibit B-3)
5) Determine Reference Table and Distance	
Dense or Neutrally Buoyant Plume (liquids)	Chapter 4 and Appendix B (Exhibit B-2)
Dense or Neutrally Buoyant Plume (solutions)	Chapter 4 and Appendix B (Exhibit B-3)
Chemical Specific Table (aqueous ammonia)	Chapter 4
Urban or Rural	Section 2.1 and Chapter 4
Release Duration (liquids)	Section 3.2.2
Release Duration (solutions)	Chapter 4

Roadmap to Offsite Consequence Analysis Guidance by Type of Chemical (continued)

Type of Chemical and Release Scenario	**Applicable Sections and Appendices**
Toxic Liquid	
Alternative Scenario	
1) Define Alternative Scenario	Chapter 6
2) Select Scenario	Chapter 6
3) Calculate Release Rates	Section 7.2
Unmitigated (from tanks and pipes)	Section 7.2.1
Active or Passive Mitigation	Section 7.2.2
Release at Ambient Temperature	Section 7.2.3
Release at Elevated Temperature	Section 7.2.3
Release of Solution	Sections 7.2.4 and 3.3 and Appendix B (Exhibit B-3)
4) Find Toxic Endpoint	
For Liquids/Mixtures	Appendix B (Exhibit B-2)
For Solutions	Appendix B (Exhibit B-3)
5) Determine Reference Table and Distance	
Dense or Neutrally Buoyant Plume (liquids/mixtures)	Chapter 8 and Appendix B (Exhibit B-2)
Dense or Neutrally Buoyant Plume (solutions)	Chapter 8 and Appendix B (Exhibit B-3)
Chemical-Specific Table (aqueous ammonia)	Chapter 8
Urban or Rural	Section 2.1 and Chapter 8
Release Duration (liquids/mixtures)	Section 7.2
Release Duration (solutions)	Chapter 8

Roadmap to Offsite Consequence Analysis Guidance by Type of Chemical (continued)

Type of Chemical and Release Scenario	Applicable Sections and Appendices
Flammable Substance	
Worst-Case Scenario	
1) Define Worst Case	Sections 5.1 and 2.1
2) Select Scenario	Sections 5.1, 2.2, and 2.3
3) Determine Distance to Overpressure Endpoint	
For Pure Flammable Substances	Section 5.1
For Flammable Mixtures	Section 5.2
Alternative Scenario	
1) Define Alternative Scenario	Chapter 6
2) Select Scenario	Chapter 6
3) For Vapor Cloud Fires	
Calculate Release Rates (gases)	Section 9.1 and Appendix C (Exhibit C-2)
Calculate Release Rates (liquids)	Section 9.2 and Appendix C (Exhibit C-3)
Find Lower Flammability Limit (gases)	Appendix C (Exhibit C-2)
Find Lower Flammability Limit (liquids)	Appendix C (Exhibit C-3)
Dense or Neutrally Buoyant (gases)	Appendix C (Exhibit C-2)
Dense or Neutrally Buoyant (liquids)	Appendix C (Exhibit C-3)
Urban or Rural	Section 10.1
Release Duration	Section 10.1
Determine Distance	Section 10.1
4) For Pool Fires	Section 10.2 and Appendix C (Exhibit C-3)
5) For BLEVEs	Section 10.3
6) For Vapor Cloud Explosions	Section 10.4

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1 INTRODUCTION

1.1 Purpose of this Guidance

This document provides guidance on how to conduct the offsite consequence analyses for Risk Management Programs required under the Clean Air Act (CAA). Section 112(r)(7) of the CAA directed the U.S. Environmental Protection Agency (EPA) to issue regulations requiring facilities with large quantities of very hazardous chemicals to prepare and implement programs to prevent the accidental release of those chemicals and to mitigate the consequences of any releases that do occur. EPA issued that rule, "Chemical Accident Prevention Provisions" on June 20, 1996. The rule is codified at part 68 of Title 40 of the Code of Federal Regulations (CFR). If you handle, manufacture, use, or store any of the toxic or flammable substances listed in 40 CFR 68.130 above the specified threshold quantities in a process, you are required to develop and implement a risk management program under part 68 of 40 CFR. The rule applies to a wide variety of facilities that handle, manufacture, store, or use toxic substances, including chlorine and ammonia, and highly flammable substances, such as propane. If you are not sure whether you are subject to the rule, you should review the rule and Chapters 1 and 2 of EPA's *General Guidance for Risk Management Programs (40 CFR part 68),* available from EPA at www.epa.gov/emergencies/rmp.

If you are subject to the rule, you are required to conduct an offsite consequence analysis to provide information to the state, local, and federal governments and the public about the potential consequences of an accidental chemical release. The offsite consequence analysis consists of two elements:

- A worst-case release scenario, and
- Alternative release scenarios.

To simplify the analysis and ensure comparability, EPA has defined the worst-case scenario as the release of the largest quantity of a regulated substance from a single vessel or process line failure that results in the greatest distance to an endpoint. In broad terms, the distance to the endpoint is the distance a toxic vapor cloud, heat from a fire, or blast waves from an explosion will travel before dissipating to the point that serious injuries from short-term exposures will no longer occur. Endpoints for regulated substances are specified in 40 CFR 68.22(a) and Appendix A of part 68 and are presented in Appendices B and C of this guidance.

Alternative release scenarios are scenarios that are more likely to occur than the worst-case scenario and that will reach an endpoint offsite, unless no such scenario exists. Within these two parameters, you have flexibility to choose alternative release scenarios that are appropriate for your site. The rule, in 40 CFR 68.28 (b)(2), and the *General Guidance for Risk Management Programs (40 CFR part 68)*, Chapter 4, provide examples of alternative release scenarios that you should consider when conducting the offsite consequence analysis.

RMP*Comp™

To assist those using this guidance, the National Oceanic and Atmospheric Administration (NOAA) and EPA have developed a software program, RMP*Comp™, that performs the calculations described in this document. This software can be downloaded from the EPA/OEM website at www.epa.gov/emergencies/rmp.

This guidance document provides a simple methodology for conducting offsite consequence analyses. You may use simple equations to estimate release rates and reference tables to determine distances to the endpoint of concern. This guidance provides generic reference tables of distances, applicable to most of the regulated toxic substances, and chemical-specific tables for ammonia, chlorine, and sulfur dioxide. This guidance also provides reference tables of distances for consequences of fires and explosions of flammable substances. In some cases, the rule allows users of this document to adopt generic assumptions rather than the site-specific data required if another model is employed (see Exhibit 1).

The methodology and reference tables of distances presented here are optional. You are not required to use this guidance. You may use publicly available or proprietary air dispersion models to do your offsite consequence analysis, subject to certain conditions. If you choose to use models instead of this guidance, you should review the rule and Chapter 4 of the General Guidance for Risk Management Programs, which outline required conditions for use of models. In selected example analyses, this document presents the results of some models to provide a basis for comparison. It also indicates certain conditions of a release that may warrant more sophisticated modeling than is represented here. However, this guidance does not discuss the procedures to follow when using models; if you choose to use models, you should consult the appropriate references or instructions for those models.

This guidance provides distances to endpoints for toxic substances that range from 0.1 miles to 25 miles. Other models may not project distances this far (and some may project even longer distances). One commonly used model, ALOHA, has an artificial distance cutoff of 6 miles (i.e., any scenario which would result in an endpoint distance beyond 6 miles is reported as “greater than 6 miles”). Although you may use ALOHA if it is appropriate for the substance and scenario, you should consider choosing a different model if the scenario would normally result in an endpoint distance significantly greater than 6 miles. Otherwise, you should be prepared to explain the difference between your results and those in this guidance or other commonly used models. Also, you should be aware that the RMP*eSubmit system accepts only numerical entries (i.e., it will not accept a “greater than” distance). If you do enter a distance in RMP*eSubmit that is the result of a particular model’s maximum distance cutoff (including the maximum distance cutoff in this guidance), you can explain this in the executive summary of your RMP.

Exhibit 1
Required Parameters for Modeling (40 CFR 68.22)

WORST CASE	ALTERNATIVE SCENARIO
Endpoints (§68.22(a))	
Endpoints for toxic substances are specified in part 68 Appendix A.	Endpoints for toxic substances are specified in part 68 Appendix A.
For flammable substances, endpoint is overpressure of 1 pound per square inch (psi) for vapor cloud explosions.	For flammable substances, endpoint is: ✦Overpressure of 1 psi for vapor cloud explosions, or ✦Radiant heat level of 5 kilowatts per square meter (kW/m^2) for 40 seconds for heat from fires (or equivalent dose), or ✦Lower flammability limit (LFL) as specified in NFPA documents or other generally recognized sources.
Wind speed/stability (§68.22(b))	
This guidance assumes 1.5 meters per second and F stability. For other models, use wind speed of 1.5 meters per second and F stability class unless you can demonstrate that local meteorological data applicable to the site show a higher minimum wind speed or less stable atmosphere at all times during the previous three years. If you can so demonstrate, these minimums may be used for site-specific modeling.	This guidance assumes wind speed of 3 meters per second and D stability. For other models, you must use typical meteorological conditions for your site.
Ambient temperature/humidity (§68.22(c))	
This guidance assumes 25°C (77°F) and 50 percent humidity. For other models for toxic substances, you must use the highest daily maximum temperature and average humidity for the site during the past three years.	This guidance assumes 25°C and 50 percent humidity. For other models, you may use average temperature/humidity data gathered at the site or at a local meteorological station.
Height of release (§68.22(d))	
For toxic substances, you must assume a ground level release.	This guidance assumes a ground-level release. For other models, release height may be determined by the release scenario.
Surface roughness (§68.22(e))	
Use urban (obstructed terrain) or rural (flat terrain) topography, as appropriate.	Use urban (obstructed terrain) or rural (flat terrain) topography, as appropriate.
Dense or neutrally buoyant gases (§68.22(f))	
Tables or models used for dispersion of regulated toxic substances must appropriately account for gas density. If you use this guidance, see Tables 1-4 for neutrally buoyant gases and Tables 5-8 for dense gases, or Tables 9-12 for specific chemicals.	Tables or models used for dispersion must appropriately account for gas density. If you use this guidance, see Tables 14-1 7 for neutrally buoyant gases and Tables 18-21 for dense gases, or Tables 22-25 for specific chemicals.
Temperature of released substance (§68.22(g))	
You must consider liquids (other than gases liquefied by refrigeration) to be released at the highest daily maximum temperature, from data for the previous three years, or at process temperature, whichever is higher. Assume gases liquefied by refrigeration at atmospheric pressure to be released at their boiling points. This guidance provides factors for estimation of release rates at 25°C or the boiling point of the released substance, and also provides temperature correction factors.	Substances may be considered to be released at a process or ambient temperature that is appropriate for the scenario. This guidance provides factors for estimation of release rates at 25 °C or the boiling point of the released substance, and also provides temperature correction factors.

1.2 This Guidance Compared to Other Models

Results obtained using the methods in this document are expected to be conservative (i.e., they will generally, but not always, overestimate the distance to endpoints). The chemical-specific reference tables in this guidance provide less conservative results than the generic reference tables, because the chemical-specific tables were derived using more realistic assumptions and considering more factors.

Complex models that can account for many site-specific factors may give less conservative estimates of offsite consequences than the simple methods in this guidance. This is particularly true for alternative scenarios, for which EPA has not specified many assumptions. However, complex models may be expensive and require considerable expertise to use; this guidance is designed to be simple and straightforward. You will need to consider these tradeoffs in deciding how to carry out your required consequence analyses. Appendix A provides information on references for some other methods of analysis; these references do not include all models that you may use for these analyses. You will find that modeling results will sometimes vary considerably from model to model.

1.3 Number of Scenarios to Analyze

The number and type of analyses you must perform depend on the “Program” level of each of your processes. The rule defines three Program levels. Processes are eligible for Program 1 if, among other criteria, there are no public receptors within the distance to the endpoint for the worst-case scenario. Because no public receptors would be affected by the worst-case release, no further modeling is required for these processes. For processes subject to Program 2 or Program 3, both worst-case release scenarios and alternative release scenarios are required. To determine the Program level of your processes, consult 40 CFR 68.10(b), (c), and (d), or Chapter 2 of EPA’s *General Guidance for Risk Management Programs (40 CFR part 68)*.

Once you have determined the Program level of your processes, you are required to conduct the following offsite consequence analyses:

- One worst-case release scenario for each Program 1 process;
- One worst-case release scenario to represent all regulated toxic substances in Program 2 and Program 3 processes;
- One worst-case release scenario to represent all regulated flammable substances in Program 2 and Program 3 processes;
- One alternative release scenario for each regulated toxic substance in Program 2 and Program 3 processes; and
- One alternative release scenario to represent all regulated flammable substances in Program 2 and Program 3 processes.

NOTE: You may need to analyze additional worst-case scenarios if release scenarios for regulated flammable or toxic substances from other covered processes at your facility would affect different public receptors. For example, worst-case release scenarios for storage tanks at opposite ends of your facility may potentially reach different areas where people could be affected. In that case, you will have to conduct analyses of and report on both releases.

GUIDANCE FOR INDUSTRY-SPECIFIC RISK MANAGEMENT PROGRAMS

EPA developed guidance for industry-specific risk management programs for the following industries:

- ✦ Propane storage facilities
- ✦ Chemical distributors
- ✦ Waste water treatment plants
- ✦ Warehouses
- ✦ Ammonia refrigeration
- ✦ Small propane retailers & users

Industry-specific guidance is either appended to this guidance or is contained in stand-alone documents that you can obtain from EPA's website at www.epa.gov/emergencies/rmp. If an industry-specific appendix or guidance document exists for your process(es), you should consider using it because it will provide more information that is specific to your process(es), including dispersion modeling and prevention program elements.

1.4 Modeling Issues

The consequences of an accidental chemical release depend on the conditions of the release and the conditions at the site at the time of the release. This guidance provides reference tables of distances, based on results of modeling, for estimation of worst-case and alternative scenario consequence distances. Worst-case consequence distances obtained using these tables are not intended to be precise predictions of the exact distances that might be reached in the event of an actual accidental release. For this guidance, worst-case distances are based on modeling results assuming the combination of worst-case conditions required by the rule. This combination of conditions occurs rarely and is unlikely to persist for very long. To derive the alternative scenario distances, less conservative assumptions were used for modeling; these assumptions were chosen to represent more likely conditions than the worst-case assumptions. Nevertheless, in an actual accidental release, the conditions may be very different. Users of this guidance should remember that the results derived from the methods presented here are rough estimates of potential consequence distances. Other models may give different results; the same model also may give different results if different assumptions about release conditions and/or site conditions are used.

The reference tables of distances in this guidance provide results to a maximum distance of 25 miles. EPA recognizes that modeling results at such large distances are highly uncertain. Almost no experimental data or data from accidents are available at such large distances to compare to modeling results. Most data are reported for distances well under 10 miles. Modeling uncertainties are likely to increase as distances increase because conditions (e.g., atmospheric stability, wind speed, surface roughness) are not likely to remain constant over large distances. Thus, at large distances (e.g., greater than about 6 to 10 miles), the modeling results should be viewed as very coarse estimates of consequence distances. EPA believes, however, that the results, even at large distances, can provide useful information for comparison purposes. For example, Local Emergency Planning Committees (LEPCs) and other local agencies can use relative differences in distance to aid in establishing chemical accident prevention and preparedness priorities among facilities in a community. Since worst-case scenario distances are based on modeling conditions that are unlikely to occur, and since modeling of any scenario that results in large distances is very uncertain, EPA strongly urges communities and industry not to rely on the results of worst-case modeling or any modeling that results in very large toxic endpoint distances in emergency planning and response activities. Results of alternative scenario models are apt to provide a more reasonable basis for planning and response.

1.5 Steps for Performing the Analysis

This Chapter presents the steps you should follow in using this guidance to carry out an offsite consequence analysis. Before carrying out one or more worst-case and/or alternative release analyses, you will need to obtain several pieces of information about the regulated substances you have, the area surrounding your site, and typical meteorological conditions:

- Determine whether each regulated substance is toxic or flammable, as indicated in the rule or Appendices B and C of this guidance.

- For the worst-case analysis, determine the quantity of each substance held in the largest single vessel or pipe.

- Collect information about any passive or active (alternative scenarios only) release mitigation measures that are in place for each substance.

- For toxic substances, determine whether the substance is stored as a gas, as a liquid, as a gas liquefied by refrigeration, or as a gas liquefied under pressure. For alternative scenarios involving a vapor cloud fire, you may also need this information for flammable substances.

- For toxic liquids, determine the highest daily maximum temperature of the liquid, based on data for the previous three years, or process temperature, whichever is higher.

- For toxic substances, determine whether the substance behaves as a dense or neutrally buoyant gas or vapor (see Appendix B, Exhibits B-1 and B-2). For alternative scenarios involving a vapor cloud fire, you will also need this information for flammable substances (see Appendix C, Exhibits C-2 and C-3).

- For toxic substances, determine whether the topography (surface roughness) of your site is either urban or rural as thse terms are defined by the rule (see 40 CFR 68.22(e)). For alternative scenarios involving a vapor cloud fire, you will also need this information for flammable substances.

After you have gathered the above information, you will need to take three steps (except for flammable worst-case releases):

(1) Select a scenario;

(2) Determine the release or volatilization rate; and
(3) Determine the distance to the endpoint.

For flammable worst-case scenarios, only steps one and three are needed. Sections 1.5.1 through 1.5.6 outline the procedures to perform the analyses. In addition to basic procedures, these sections provide references to sections of this guidance where you will find detailed instructions on carrying out the applicable portion of the analysis. Sections 1.5.1 through 1.5.3 below provide basic steps to analyze worst-case scenarios for toxic gases, toxic liquids, and flammable substances. Sections 1.5.4 through 1.5.6 provide basic steps for alternative scenario analysis. Appendix E of this document provides worksheets that may help you to perform the analyses.

1.5.1 Worst-Case Analysis for Toxic Gases

To conduct worst-case analyses for toxic gases, including toxic gases liquefied by pressurization (see Appendix E, Worksheet 1, for a worksheet that can be used in carrying out this analysis):

Step 1: Determine worst-case scenario. Identify the toxic gas, quantity, and worst-case release scenario, as defined by the rule (Chapter 2).

Step 2: Determine release rate. Estimate the release rate for the toxic gas, using the parameters required by the rule. This guidance provides methods for estimating the release rate for:

- Unmitigated releases (Section 3.1.1).
- Releases with passive mitigation (Section 3.1.2).

Step 3: Determine distance to endpoint. Estimate the worst-case consequence distance based on the release rate and toxic endpoint (defined by the rule) (Chapter 4). This guidance provides reference tables of distances (Reference Tables 1-12). Select the appropriate reference table based on the density of the released substance, the topography of your site, and the duration of the release (always 10 minutes for gas releases). Estimate distance to the endpoint from the appropriate table.

1.5.2 Worst-Case Analysis for Toxic Liquids

To conduct worst-case analyses for toxic substances that are liquids at ambient conditions or for toxic gases that are liquefied by refrigeration alone (see Appendix E, Worksheet 2, for a worksheet for this analysis):

Step 1: Determine worst-case scenario. Identify the toxic liquid, quantity, and worst-case release scenario, as defined by the rule (Chapter 2). To estimate the quantity of liquid released from piping, see Section 3.2.1.

Step 2: Determine release rate. Estimate the volatilization rate for the toxic liquid and the duration of the release, using the parameters required by the rule. This guidance provides methods for estimating the pool evaporation rate for:

- Gases liquefied by refrigeration alone (Sections 3.1.3 and 3.2.3).
- Unmitigated releases (Section 3.2.2).
- Releases with passive mitigation (Section 3.2.3).
- Releases at ambient or elevated temperature (Sections 3.2.2, 3.2.3, and 3.2.5).
- Releases of mixtures of toxic liquids (Section 3.2.4).
- Releases of common water solutions of regulated substances and of oleum (Section 3.3).

Step 3: Determine distance to endpoint. Estimate the worst-case consequence distance based on the release rate and toxic endpoint (defined by the rule) (Chapter 4). This guidance provides reference tables of distances (Reference Tables 1-12). Select the appropriate reference table based on the density of the released substance, the topography of your site, and the duration of the release. Estimate distance to the endpoint from the appropriate table.

1.5.3 Worst-Case Analysis for Flammable Substances

To conduct worst-case analyses for all regulated flammable substances (i.e., gases and liquids) (see Appendix E, Worksheet 3, for a worksheet for this analysis):

Step 1: Determine worst-case scenario. Identify the appropriate flammable substance, quantity, and worst-case scenario, as defined by the rule (Chapter 2).

Step 2: Determine distance to endpoint. Estimate the distance to the required overpressure endpoint of 1 psi for a vapor cloud explosion of the flammable substance, using the assumptions required by the rule (Chapter 5). This guidance provides a reference table of distances (Reference Table 13) for worst-case vapor cloud explosions. Estimate the distance to the endpoint from the quantity released and the table.

1.5.4 Alternative Scenario Analysis for Toxic Gases

To conduct alternative release scenario analyses for toxic gases, including toxic gases liquefied by pressurization (see Appendix E, Worksheet 4, for a worksheet for this analysis):

Step 1: Select alternative scenario. Choose an appropriate alternative release scenario for the toxic gas. This scenario should have the potential for offsite impacts unless no such scenario exists. (Chapter 6).

Step 2: Determine release rate. Estimate the release rate and duration of the release of the toxic gas, based on your scenario and site-specific conditions. This guidance provides methods for:

- Unmitigated releases (Section 7.1.1).
- Releases with active or passive mitigation (Section 7.1.2).

Step 3: Determine distance to endpoint. Estimate the alternative scenario distance based on the release rate and toxic endpoint (Chapter 8). This guidance provides reference tables of distances (Reference Tables 14-25) for alternative scenarios for toxic substances. Select the appropriate reference table based on the density of the released substance, the topography of your site, and the duration of the release. Estimate distance to the endpoint from the appropriate table.

1.5.5 Alternative Scenario Analysis for Toxic Liquids

To conduct alternative release scenario analyses for toxic substances that are liquids at ambient conditions or for toxic gases that are liquefied by refrigeration alone (see Appendix E, Worksheet 5, for a worksheet for this analysis):

Step 1: Select alternative scenario. Choose an appropriate alternative release scenario and release quantity for the toxic liquid. This scenario should have the potential for offsite impacts (Chapter 6), unless no such scenario exists.

Step 2: Determine release rate. Estimate the release rate and duration of the release of the toxic liquid, based on your scenario and site-specific conditions. This guidance provides methods to estimate the liquid release rate and quantity of liquid released for:

- Unmitigated liquid releases (Section 7.2.1).
- Mitigated liquid releases (Section 7.2.2).

The released liquid is assumed to form a pool. This guidance provides methods to estimate the pool evaporation rate and release duration for:

- Unmitigated releases (Section 7.2.3).
- Releases with passive or active mitigation (Section 7.2.3).
- Releases at ambient or elevated temperature (Sections 7.2.3).
- Releases of common water solutions of regulated substances and of oleum (Section 7.2.4).

Step 3: Determine distance to endpoint. Estimate the alternative scenario distance based on the release rate and toxic endpoint (Chapter 8). This guidance provides reference tables of distances (Reference Tables 14-25) for alternative scenarios for toxic substances. Select the appropriate reference table based on the density of the released substance, the topography of your site, and the duration of the release. Estimate distance to the endpoint from the appropriate table.

1.5.6 Alternative Scenario Analysis for Flammable Substances

To conduct alternative release scenario analyses for all regulated flammable substances (i.e., gases and liquids) (see Appendix E, Worksheet 6, for a worksheet for this analysis):

Step 1: Select alternative scenario. Identify the flammable substance, and choose the quantity and type of event for the alternative scenario consequence analysis (Chapter 6).

Step 2: Determine release rate. Estimate the release rate to air of the flammable gas or liquid, if the scenario involves a vapor cloud fire (Section 9.1 for flammable gases, Section 9.2 for flammable liquids).

Step 3: Determine distance to endpoint. Estimate the distance to the appropriate endpoint (defined by the rule). This guidance provides methods for:

- Vapor cloud fires (Section 10.1 and Reference Tables 26-29); select the appropriate reference table based on the density of the released substance and the topography of your site, and estimate distance to the endpoint from the appropriate table.
- Pool fires (Section 10.2); estimate distance from the equation and chemical-specific factors provided.
- BLEVEs (Section 10.3 and Reference Table 30); estimate distance from the quantity of flammable substance and the table.
- Vapor cloud explosions (Section 10.4 and Reference Table 13); estimate quantity in the cloud from the equation and chemical-specific factors provided, and estimate distance from the quantity, the table, and a factor provided for alternative scenarios.

1.6 Additional Sources of Information

EPA's risk management program requirements may be found at 40 CFR part 68. The relevant sections were published in the Federal Register on January 31, 1994 (59 FR 4478) and June 20, 1996 (61 FR 31667). Final rules amending the list of substances and thresholds were published on August 25, 1997 (62 FR 45130) and January 6, 1998 (63 FR 640). A consolidated copy of these regulations is available in Appendix F.

EPA is working with industry and local, state, and federal government agencies to assist sources in complying with these requirements. For more information, refer to the General Guidance for Risk Management Programs Appendix E (Technical Assistance). Appendices C and D of the General Guidance also provide points of contact for EPA and Occupational Safety and Health Administration (OSHA) at the state and federal levels for your questions. Your LEPC also can be a valuable resource.

Finally, if you have access to the Internet, EPA has made copies of the rules, fact sheets, and other related materials available from EPA's website at www.epa.gov/emergencies/rmp. Please check the site regularly, as additional materials are posted when they become available. If you do not have access to the Internet, you can call EPA's hotline at (800) 424-9346.

2 DETERMINING WORST-CASE SCENARIOS

In Chapter 2

- 2.1 EPA's definition of a worst-case scenario.
- 2.2 How to determine the quantity released.
- 2.3 How to identify the appropriate worst-case scenario.

2.1 Definition of Worst-Case Scenario

A worst-case release is defined as:

- The release of the largest quantity of a regulated substance from a vessel or process line failure, and
- The release that results in the greatest distance to the endpoint for the regulated toxic or flammable substance.

You may take administrative controls into account when determining the largest quantity. Administrative controls are written procedures that limit the quantity of a substance that can be stored or processed in a vessel or pipe at any one time or, alternatively, procedures that allow the vessel or pipe to occasionally store larger than usual quantities (e.g., during shutdown or turnaround). Endpoints for regulated substances are specified in the rule (40 CFR 68.22(a), and Appendix A to part 68 for toxic substances). For the worst-case analysis, you do not need to consider the possible causes of the worst-case release or the probability that such a release might occur; the release is simply assumed to take place. You must assume all releases take place at ground level for the worst-case analysis.

This guidance assumes meteorological conditions for the worst-case scenario of atmospheric stability class F (stable atmosphere) and wind speed 1.5 meters per second (3.4 miles per hour). Ambient air temperature for this guidance is 25 °C (77 °F). If you use this guidance, you may assume this ambient temperature for the worst case, even if the maximum temperature at your site in the last three years is higher.

The rule provides two choices for topography, urban and rural. EPA (40 CFR 68.22(e)) has defined urban as many obstacles in the immediate area, where obstacles include buildings or trees. Rural, by EPA's definition, means there are no buildings in the immediate area, and the terrain is generally flat and unobstructed. Thus, if your site is located in an area with few buildings or other obstructions (e.g., hills, trees), you should assume open (rural) conditions. If your site is in an area with many obstructions, even if it is in a remote location that would not usually be considered urban, you should assume urban conditions.

Toxic Gases

Toxic gases include all regulated toxic substances that are gases at ambient temperature (25 °C, 77 °F), with the exception of gases liquefied by refrigeration under atmospheric pressure and released into diked areas. For the worst-case consequence analysis, you must assume that a gaseous release of the total quantity occurs in 10 minutes. You may take passive mitigation measures (e.g., enclosure) into account in the analysis of the worst-case scenario.

Gases liquefied by refrigeration alone and released into diked areas may be modeled as liquids at their boiling points and assumed to be released from a pool by evaporation (40 CFR 68.25(c)(2)). Gases liquefied by refrigeration alone that would form a pool one centimeter or less in depth upon release must be modeled as gases. (Modeling indicates that pools one centimeter or less deep formed by gases liquefied by refrigeration would completely evaporate in 10 minutes or less, giving a release rate that is equal to or greater than the worst-case release rate for a gaseous release. In this case, therefore, it is appropriate to treat these substances as gases for the worst-case analysis.)

Endpoints for consequence analysis for regulated toxic substances are specified in the rule (40 CFR part 68, Appendix A). Exhibit B-1 of Appendix B lists the endpoint for each toxic gas. These endpoints are used for air dispersion modeling to estimate the consequence distance.

Toxic Liquids

For toxic liquids, you must assume that the total quantity in a vessel is spilled. This guidance assumes the spill takes place onto a flat, non-absorbing surface. For toxic liquids carried in pipelines, the quantity that might be released from the pipeline is assumed to form a pool. You may take passive mitigation systems (e.g., dikes) into account in consequence analysis. The total quantity spilled is assumed to spread instantaneously to a depth of one centimeter (0.033 foot or 0.39 inch) in an undiked area or to cover a diked area instantaneously. The temperature of the released liquid must be the highest daily maximum temperature occurring in the past three years or the temperature of the substance in the vessel, whichever is higher (40 CFR 68.25(d)(2)). The release rate to air is estimated as the rate of evaporation from the pool. If liquids at your site might be spilled onto a surface that could rapidly absorb the spilled liquid (e.g., porous soil), the methods presented in this guidance may greatly overestimate the consequences of a release. Consider using another method in such a case.

Exhibit B-2 of Appendix B presents the endpoint for air dispersion modeling for each regulated toxic liquid (the endpoints are specified in 40 CFR part 68, Appendix A).

Flammable Substances

For all regulated flammable substances, you must assume that the worst-case release results in a vapor cloud containing the total quantity of the substance that could be released from a vessel or pipeline. For the worst-case consequence analysis, you must assume the vapor cloud detonates. If you use a TNT-equivalent method for your analysis, you must assume a 10 percent yield factor.

The rule specifies the endpoint for the consequence analysis of a vapor cloud explosion of a regulated flammable substance as an overpressure of 1 pound per square inch (psi). This endpoint was chosen as the threshold for potential serious injuries to people as a result of property damage caused by an explosion (e.g., injuries from flying glass from shattered windows or falling debris from damaged houses). (See Appendix D, Section D.5 for additional information on this endpoint.)

Effect of Required Assumptions

The assumptions required for the worst-case analysis are intended to provide conservative worst-case consequence distances, rather than accurate predictions of the potential consequences of a release; that is, in most cases your results will overestimate the effects of a release. In certain cases, actual conditions could be even more severe than these worst-case assumptions (e.g., very high process temperature, high process pressure, or unusual weather conditions, such as temperature inversions); in such cases, your results might underestimate the effects. However, the required assumptions generally are expected to give conservative results.

2.2 Determination of Quantity for the Worst-Case Scenario

EPA has defined a worst-case release as the release of the largest quantity of a regulated substance from a vessel or process line failure that results in the greatest distance to a specified endpoint. For substances in vessels, you must assume release of the largest amount in a single vessel. For substances in pipes, you must assume release of the largest amount in a pipe. The largest quantity should be determined taking into account administrative controls rather than absolute capacity of the vessel or pipe. Administrative controls are written procedures that limit the quantity of a substance that can be stored or processed in a vessel or pipe at any one time, or, alternatively, occasionally allow a vessel or pipe to store larger than usual quantities (e.g., during turnaround).

2.3 Selecting Worst-Case Scenarios

Under part 68, a worst-case release scenario analysis must be completed for all covered processes, regardless of program level. The number of worst-case scenarios you must analyze depends on several factors. You need to consider only the hazard (toxicity or flammability) for which a substance is regulated (i.e., even if a regulated toxic substance is also flammable, you only need to consider toxicity in your analysis; even if a regulated flammable substance is also toxic, you only need to consider flammability).

For every Program 1 process, you must report the worst-case scenario with the greatest distance to an endpoint. If a Program 1 process has more than one regulated substance held above its threshold, you must determine which substance produces the greatest distance to its endpoint and report on that substance. If a Program 1 process has both regulated toxics and flammables above their thresholds, you still report only the one scenario that produces the greatest distance to the endpoint. The process is eligible for Program 1 if there are no public receptors within the distance to an endpoint of the worst-case scenario for the process and the other Program 1 criteria are met. For Program 2 or Program 3 processes, you must analyze and report on one worst-case analysis representing all toxic regulated substances present above the threshold quantity and one worst-case analysis representing all flammable regulated substances present above the threshold quantity. You may need to submit an additional worst-case analysis if a worst-case release from elsewhere at the source would potentially affect public receptors different from those affected by the initial worst-case scenario(s).

If you have more than one regulated substance in a class, the substance chosen for the consequence analysis for each hazard for Program 2 and 3 processes should be the substance that has the potential to cause the greatest offsite consequences. Choosing the toxic regulated substance that might lead to the greatest offsite consequences may require a screening analysis of the toxic regulated substances on site, because the potential consequences are dependent on a number of factors, including quantity, toxicity, and volatility.

Location (distance to the fenceline) and conditions of processing or storage (e.g., a high temperature process) also should be considered. In selecting the worst-case scenario, you may want to consider the following points:

- Toxic gases with low toxic endpoints are likely to give the greatest distances to the endpoint for a given release quantity; a toxic gas would be a likely choice for the worst-case analysis required for Program 2 and 3 processes (processes containing toxic gases are unlikely to be eligible for Program 1).

- Volatile, highly toxic liquids (i.e., liquids with high ambient vapor pressure and low toxic endpoints) also are likely to give large distances to the endpoint (processes containing this type of substance are unlikely to be eligible for Program 1).

- Toxic liquids with relatively low volatility (low vapor pressure) and low toxicity (large toxic endpoint) in ambient temperature processes may give fairly small distances to the endpoint; you probably would not choose such substances for the worst-case analysis for Program 2 or 3 if you have other regulated toxics, but you may want to consider carrying out a worst-case analysis to demonstrate potential Program 1 eligibility.

For flammable substances, you must consider the consequences of a vapor cloud explosion in the analysis. The severity of the consequences of a vapor cloud explosion depends on the quantity of the released substance in the vapor cloud, its heat of combustion, and other factors that are assumed to be the same for all flammable substances. In most cases, the analysis probably should be based on the regulated flammable substance present in the greatest quantity; however, a substance with a high heat of combustion may have a greater potential offsite impact than a larger quantity of a substance with a lower heat of combustion. In some cases, a regulated flammable substance that is close to the fenceline might have a greater potential offsite impact than a larger quantity farther from the fenceline.

You are likely to estimate smaller worst-case distances for flammable substances than for similar quantities of most toxic substances. Because the distance to the endpoint may be relatively small, you may find it worthwhile to carry out a worst-case analysis for each process containing flammable substances to demonstrate potential eligibility for Program 1, unless there are public receptors close to the process.

3 RELEASE RATES FOR TOXIC SUBSTANCES

In Chapter 3

- 3.1 Estimation of worst-case release rates for toxic gases.
- 3.2 Estimation of release rates for toxic liquids evaporating from pools.
- 3.3 Estimation of release rates for common water solutions of toxic substances and for oleum.

This chapter describes simple methods for estimating release rates for regulated toxic substances for the worst-case scenario. Simple release rate equations are provided, and factors to be used in these equations are provided (in Appendix B) for each regulated substance. The estimated release rates may be used to estimate dispersion distances to the toxic endpoint for regulated toxic gases and liquids, as discussed in Chapter 4.

3.1 Release Rates for Toxic Gases

In Section 3.1

- 3.1.1 Method to estimate worst-case release rates for unmitigated releases (releases directly to the air) of toxic gas.
- 3.1.2 Method to estimate worst-case release rates for toxic gas in enclosures (passive mitigation).
- 3.1.3 Method to estimate worst-case release rates for liquefied refrigerated toxic gases in diked areas (as toxic liquid - see Section 3.2.3), including consideration of the duration of the release.

Regulated substances that are gases at ambient temperature (25 °C, 77 °F) should be considered gases for consequence analysis, with the exception of gases liquefied by refrigeration at atmospheric pressure. Gases liquefied under pressure should be treated as gases. Gases liquefied by refrigeration alone and released into diked areas may be treated as liquids at their boiling points if they would form a pool upon release that is more than one centimeter (0.033 foot) in depth. Gases liquefied by refrigeration alone that would form a pool one centimeter (0.033 foot) or less in depth should be treated as gases. Modeling shows that the evaporation rate from such a pool would be equal to or greater than the rate for a toxic gas, which is assumed to be released over 10 minutes; therefore, treating liquefied refrigerated gases as gases rather than liquids in such cases is reasonable. You may consider passive mitigation for gaseous releases and releases of gases liquefied by refrigeration.

3.1.1 Unmitigated Releases of Toxic Gas

If no passive mitigation system is in place, estimate the release rate for the release over a 10-minute period of the largest quantity resulting from a pipe or vessel failure, as required by the rule (40 CFR 68.25(c)). For a release from a vessel, calculate the release rate as follows:

$$QR = \frac{QS}{10} \qquad \textbf{(3-1)}$$

where: QR = Release rate (pounds per minute)
QS = Quantity released (pounds)

Example 1. Gas Release (Diborane)

You have a tank containing 2,500 pounds of diborane gas. Assuming the total quantity in the tank is released over a 10-minute period, the release rate (QR), from Equation 3-1, is:

QR = 2,500 pounds/10 minutes = 250 pounds per minute

3.1.2 Releases of Toxic Gas in Enclosed Space

If a gas is released in an enclosure such as a building or shed, the release rate to the outside air may be lessened considerably. The dynamics of this type of release are complex; however, you may use the simplified method presented here to estimate an approximate release rate to the outside air from a release in an enclosed space. The mitigation factor (i.e., 55 percent) presented in this method assumes that the release occurs in a fully enclosed, non-airtight space that is directly adjacent to the outside air. If you are modeling a release in an interior room that is enclosed within a building, a smaller factor (i.e., more mitigation) may be appropriate. On the other hand, a larger factor (i.e., less mitigation) should be used for a space that has doors or windows that could be open during a release. If any of these special circumstances apply to your site, you may want to consider performing site-specific modeling to determine the appropriate amount of passive mitigation. In addition, you should not incorporate the passive mitigation effect of building enclosures into your modeling if you have reason to believe the enclosure would not withstand the force of the release or if the chemical is handled outside the building (e.g., moved from one building to another building).

For the worst case, assume as before that the largest quantity resulting from a pipe or vessel failure is released over a 10-minute period. Determine the unmitigated worst-case scenario release rate of the gas as the quantity released divided by 10 (Equation 3-1). The release rate from the building will be approximately 55 percent of the worst-case scenario release rate (see Appendix D, Section D.1.2 for the derivation of this factor). Estimate the mitigated release rate as follows:

$$QR = \frac{QS}{10} \times 0.55 \qquad \textbf{(3-2)}$$

where:
QR = Release rate (pounds per minute)
QS = Quantity released (pounds)
0.55 = Mitigation factor (discussed in Appendix D, Section D.1.2)

Example 2. Gas Release in Enclosure (Diborane)

Suppose the diborane gas from Example 1 is released inside a building at the rate of 250 pounds per minute. The mitigated release to the outside air from the building would be:

QR = 250 pounds/minute × 0.55 = 138 pounds per minute

3.1.3 Releases of Liquefied Refrigerated Toxic Gas in Diked Area

If you have a toxic gas that is liquefied by refrigeration alone, and it will be released into an area where it will be contained by dikes to form a pool more than one centimeter (0.033 foot) in depth, you may carry out the worst-case analysis assuming evaporation from a liquid pool at the boiling point of the liquid. If your gas liquefied by refrigeration would form a pool one centimeter (0.033 foot) or less in depth, use the methods described in Section 3.1.1 or 3.1.2 above for the analysis. For a release in a diked area, first compare the diked area to the maximum area of the pool that could be formed. You can use Equation 3-6 in Section 3.2.3 to estimate the maximum size of the pool. Density factors (DF), needed for Equation 3-6, for toxic gases at their boiling points are listed in Exhibit B-1 of Appendix B. If the pool formed by the released liquid would be smaller than the diked area, assume a 10-minute gaseous release, and estimate the release rate as described in Section 3.1.1. If the dikes prevent the liquid from spreading out to form a pool of maximum size (one centimeter in depth), you may use the method described in Section 3.2.3 for mitigated liquid releases to estimate a release rate from a pool at the boiling point of the released substance. Use Equation 3-8 in Section 3.2.3 for the release rate. The Liquid Factor Boiling (LFB) for each toxic gas, needed to use Equation 3-8, is listed in Exhibit B-1 of Appendix B. See the example release rate estimation on the next page.

After you have estimated the release rate, estimate the duration of the vapor release from the pool (the time it will take for the pool to evaporate completely) by dividing the total quantity spilled by the release rate. You need to know the duration of release to choose the appropriate reference table of distances to estimate the consequence distance, as discussed in Section 4. (You do not need to consider the duration of the release for chlorine or sulfur dioxide, liquefied by refrigeration alone. Only one reference table of distances is provided for worst-case releases of each of these substances, and these tables may be used regardless of the release duration. The principal reason for making no distinction between 10-minute and longer releases for the chemical-specific tables is that the differences between the two are small relative to the uncertainties that have been identified.)

Example 3. Mitigated Release of Gases Liquefied by Refrigeration (Chlorine)

You have a refrigerated tank containing 50,000 pounds of liquid chlorine at ambient pressure. A diked area around the chlorine tank of 275 square feet is sufficient to hold all of the spilled liquid chlorine. Once the liquid spills into the dike, it is then assumed to evaporate at its boiling point (-29 °F). The evaporation rate at the boiling point is determined from Equation 3-8. For the calculation, wind speed is assumed to be 1.5 meters per second and the wind speed factor is 1.4, LFB for chlorine (from Exhibit B-1) is 0.19, and A is 275 square feet. The release rate is:

$$QR = 1.4 \times 0.19 \times 275 = 73 \text{ pounds per minute}$$

The duration of the release does not need to be considered for chlorine.

3.2 Release Rates for Toxic Liquids

<u>In Section 3.2</u>

- 3.2.1 Method to estimate the quantity of toxic liquid that could be released from a broken pipe.
- 3.2.2 Method to estimate the release rate of a toxic liquid evaporating from a pool with no mitigation (no dikes or enclosures), including:
  - Releases at ambient temperature (25 °C),
  - Releases at elevated temperature, and
  - Estimation of the duration of the release.
- 3.2.3 Method to estimate the release rate of a toxic liquid evaporating from a pool with passive mitigation, including:
  - Releases in diked areas,
  - Releases into other types of containment, and
  - Releases into buildings.
- 3.2.4 Estimation of release rates for mixtures containing toxic liquids.
- 3.2.5 Method to correct the estimated release rate for liquids released at temperatures between 25 °C and 50 °C.

For the worst-case analysis, the release rate to air for toxic liquids is assumed to be the rate of evaporation from the pool formed by the released liquid. This section provides methods to estimate the evaporation rate. Assume the total quantity in a vessel or the maximum quantity from pipes is released into the pool. Passive mitigation measures (e.g., dikes) may be considered in determining the area of the pool and the release rate. To estimate the consequence distance using this guidance, you must estimate how long it will take for the pool to evaporate (the duration of the release), as well as the release rate, as discussed below.

The rule (40 CFR 68.22(g)) requires you to assume that liquids (other than gases liquefied by refrigeration) are released at the highest maximum daily temperature for the previous three years or at process temperature, whichever is higher. This chapter provides methods to estimate the release rate at 25 °C (77 °F) or at the boiling point, and also provides a method to correct the release rate at 25 °C for releases at temperatures between 25 °C and 50 °C.

The calculation methods provided in this section apply to substances that are liquids under ambient conditions or gases liquefied by refrigeration alone that are released to form pools deeper than one centimeter (see Section 3.1.3 above). You must treat gases liquefied under other conditions (under pressure or a combination of pressure and refrigeration) or gases liquefied by refrigeration alone that would form pools one centimeter or less in depth upon release as gas rather than liquid releases (see Sections 3.1.1 and 3.1.2 above).

3.2.1 Releases of Toxic Liquids from Pipes

To consider a liquid release from a broken pipe, estimate the maximum quantity that could be released assuming that the pipe is full of liquid. To estimate the quantity in the pipe, you need to know the length of the pipe (in feet) and cross-sectional area of the pipe (in square feet). Note also that liquid may be released from both directions at a pipe shear (both in the direction of operational flow and the reverse direction, depending on the location of the shear). Therefore, the length would be the full length of pipe carrying the liquid on the facility grounds. Then, the volume of the liquid in the pipe (in cubic feet) is the length of the pipe times the cross-sectional area. The quantity in the pipe (in pounds) is the volume divided by the Density Factor (DF) times 0.033. (DF values are listed in Appendix B, Exhibit B-2. Density in pounds per cubic foot is equal to 1/(DF times 0.033).) Assume the estimated quantity (in pounds) is released into a pool and use the method and equations described below in Section 3.2.2 (unmitigated releases) or 3.2.3 (releases with passive mitigation) to determine the evaporation rate of the liquid from the pool.

3.2.2 Unmitigated Releases of Toxic Liquids

If no passive mitigation measures are in place, the liquid is assumed to form a pool one centimeter (0.39 inch or 0.033 foot) deep instantaneously. You may calculate the release rate to air from the pool (the evaporation rate) as discussed below for releases at ambient or elevated temperature.

Ambient Temperature

If the liquid is always at ambient temperature, find the Liquid Factor Ambient (LFA) and the Density Factor (DF) in Exhibit B-2 of Appendix B. The LFA and DF apply to liquids at 25 °C; if your ambient temperature is between 25 °C and 50 °C, you may use the method described here and then apply a Temperature Correction Factor (TCF), as discussed in Section 3.2.5 below, to correct the calculated release rate. Calculate the release rate of the liquid at 25 °C from the following equation:

$$QR = QS \times 1.4 \times LFA \times DF \tag{3-3}$$

where: QR = Release rate (pounds per minute)
QS = Quantity released (pounds)
1.4 = Wind speed factor = $1.5^{0.78}$, where 1.5 meters per second (3.4 miles per hour) is the wind speed for the worst case
LFA = Liquid Factor Ambient
DF = Density Factor

Example 4. Unmitigated Liquid Release at Ambient Temperature (Acrylonitrile)

You have a tank containing 20,000 pounds of acrylonitrile at ambient temperature. The total quantity in the tank is spilled onto the ground in an undiked area, forming a pool. Assume the pool spreads out to a depth of one centimeter. The release rate from the pool (QR) is calculated from Equation 3-3. For the calculation, the wind speed is assumed to be 1.5 meters per second and the wind speed factor is 1.4. From Exhibit B-2, Appendix B, LFA for acrylonitrile is 0.018 and DF is 0.61. Then:

$$\text{QR} = 20{,}000 \times 1.4 \times 0.018 \times 0.61 = 307 \text{ pounds per minute}$$

The duration of the release (from Equation 3-5) would be:

$$t = 20{,}000 \text{ pounds}/307 \text{ pounds per minute} = 65 \text{ minutes}$$

Elevated Temperature

If the liquid is at an elevated temperature (above 50 °C or at or close to the boiling point), find the Liquid Factor Boiling (LFB) and the Density Factor (DF) in Exhibit B-2 of Appendix B (see Appendix D, Section D.2.2, for the derivation of these factors). For temperatures up to 50 °C, you may use the method above for ambient temperature and apply the Temperature Correction Factors, as discussed in Section 3.2.5. If the temperature is above 50 °C, or the liquid is at or close to its boiling point, or no Temperature Correction Factors are available for your liquid, calculate the release rate of the liquid from the following equation:

$$QR = QS \times 1.4 \times LFB \times DF \tag{3-4}$$

where: QR = Release rate (pounds per minute)
QS = Quantity released (pounds)
1.4 = Wind speed factor = $1.5^{0.78}$, where 1.5 meters per second (3.4 miles per hour) is the wind speed for the worst case
LFB = Liquid Factor Boiling
DF = Density Factor

Example 5. Unmitigated Release at Elevated Temperature (Acrylonitrile)

You have a tank containing 20,000 pounds of acrylonitrile at an elevated temperature. The total quantity in the tank is spilled onto the ground in an undiked area, forming a pool. Assume the pool spreads out to a depth of one centimeter. The release rate from the pool is calculated from Equation 3-4. For the calculation, the wind speed factor for 1.5 meters per second is 1.4. From Exhibit B-2, Appendix B, LFB for acrylonitrile is 0.11 and DF is 0.61. Then:

QR = 20,000 × 1.4 × 0.11 × 0.61 = 1,880 pounds per minute

The duration of the release (from Equation 3-5) would be:

t = 20,000 pounds/1880 pounds per minute = 11 minutes

Duration of Release

After you have estimated a release rate as described above, determine the duration of the vapor release from the pool (the time it will take for the liquid pool to evaporate completely). If you calculate a corrected release rate for liquids above 25 °C, use the corrected release rate, estimated as discussed in Section 3.2.5 below, to estimate the release duration. To estimate the time in minutes, divide the total quantity released (in pounds) by the release rate (in pounds per minute) as follows:

$$t = \frac{QS}{QR} \qquad \textbf{(3-5)}$$

where:
t = Duration of the release (minutes)
QR = Release rate (pounds per minute) (use release rate corrected for temperature, QR_C, if appropriate)
QS = Quantity released (pounds)

You will use the duration of the vapor release from the pool to decide which table is appropriate for estimating distance, as discussed in Chapter 4 below.

3.2.3 Releases of Toxic Liquids with Passive Mitigation

Diked Areas

If the toxic liquid will be released into an area where it will be contained by dikes, compare the diked area to the maximum area of the pool that could be formed; the smaller of the two areas should be used in determination of the evaporation rate. The maximum area of the pool (assuming a depth of one centimeter) is:

$$A = QS \times DF \qquad \textbf{(3-6)}$$

where:
A = Maximum area of pool (square feet) for depth of one centimeter
QS = Quantity released (pounds)
DF = Density Factor (listed in Exhibit B-2, Appendix B)

Maximum Area Smaller than Diked Area. If the maximum area of the pool is smaller than the diked area, calculate the release rate as described for "no mitigation" above.

Diked Area Smaller than Maximum Area. If the diked area is smaller than the maximum pool area, go to Exhibit B-2 in Appendix B to find the Liquid Factor Ambient (LFA), if the liquid is at ambient temperature, or the Liquid Factor Boiling (LFB), if the liquid is at an elevated temperature. For liquids at temperatures between 25 °C and 50 °C, you may use the method described here and then apply a Temperature Correction Factor (TCF), as discussed in Section 3.2.5 below, to correct the calculated release rate. For gases liquefied by refrigeration alone, use LFB from Exhibit B-1. Calculate the release rate from the diked area as follows for liquids at ambient temperature:

$$QR = 1.4 \times LFA \times A \qquad \textbf{(3-7)}$$

or, for liquids at elevated temperature or for gases liquefied by refrigeration alone:

$$QR = 1.4 \times LFB \times A \qquad \textbf{(3-8)}$$

where:
QR = Release rate (pounds per minute)
1.4 = Wind speed factor = $1.5^{0.78}$, where 1.5 meters per second (3.4 miles per hour) is the wind speed for the worst case
LFA = Liquid Factor Ambient (listed in Exhibit B-2, Appendix B)
LFB = Liquid Factor Boiling (listed in Exhibit B-1 (for liquefied gases) or B-2 (for liquids), Appendix B)
A = Diked area (square feet)

Potential Overflow of Diked Area. In case of a large liquid spill, you also need to consider whether the liquid could overflow the diked area. Follow these steps:

- Determine the volume of the diked area in cubic feet from surface area times depth or length times width times depth (in feet).
- Determine the volume of liquid spilled in cubic feet from QS × DF × 0.033 (DF × 0.033 is equal to 1/density in pounds per cubic foot).
- Compare the volume of the diked area to the volume of liquid spilled. If the volume of liquid is greater than the volume of the diked area:
  - Subtract the volume of the diked area from the total volume spilled to determine the volume that might overflow the diked area.

- Estimate the maximum size of the pool formed by the overflowing liquid (in square feet) by dividing the overflow volume (in cubic feet) by 0.033 (the depth of the pool in feet).
- Add the surface area of the diked area and the area of the pool formed by the overflow to estimate the total pool area (A).
- Estimate the evaporation rate from Equation 3-7 or 3-8 above.

After you have estimated the release rate, estimate the duration of the vapor release from the pool by dividing the total quantity spilled by the release rate (Equation 3-5 above).

Example 6. Mitigated Liquid Release at Ambient Temperature (Bromine)

You have a tank containing 20,000 pounds of bromine at an ambient temperature of 25 °C. Assume that the total quantity in the tank is spilled into a square diked area 10 feet by 10 feet (area 100 square feet). The dike walls are four feet high. The area (A) that would be covered to a depth of 0.033 feet (one centimeter) by the spilled liquid is given by Equation 3-6 as the quantity released (QS) times the Density Factor (DF). From Exhibit B-2, Appendix B, DF for bromine is 0.16. Then:

$$A = 20{,}000 \times 0.16, \text{ or } 3{,}200 \text{ square feet}$$

The diked area is smaller than the maximum pool area. The volume of bromine spilled is 20,000 × 0.16 × 0.033, or 106 cubic feet. The spilled liquid would fill the diked area to a depth of a little more than one foot, well below the top of the wall. You use the diked area to determine the evaporation rate from Equation 3-7. For the calculation, wind speed is 1.5 meters per second, the wind speed factor is 1.4, LFA for bromine (from Exhibit B-2) is 0.073, and A is 100 square feet. The release rate is:

$$QR = 1.4 \times 0.073 \times 100 = 10 \text{ pounds per minute}$$

The maximum duration of the release would be:

$$t = 20{,}000 \text{ pounds}/10 \text{ pounds per minute} = 2{,}000 \text{ minutes}$$

Other Containment

If the toxic liquid will be contained by other means (e.g., enclosed catch basins or trenches), consider the total quantity that could be spilled and estimate the surface area of the released liquid that potentially would be exposed to the air. Look at the dimensions of trenches or other areas where spilled liquids would be exposed to the air to determine the surface area of pools that could be formed. Use the instructions above to estimate a release rate from the total surface area.

Releases into Buildings

If the toxic liquid is released inside a building, compare the area of the pool that would be formed (depending upon floor space or passive mitigation) to the maximum area of the pool that could be formed (if the liquid is not contained); the smaller of the two areas should be used in determining the evaporation rate. The maximum area of the pool is determined as described above for releases into diked areas, using Equation 3-6. If the toxic liquid would spread to cover the building floor, you determine the area of the building floor as:

$$A = L \times W \tag{3-9}$$

where:
A = Area (square feet)
L = Length (feet)
W = Width (feet)

If there are obstacles such as dikes inside the building, determine the size of the pool that would be formed based on the area defined by the dikes or other obstacles.

The evaporation rate is then determined for a worst-case scenario (i.e., wind speed is 1.5 meters per second (3.4 miles per hour)), using Equation 3-3 or 3-4, if the liquid spreads to its maximum area, or Equation 3-7 or 3-8, if the pool area is smaller than the maximum. The maximum rate of evaporated liquid exiting the building is taken to be 10 percent of the calculated worst-case scenario evaporation rate (see Appendix D, Section D.2.4 for the derivation of this factor), as follows:

$$QR_B = 0.1 \times QR \tag{3-10}$$

where:
QR_B = Release rate from building
QR = Release rate from pool, estimated as discussed above
0.1 = Mitigation factor, discussed in Appendix D, Section D.2.4

Note that the mitigation factor (i.e., 0.1) presented in this method assumes that the release occurs in a fully enclosed, non-airtight space that is directly adjacent to the outside air. It may not apply to a release in an interior room that is enclosed within a building, or to a space that has doors or windows that could be open during a release. In such cases, you may want to consider performing site-specific modeling to determine the appropriate amount of passive mitigation.

Example 7. Liquid Release Inside Building (Bromine)

Suppose that your tank of bromine from Example 6 is contained inside a storage shed 10 feet by 10 feet (area 100 square feet). There are no dikes inside the shed. From Example 6, you see that the area covered by the bromine in an unenclosed space would be 3,200 square feet. The building area is smaller than the maximum pool area; therefore, the building floor area should be used to determine the evaporation rate from Equation 3-7. For the calculation, first determine the worst-case scenario evaporation rate:

$$QR = 1.4 \times 0.073 \times 100 = 10 \text{ pounds per minute}$$

The release rate to the outside air of the evaporated liquid leaving the building would then be:

$$QR_B = 0.1 \times 10 \text{ pounds per minute} = 1 \text{ pound per minute}$$

3.2.4 Mixtures Containing Toxic Liquids

Mixtures containing regulated toxic substances do not have to be considered if the concentration of the regulated substance in the mixture is below one percent by weight or if you can demonstrate that the partial vapor pressure of the regulated substances in the mixture is below 10 millimeters of mercury (mm Hg). Regulated substances present as by-products or impurities would need to be considered if they are present in concentrations of one percent or greater in quantities above their thresholds, and their partial vapor pressures are 10 mm Hg or higher. In case of a spill of a liquid mixture containing a regulated toxic substance with partial vapor pressure of 10 mm Hg or higher (with the exception of common water solutions, discussed in the next section), you have several options for estimating a release rate:

- Carry out the analysis as described above in Sections 3.2.2 or 3.2.3 using the quantity of the regulated substance in the mixture and the liquid factor (LFA or LFB) and density factor for the regulated substance in pure form. This is a simple approach that likely will give conservative results.

- If you know the partial pressure of the regulated substance in the mixture, you may estimate a more realistic evaporation rate. An equation for the evaporation rate is given at the end of Section B.2 in Appendix B.

  -- In this case, estimate a pool size for the entire quantity of the mixture, for an unmitigated release. If you know the density of the mixture, you may use it in estimating the pool size; otherwise, you may assume the density is the same as the pure regulated substance (in most cases, this assumption is unlikely to have a large effect on the results).

- You may estimate the partial pressure of the regulated substance in the mixture by the method described in Section B.2 in Appendix B and use the equation presented there to estimate an evaporation rate. This equation is appropriate to mixtures and solutions in which the components do not interact with each other. It is probably inappropriate for most water solutions. It is likely to overestimate the partial vapor pressure of regulated substances in water solutions in which hydrogen bonding may occur (e.g., solutions of acids or alcohols). As discussed above, use the pool size for the entire quantity of the mixture for an unmitigated release.

Example 8. Mixture Containing Toxic Liquid (Acrylonitrile)

You have a tank containing 50,000 pounds of a mixture of acrylonitrile (a regulated substance) and N,N-dimethylformamide (not regulated). The weight of each of the components of the mixture is known (acrylonitrile = 20,000 pounds; N,N-dimethylformamide = 30,000 pounds.) The molecular weight of acrylonitrile, from Exhibit B-2, is 53.06, and the molecular weight of N,N-dimethylformamide is 73.09. Using Equation B-3, Appendix B, calculate the mole fraction of acrylonitrile in the solution as follows:

$$X_r = \frac{(20{,}000/53.06)}{(20{,}000/53.06) + (30{,}000/73.09)}$$

$$X_r = \frac{377}{377 + 410}$$

$$X_r = 0.48$$

Estimate the partial vapor pressure of acrylonitrile using Equation B-4 as follows (using the vapor pressure of acrylonitrile in pure form at 25°C, 108 mm Hg, from Exhibit B-2, Appendix B):

$$VP_m = 0.48 \times 108 = 51.8 \text{ mm Hg}$$

Before calculating evaporation rate for acrylonitrile in the mixture, you must determine the surface area of the pool formed by the entire quantity of the mixture, using Equation 3-6. The quantity released is 50,000 pounds and the Density Factor for acrylonitrile is 0.61 in Exhibit B-2; therefore:

$$A = 50{,}000 \times 0.61 = 30{,}500 \text{ square feet}$$

Now calculate the evaporation rate for acrylonitrile in the mixture from Equation B-5 using the VP_m and A calculated above:

$$QR = \frac{0.0035 \times 1.0 \times (53.06)^{2/3} \times 30{,}500 \times 51.8}{298}$$

$$QR = 262 \text{ pounds per minute}$$

3.2.5 Release Rate Correction for Toxic Liquids Released at Temperatures Between 25 °C and 50 °C

If your liquid is at a temperature between 25 °C (77 °F) and 50 °C (122 °F), you must use the higher temperature for the offsite consequence analysis. You may correct the release rate calculated for a pool at 25

°C to estimate from a pool at the higher temperature using Temperature Correction Factors (TCF) provided in Appendix B, Exhibit B-4. Calculate a corrected release rate as follows:

- Calculate the release rate (QR) of the liquid at 25 °C (77 °F) as described in Section 3.2.2 (for unmitigated releases) or 3.2.3 (for releases with passive mitigation).

- From Exhibit B-4 in Appendix B:

  - Find your liquid in the left-hand column of the table.

  - Find the temperature closest to your temperature at the top of the table. If your temperature is at the midpoint between two temperatures, go to the higher temperature; otherwise go to the closest temperature (higher or lower than your temperature).

  - Find the TCF for your liquid in the column for the appropriate temperature.

- Estimate a corrected release rate (QR_C) by multiplying the estimated release rate by the TCF; i.e.,

$$QR_C = QR \times TCF \tag{3-11}$$

where: QR_C = Corrected release rate
QR = Release rate calculated for 25 °C
TCF = Temperature Correction Factor (from Exhibit B-4, Appendix B)

The derivation of the Temperature Correction Factors is discussed in Appendix D, Section D.2.2. If you have vapor pressure-temperature data for a liquid not covered in Exhibit B-4, you may correct the evaporation rate using the method presented in Section D.2.2.

Example 9. Liquid Release at Ambient Temperature Between 25 ºC and 50 ºC (Bromine)

Assume the tank containing 20,000 pounds of bromine, from Example 6, is at an ambient temperature of 35 ºC (95 ºF). As in Example 6, the total quantity in the tank is spilled into a diked enclosure that completely contains the spill. The surface area is 100 square feet. In Example 6, the release rate (QR) at 25 ºC was calculated from Equation 3-7 to be 10 pounds per minute. To adjust the release rate for the temperature of 35 ºC, you find the Temperature Correction Factor (TCF) for bromine at 35 ºC from Exhibit B-4 in Appendix B. The TCF at this temperature is 1.5; the corrected release rate (QR_C) at 35 ºC, from Equation 3-11, is

$$QR_C = 10 \times 1.5 = 15 \text{ pounds per minute}$$

The duration of the release (from Equation 3-5) would be:

$$t = 20{,}000 \text{ pounds}/15 \text{ pounds per minute} = 1{,}300 \text{ minutes}$$

3.3 Release Rates for Common Water Solutions of Toxic Substances and for Oleum

In Section 3.3

- Methods to estimate the release rates for several common water solutions and for oleum, including:
  - Evaporation from pools with no mitigation (see 3.2.2),
  - Evaporation from pools with dikes (see 3.2.3),
  - Releases at elevated temperatures of solutions of gases, and
  - Releases at elevated temperatures of solutions of liquids.

This section presents a simple method of estimating the release rate from spills of water solutions of several substances. Oleum (a solution of sulfur trioxide in sulfuric acid) also is discussed in this section.

The vapor pressure and evaporation rate of a substance in solution depends on its concentration in the solution. If a concentrated water solution containing a volatile toxic substance is spilled, the toxic substance initially will evaporate more quickly than water from the spilled solution, and the vapor pressure and evaporation rate will decrease as the concentration of the toxic substance in the solution decreases. At much lower concentrations, water may evaporate more quickly than the toxic substance. There is one concentration at which the composition of the solution does not change as evaporation occurs. For most situations of interest, the concentration exceeds this concentration, and the toxic substance evaporates more quickly than water.

For estimating release rates from solutions, this guidance lists liquid factors (ambient) for several common water solutions at several concentrations that take into account the decrease in evaporation rate with decreasing concentration. Exhibit B-3 in Appendix B provides LFA and DF values for several concentrations of ammonia, formaldehyde, hydrochloric acid, hydrofluoric acid, and nitric acid in water solution. Factors for oleum are also included in the exhibit. Chlorine dioxide also may be found in water solutions; however, solutions of chlorine dioxide commonly are below one percent concentration. Solutions below one percent concentration do not have to be considered. Chlorine dioxide, therefore, is not included in Exhibit B-3. These factors may be used to estimate an average release rate for the listed substances from a pool formed by a spill of solution. Liquid factors are provided for two different wind speeds, because the wind speed affects the rate of evaporation.

For the worst case, use the factor for a wind speed of 1.5 meters per second (3.4 miles per hour). You need to consider only the first 10 minutes of the release for solutions under ambient conditions in estimating the consequence distance, because the toxic component in a solution evaporates fastest during the first few minutes of a spill, when its concentration is highest. Modeling indicates that analysis considering the first 10 minutes of the release gives a good approximation of the overall consequences of the release. Although the toxic substance will continue to evaporate from the pool after 10 minutes, the rate of evaporation is so much lower that it can safely be ignored in estimating the consequence distance. (See Appendix D, Section D.2.3, for more information.) Estimate release rates as follows:

Ambient Temperature

- Unmitigated. If no passive mitigation measures are in place, and the solution is at ambient temperature, find the LFA at 1.5 meters per second (3.4 miles per hour) and DF for the solution in Appendix B, Exhibit B-3. Follow the instructions for liquids presented in Section 3.2.2 above to estimate the release rate of the listed substance in solution. Use the total quantity of the solution as the quantity released (QS) in carrying out the calculation of release rate.

- Mitigated. If passive mitigation is in place, and the solution is at ambient temperature, find the LFA at 1.5 meters per second (3.4 miles per hour) in Appendix B, Exhibit B-3, and follow the instructions for liquids in Section 3.2.3 above. Use the total quantity of the solution to estimate the maximum pool area for comparison with the diked area.

Example 10. Evaporation Rate for Water Solution at Ambient Temperature (Hydrochloric Acid)

You have a tank containing 50,000 pounds of 37 percent hydrochloric acid solution, at ambient temperature. For the worst-case analysis, you assume the entire contents of the tank is released, forming a pool. The release occurs in a diked area of 9,000 square feet.

From Exhibit B-3, Appendix B, the Density Factor (DF) for 37 percent hydrochloric acid is 0.42. From Equation 3-6, the maximum area of the pool would be 50,000 times 0.42, or 21,000 square feet. The diked area is smaller; therefore, the diked area should be used in the evaporation rate (release rate) calculation, using Equation 3-7.

For the calculation using Equation 3-7, you need the pool area (9,000 square feet) and the Liquid Factor Ambient (LFA) for 37 percent hydrochloric acid; you assume a wind speed of 1.5 meters per second, so the wind speed factor is 1.4. From Exhibit B-3, Appendix B, the LFA is 0.0085. From Equation 3-7, the release rate (QR) of hydrogen chloride from the pool is:

$$QR = 1.4 \times 9{,}000 \times 0.0085 = 107 \text{ pounds per minute}$$

You do not need to consider the duration of the release, because only the first ten minutes are considered.

Elevated Temperature

- Known Vapor Pressure. If the solution is at an elevated temperature, the vapor pressure of the regulated substance and its release rate from the solution will be much higher. This guidance does not include temperature correction factors for evaporation rates of regulated substances from solutions. If you know the partial vapor pressure of the toxic substance in solution at the relevant temperature, you can carry out the calculation of the release rate using the equations in Appendix D, Sections D.2.1 and D.2.2. As for releases of solutions at ambient temperature, you only need to consider the first 10 minutes of the release, because the evaporation rate of the toxic substance from the solution will decrease rapidly as its concentration decreases.

- Unknown Vapor Pressure. If you do not know the vapor pressure of the substance in solution, as a conservative approach for the worst-case analysis, use the appropriate instructions, as follows:

  -- *Solutions containing substances that are gases under ambient conditions*. The list of regulated substances includes several substances that, in their pure form, are gases under ambient conditions, but that may commonly be found in water solutions. These substances include ammonia, formaldehyde, hydrogen chloride, and hydrogen fluoride. For a release of a solution of ammonia, formaldehyde, hydrochloric acid, or hydrofluoric acid above ambient temperature, if you do not have vapor pressure data for the temperature of interest or prefer a simpler method, assume the quantity of the pure substance in the solution is released as a gas over 10 minutes, as discussed in Section 3.1 above. You may determine the amount of pure substance in the solution from the concentration (e.g., a solution of 37 percent hydrochloric acid by weight would contain a quantity of hydrogen chloride equal to 0.37 times the total weight of the solution).

Example 11. Evaporation Rate for Gas in Water Solution at Elevated Temperature (Hydrochloric Acid)

You have 50,000 pounds of 37 percent hydrochloric acid solution in a high-temperature process. For the worst-case analysis, you assume the entire contents of the process vessel is released. In this case, because the solution is at an elevated temperature, you consider the release of gaseous hydrogen chloride from the hot solution.

The solution would contain 50,000 × 0.37 pounds of hydrogen chloride, or 18,500 pounds. You assume the entire 18,500 pounds is released over 10 minutes. From Equation 3-1, the release rate is 18,500 divided by 10, or 1,850 pounds per minute.

-- *Liquids in solution*. If you have vapor pressure data for the liquid in solution (including nitric acid in water solution and sulfur trioxide in oleum) at the temperature of interest, you may use that data to estimate the release rate, as discussed above. You only need to consider the first 10 minutes of the evaporation.

For a release of nitric acid solution at a temperature above ambient, if you do not have vapor pressure data or prefer to use this simpler method, determine the quantity of pure nitric acid in the solution from the concentration. Assume the quantity of pure nitric acid is released at an elevated temperature and estimate a release rate as discussed in Section 3.2 above, using the LFB. For temperatures between 25 °C and 50 °C, you may use the LFA and the temperature correction factors for the pure substance, as described in Section 3.2.5. You do not need to estimate the duration of the release, because you only consider the first 10 minutes.

Similarly, for a release of oleum at an elevated temperature, determine the quantity of free sulfur trioxide in the oleum from the concentration and assume the sulfur trioxide is released at an elevated temperature. Use the LFB or the LFA and temperature correction factors for sulfur trioxide to estimate a release rate as discussed in Section 3.2. You only need to consider the first 10 minutes of the release in your analysis.

For a spill of liquid in solution into a diked area, you would need to consider the total quantity of solution in determining whether the liquid could overflow the diked area (see the steps in Section 3.2.3). If you find that the liquid could overflow the dikes, you would need to consider both the quantity of pure substance remaining inside the diked area and the quantity of pure substance spilled outside the diked area in carrying out the release rate analysis as discussed in Section 3.2.3.

Example 12. Evaporation Rate for Liquid in Water Solution at Elevated Temperature (Nitric Acid)

You have 18,000 pounds of 90 percent nitric acid solution in a high temperature process. The solution would contain 18,000 x 0.90 pounds of nitric acid, or 16,200 pounds. You assume 16,200 pounds of pure nitric acid is released at an elevated temperature.

For the calculation using Equation 3-4, you need the quantity released (16,200); the Liquid Factor Boiling (LFB) for nitric acid (0.12 from Exhibit B-2); the Density Factor (DF) for nitric acid (0.32 from Exhibit B-2); and you assume a wind speed of 1.5 meter per second, so the wind speed factor is 1.4. From Equation 3-4, the release rate (QR) of hot nitric acid is:

$$QR = 16{,}200 \times 1.4 \times 0.12 \times 0.32 = 870 \text{ pounds per minute}$$

You do not need to estimate the duration of release, because you only consider the first 10 minutes.

4 ESTIMATION OF WORST-CASE DISTANCE TO TOXIC ENDPOINT

In Chapter 4

- Reference tables of distances for worst-case releases, including:
  - Generic reference tables (Exhibit 2), and
  - Chemical-specific reference tables (Exhibit 3).
- Considerations include:
  - Gas density (neutrally buoyant or dense),
  - Duration of release (10 minutes or 60 minutes),
  - Topography (rural or urban).

This guidance provides reference tables giving worst-case distances for neutrally buoyant gases and vapors and for dense gases and vapors for both rural (open) and urban (obstructed) areas. This chapter describes these reference tables and gives instructions to help you choose the appropriate table to estimate consequence distances for the worst-case analysis.

Neutrally buoyant gases and vapors have approximately the same density as air, and dense gases and vapors are heavier than air. Neutrally buoyant and dense gases are dispersed in different ways when they are released; therefore, modeling was carried out to develop separate reference tables. These generic reference tables can be used to estimate distances using the specified toxic endpoint for each substance and the estimated release rate to air. In addition to the generic tables, chemical-specific reference tables are provided for ammonia, chlorine, and sulfur dioxide. These chemical-specific tables were developed based on modeling carried out for industry-specific guidance documents. All the tables were developed assuming a wind speed of 1.5 meters per second (3.4 miles per hour) and F stability. To use the reference tables, you need the worst-case release rates estimated as described in the previous sections. For liquid pool evaporation, you also need the duration of the release. In addition, to use the generic tables, you will need to determine the appropriate toxic endpoint and whether the gas or vapor is neutrally buoyant or dense, using the exhibits in Appendix B. You may interpolate between entries in the reference tables.

Generic reference tables are provided for both 10-minute releases and 60-minute releases. You should use the tables for 10-minute releases if the duration of your release is 10 minutes or less; use the tables for 60-minute releases if the duration of your release is more than 10 minutes. For the worst-case analysis, all releases of toxic gases are assumed to last for 10 minutes. You need to consider the estimated duration of the release (from Equation 3-5) for evaporation of pools of toxic liquids. For evaporation of water solutions of toxic liquids or of oleum, you should always use the tables for 10-minute releases.

The generic reference tables of distances (Reference Tables 1-8), which should be used for substances other than ammonia, chlorine, and sulfur dioxide, are found at the end of Chapter 5. The generic tables and the conditions for which each table are applicable are described in Exhibit 2. Chemical-specific reference tables of distances (Reference Tables 9-12) follow the generic reference tables at the end of Chapter 5. Each of these chemical-specific tables includes distances for both rural and urban topography. These tables are described in Exhibit 3.

Remember that these reference tables provide only rough estimates, not accurate predictions, of the distances that might be reached under worst-case conditions. In particular, although the distances in the tables are as great as 25 miles, you should bear in mind that the larger distances (more than six to ten miles) are very uncertain.

To use the reference tables of distances, follow these steps:

For Regulated Toxic Substances Other than Ammonia, Chlorine, and Sulfur Dioxide

- Find the toxic endpoint for the substance in Appendix B (Exhibit B-1 for toxic gases or Exhibit B-2 for toxic liquids).

- Determine whether the table for neutrally buoyant or dense gases and vapors is appropriate from Appendix B (Exhibit B-1 for toxic gases or Exhibit B-2 for toxic liquids). A toxic gas that is lighter than air may behave as a dense gas upon release if it is liquefied under pressure, because the released gas may be mixed with liquid droplets, or if it is cold. Consider the state of the released gas when you decide which table is appropriate.

- Determine whether the table for rural or urban conditions is appropriate.

    - Use the rural table if your site is in an open area with few obstructions.

    - Use the urban table if your site is in an urban or obstructed area. The urban tables are appropriate if there are many obstructions in the area, even if it is in a remote location, not in a city.

- Determine whether the 10-minute table or the 60-minute table is appropriate.

    - Always use the 10-minute table for worst-case releases of toxic gases.

    - Always use the 10-minute table for worst-case releases of common water solutions and oleum from evaporating pools, for both ambient and elevated temperatures.

    - If you estimated the release duration for an evaporating toxic liquid pool to be 10 minutes or less, use the 10-minute table.

    - If you estimated the release duration for an evaporating toxic liquid pool to be more than 10 minutes, use the 60-minute table.

Exhibit 2
Generic Reference Tables of Distances for Worst-case Scenarios

Applicable Conditions			Reference Table Number
Gas or Vapor Density	**Topography**	**Release Duration (minutes)**	
Neutrally buoyant	Rural	10	1
		60	2
	Urban	10	3
		60	4
Dense	Rural	10	5
		60	6
	Urban	10	7
		60	8

Exhibit 3
Chemical-Specific Reference Tables of Distances for Worst-case Scenarios

Substance	Applicable Conditions			Reference Table Number
	Gas or Vapor Density	**Topography**	**Release Duration (minutes)**	
Anhydrous ammonia liquefied under pressure	Dense	Rural, Urban	10	9
Non-liquefied ammonia, ammonia liquefied by refrigeration, or aqueous ammonia	Neutrally buoyant	Rural, Urban	10	10
Chlorine	Dense	Rural, Urban	10	11
Sulfur dioxide (anhydrous)	Dense	Rural, Urban	10	12

Neutrally Buoyant Gases or Vapors

- If Exhibit B-1 or B-2 indicates the gas or vapor should be considered neutrally buoyant, and other factors would not cause the gas or vapor to behave as a dense gas, divide the estimated release rate (pounds per minute) by the toxic endpoint (milligrams per liter).

- Find the range of release rate/toxic endpoint values that includes your calculated release rate/toxic endpoint in the first column of the appropriate table (Reference Table 1, 2, 3, or 4), then find the corresponding distance to the right (see Example 13 below).

Dense Gases or Vapors

- If Exhibit B-1 or B-2 or consideration of other relevant factors indicates the substance should be considered a dense gas or vapor (heavier than air), find the distance in the appropriate table (Reference Table 5, 6, 7, or 8) as follows;

  -- Find the toxic endpoint closest to that of the substance by reading across the top of the table. If the endpoint of the substance is halfway between two values on the table, choose the value on the table that is smaller (to the left). Otherwise, choose the closest value to the right or the left.

  -- Find the release rate closest to the release rate estimated for the substance at the left of the table. If the calculated release rate is halfway between two values on the table, choose the release rate that is larger (farther down on the table). Otherwise, choose the closest value (up or down on the table).

  -- Read across from the release rate and down from the endpoint to find the distance corresponding to the toxic endpoint and release rate for your substance.

For Ammonia, Chlorine, or Sulfur Dioxide

- Find the appropriate chemical-specific table for your substance (see the descriptions of Reference Tables 9-12 in Exhibit 3).

  -- If you have ammonia liquefied by refrigeration alone, you may use Reference Table 10, even if the duration of the release is greater than 10 minutes.

  -- If you have chlorine or sulfur dioxide liquefied by refrigeration alone, you may use the chemical-specific reference tables, even if the duration of the release is greater than 10 minutes.

- Determine whether rural or urban topography is applicable to your site.

  -- Use the rural column in the reference table if your site is in an open area with few obstructions.

  - Use the urban column if your site is in an urban or obstructed area. The urban column is appropriate if there are many obstructions in the area, even if it is in a remote location, not in a city.

- Estimate the consequence distance as follows:

  - In the left-hand column of the table, find the release rate closest to your calculated release rate.

  - Read the corresponding distance from the appropriate column (urban or rural) to the right.

The development of Reference Tables 1-8 is discussed in Appendix D, Sections D.4.1 and D.4.2. The development of Reference Tables 9-12 is discussed in industry-specific risk management program guidance documents and a backup information document that are cited in Section D.4.3. If you think the results of the method presented here overstate the potential consequences of a worst-case release at your site, you may choose to use other methods or models that take additional site-specific factors into account.

Examples 14 and 15 below include the results of modeling using two other models, the Areal Locations of Hazardous Atmospheres (ALOHA) and the World Bank Hazards Analysis (WHAZAN) systems. These additional results are provided for comparison with the results of the methods presented in this guidance. The same modeling parameters were used as in the modeling carried out for development of the reference tables of distances. Appendix D, Section D.4.5, provides information on the modeling carried out with ALOHA and WHAZAN.

Example 13. Gas Release (Diborane)

In Example 1, you estimated a release rate for diborane gas of 250 pounds per minute. From Exhibit B-1, the toxic endpoint for diborane is 0.0011 mg/L, and the appropriate reference table for diborane is a neutrally buoyant gas table. Your facility and the surrounding area have many buildings, pieces of equipment, and other obstructions; therefore, you assume urban conditions. The appropriate reference table is Reference Table 3, for a 10-minute release of a neutrally buoyant gas in an urban area.

The release rate divided by toxic endpoint for this example is 250/0.0011 = 230,000.

From Reference Table 3, release rate divided by toxic endpoint falls between 221,000 and 264,000, corresponding to about 8.1 miles.

Example 14. Gas Release (Ethylene Oxide)

You have a tank containing 10,000 pounds of ethylene oxide, which is a gas under ambient conditions. Assuming the total quantity in the tank is released over a 10-minute period, the release rate (QR) from Equation 3-1 is:

QR = 10,000 pounds/10 minutes = 1,000 pounds per minute

From Exhibit B-1, the toxic endpoint for ethylene oxide is 0.09 mg/L, and the appropriate reference table is the dense gas table. Your facility is in an open, rural area with few obstructions; therefore, you use the table for rural areas.

Using Reference Table 5 for 10-minute releases of dense gases in rural areas, the toxic endpoint of 0.09 mg/L is closer to 0.1 than 0.075 mg/L. For a release rate of 1,000 pounds per minute, the distance to 0.1 mg/L is 3.6 miles.

Additional Modeling for Comparison

The ALOHA model gave a distance of 2.2 miles to the endpoint, using the same assumptions.

The WHAZAN model gave a distance of 2.7 miles to the endpoint, using the same assumptions and the dense cloud dispersion model.

Example 15. Liquid Evaporation from Pool (Acrylonitrile)

You estimated an evaporation rate of 307 pounds per minute for acrylonitrile from a pool formed by the release of 20,000 pounds into an undiked area (Example 4). You estimated the time for evaporation of the pool as 65 minutes. From Exhibit B-2, the toxic endpoint for acrylonitrile is 0.076 mg/L, and the appropriate reference table for a worst-case release of acrylonitrile is the dense gas table. Your facility is in an urban area. You use Reference Table 8 for 60-minute releases of dense gases in urban areas.

From Reference Table 8, the toxic endpoint closest to 0.076 mg/L is 0.075 mg/L, and the closest release rate to 307 pounds per minute is 250 pounds per minute. Using these values, the table gives a worst-case consequence distance of 2.9 miles.

Additional Modeling for Comparison

The ALOHA model gave a distance of 1.3 miles to the endpoint for a release rate of 307 pounds per minute, using the same assumptions.

The WHAZAN model gave a distance of 1.0 mile to the endpoint for a release rate of 307 pounds per minute, using the same assumptions and the dense cloud dispersion model.

5 ESTIMATION OF DISTANCE TO OVERPRESSURE ENDPOINT FOR FLAMMABLE SUBSTANCES

In Chapter 5

- Methods to estimate the worst-case consequence distances for releases of flammable substances.
    - -- 5.1 Vapor cloud explosions of flammable substances that are not mixed with other substances, and
    - -- 5.2 Vapor cloud explosions of flammable substances in mixtures.

For the worst-case scenario involving a release of flammable gases and volatile flammable liquids, you must assume that the total quantity of the flammable substance forms a vapor cloud within the upper and lower flammability limits and the cloud detonates. As a conservative worst-case assumption, if you use the method presented here, you must assume that 10 percent of the flammable vapor in the cloud participates in the explosion. You need to estimate the consequence distance to an overpressure level of 1 pound per square inch (psi) from the explosion of the vapor cloud. An overpressure of 1 psi may cause partial demolition of houses, which can result in serious injuries to people, and shattering of glass windows, which may cause skin laceration from flying glass.

This chapter presents a simple method for estimating the distance to the endpoint for a vapor cloud explosion of a regulated substance. The method presented here for analysis of vapor cloud explosions is based on a TNT-equivalent model. Other methods are available for analysis of vapor cloud explosions, including methods that consider site-specific conditions. You may use other methods for your worst-case analysis if you so choose, provided you assume the total quantity of flammable substance is in the cloud and use an endpoint of 1 psi. If you use a TNT-equivalent model, you must assume a yield factor of 10 percent. Appendix A includes references to documents and journal articles on vapor cloud explosions that may provide useful information on methods of analysis.

5.1 Flammable Substances Not in Mixtures

For the worst-case analysis of a regulated flammable substance that is not in a mixture with other substances, you may estimate the consequence distance for a given quantity of a regulated flammable substance using Reference Table 13. This table provides distances to 1 psi overpressure for vapor cloud explosions of quantities from 500 to 2,000,000 pounds. These distances were estimated by a TNT-equivalent model, Equation C-1 in Appendix C, Section C.1, using the worst-case assumptions described above and data provided in Exhibit C-1, Appendix C. If you prefer, you may calculate your worst-case consequence distance for flammable substances from the heat of combustion of the flammable substance and Equation C-1 or C-2.

Example 16. Vapor Cloud Explosion (Propane)

You have a tank containing 50,000 pounds of propane. From Reference Table 13, the distance to 1 psi overpressure is 0.3 miles for 50,000 pounds of propane.

Alternatively, you can calculate the distance to 1 psi using Equation C-2 from Appendix C:

$$D = 0.0081 \times [\ 0.1 \times 50{,}000 \times (46{,}333/4{,}680)\ ]^{1/3}$$

$$D = 0.3 \text{ miles}$$

5.2 Flammable Mixtures

If you have more than 10,000 pounds of a mixture of flammable substances that meets the criteria for listing under CAA section 112(r) (flash point below 22.8 °C (73 °F), boiling point below 37.8 °C (100 °F), National Fire Protection Association (NFPA) flammability hazard rating of 4), you may need to carry out a worst-case consequence analysis for the mixture. (If the mixture itself does not meet these criteria, it is not covered, and no analysis is required, even if the mixture contains one or more regulated substances.) You should carry out the analysis using the total quantity of all regulated flammable substance or substances in the mixture. Non-flammable components should not be included. However, if additional (non-regulated) flammable substances are present in the mixture, you should include them in the quantity used in the analysis.

For simplicity, you may carry out the worst-case analysis based on the predominant regulated flammable component of the mixture or a major component of the mixture with the highest heat of combustion if the whole vapor cloud consists of flammable substances (see Exhibit C-1, Appendix C for data on heat of combustion). Estimate the consequence distance from Reference Table 13 for the major component with the highest heat of combustion, assuming that the quantity in the cloud is the total quantity of the mixture. If you have a mixture in which the heats of combustion of the components do not differ significantly (e.g., a mixture of hydrocarbons), this method is likely to give reasonable results.

Alternatively, you may estimate the heat of combustion of the mixture from the heats of combustion of the components of the mixture using the method described in Appendix C, Section C.2, and then use Equation C-1 or C-2 in Appendix C to determine the vapor cloud explosion distance. This method may be appropriate if you have a mixture that includes components with significantly different heats of combustion (e.g., a mixture of hydrogen and hydrocarbons) that make up a significant portion of the mixture.

Examples 17 and 18 illustrate the two methods of analysis. In Example 17, the heat of combustion of the mixture is estimated, and the distance to the endpoint is calculated from Equation C-2. In Example 18, the component of the mixture with the highest heat of combustion is assumed to represent the entire mixture, and the distance to the endpoint is read from Reference Table 13. For the mixture of two hydrocarbons used in the example, the methods give very similar results.

Example 17. Estimating Heat of Combustion of Mixture for Vapor Cloud Explosion Analysis

You have a mixture of 8,000 pounds of ethylene (the reactant) and 2,000 pounds of isobutane (a catalyst carrier). To carry out the worst-case analysis, estimate the heat of combustion of the mixture from the heats of combustion of the components of the mixture. (Ethylene heat of combustion = 47,145 kilojoules per kilogram; isobutane heat of combustion = 45,576). Using Equation C-3, Appendix C:

$$HC_m = \left[\frac{(8{,}000/2.2)}{(10{,}000/2.2)} \times 47{,}145 \right] + \left[\frac{(2{,}000/2.2)}{(10{,}000/2.2)} \times 45{,}576 \right]$$

$$HC_m = (37{,}716) + (9{,}115)$$

$$HC_m = 46{,}831 \text{ kilojoules per kilogram}$$

Now use the calculated heat of combustion for the mixture in Equation C-2 to calculate the distance to 1 psi overpressure for vapor cloud explosion.

$$D = 0.0081 \times [\ 0.1 \times 10{,}000 \times (46{,}831/4{,}680)\ ]^{1/3}$$

$$D = 0.2 \text{ miles}$$

Example 18. Vapor Cloud Explosion of Flammable Mixture (Ethylene and Isobutane)

You have 10,000 pounds of a mixture of ethylene (the reactant) and isobutane (a catalyst carrier). To carry out the worst-case analysis, assume the quantity in the cloud is the total quantity of the mixture. Use data for ethylene because it is the component with the highest heat of combustion. (Ethylene heat of combustion = 47,145 kilojoules per kilogram; isobutane heat of combustion = 45,576, from Exhibit C-1, Appendix C). From Reference Table 13, the distance to 1 psi overpressure is 0.2 miles for 10,000 pounds of ethylene; this distance would also apply to the 10,000-pound mixture of ethylene and isobutane.

Reference Table 1
Neutrally Buoyant Plume Distances to Toxic Endpoint for Release Rate Divided by Endpoint
10-Minute Release, Rural Conditions, F Stability, Wind Speed 1.5 Meters per Second

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
0 - 4.4	0.1
4.4 - 37	0.2
37 - 97	0.3
97 - 180	0.4
180 - 340	0.6
340 - 530	0.8
530 - 760	1.0
760 - 1,000	1.2
1,000 - 1,500	1.4
1,500 - 1,900	1.6
1,900 - 2,400	1.8
2,400 - 2,900	2.0
2,900 - 3,500	2.2
3,500 - 4,400	2.4
4,400 - 5,100	2.6
5,100 - 5,900	2.8
5,900 - 6,800	3.0
6,800 - 7,700	3.2
7,700 - 9,000	3.4
9,000 - 10,000	3.6
10,000 - 11,000	3.8
11,000 - 12,000	4.0
12,000 - 14,000	4.2
14,000 - 15,000	4.4
15,000 - 16,000	4.6
16,000 - 18,000	4.8
18,000 - 19,000	5.0
19,000 - 21,000	5.2
21,000 - 23,000	5.4
23,000 - 24,000	5.6
24,000 - 26,000	5.8
26,000 - 28,000	6.0
28,000 - 29,600	6.2
29,600 - 35,600	6.8
35,600 - 42,000	7.5
42,000 - 48,800	8.1
48,800 - 56,000	8.7
56,000 - 63,600	9.3
63,600 - 71,500	9.9
71,500 - 88,500	11
88,500 - 107,000	12
107,000 - 126,000	14
126,000 - 147,000	15
147,000 - 169,000	16
169,000 - 191,000	17
191,000 - 215,000	19
215,000 - 279,000	22
279,000 - 347,000	25
>347,000	>25*

*Report distance as 25 miles

Reference Table 2
Neutrally Buoyant Plume Distances to Toxic Endpoint for Release Rate Divided by Endpoint
60-Minute Release, Rural Conditions, F Stability, Wind Speed 1.5 Meters per Second

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
0 - 5.5	0.1
5.5 - 46	0.2
46 - 120	0.3
120 - 220	0.4
220 - 420	0.6
420 - 650	0.8
650 - 910	1.0
910 - 1,200	1.2
1,200 - 1,600	1.4
1,600 - 1,900	1.6
1,900 - 2,300	1.8
2,300 - 2,600	2.0
2,600 - 2,900	2.2
2,900 - 3,400	2.4
3,400 - 3,700	2.6
3,700 - 4,100	2.8
4,100 - 4,400	3.0
4,400 - 4,800	3.2
4,800 - 5,200	3.4
5,200 - 5,600	3.6
5,600 - 5,900	3.8
5,900 - 6,200	4.0
6,200 - 6,700	4.2
6,700 - 7,000	4.4
7,000 - 7,400	4.6
7,400 - 7,700	4.8
7,700 - 8,100	5.0
8,100 - 8,500	5.2
8,500 - 8,900	5.4
8,900 - 9,200	5.6
9,200 - 9,600	5.8
9,600 - 10,000	6.0
10,000 - 10,400	6.2
10,400 - 11,700	6.8
11,700 - 13,100	7.5
13,100 - 14,500	8.1
14,500 - 15,900	8.7
15,900 - 17,500	9.3
17,500 - 19,100	9.9
19,100 - 22,600	11
22,600 - 26,300	12
26,300 - 30,300	14
30,300 - 34,500	15
34,500 - 38,900	16
38,900 - 43,600	17
43,600 - 48,400	19
48,400 - 61,500	22
61,500 - 75,600	25
>75,600	>25*

*Report distance as 25 miles

Reference Table 3
Neutrally Buoyant Plume Distances to Toxic Endpoint for Release Rate Divided by Endpoint
10-minute Release, Urban Conditions, F Stability, Wind Speed 1.5 Meters per Second

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
0 - 21	0.1
21 - 170	0.2
170 - 420	0.3
420 - 760	0.4
760 - 1,400	0.6
1,400 - 2,100	0.8
2,100 - 3,100	1.0
3,100 - 4,200	1.2
4,200 - 6,100	1.4
6,100 - 7,800	1.6
7,800 - 9,700	1.8
9,700 - 12,000	2.0
12,000 - 14,000	2.2
14,000 - 18,000	2.4
18,000 - 22,000	2.6
22,000 - 25,000	2.8
25,000 - 29,000	3.0
29,000 - 33,000	3.2
33,000 - 39,000	3.4
39,000 - 44,000	3.6
44,000 - 49,000	3.8
49,000 - 55,000	4.0
55,000 - 63,000	4.2
63,000 - 69,000	4.4
69,000 - 76,000	4.6

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
76,000 - 83,000	4.8
83,000 - 90,000	5.0
90,000 - 100,000	5.2
100,000 - 110,000	5.4
110,000 - 120,000	5.6
120,000 - 130,000	5.8
130,000 - 140,000	6.0
140,000 - 148,000	6.2
148,000 - 183,000	6.8
183,000 - 221,000	7.5
221,000 - 264,000	8.1
264,000 - 310,000	8.7
310,000 - 361,000	9.3
361,000 - 415,000	9.9
415,000 - 535,000	11
535,000 - 671,000	12
671,000 - 822,000	14
822,000 - 990,000	15
990,000 - 1,170,000	16
1,170,000 - 1,370,000	17
1,370,000 - 1,590,000	19
1,590,000 - 2,190,000	22
2,190,000 - 2,890,000	25
>2,890,000	>25*

*Report distance as 25 miles

Reference Table 4
Neutrally Buoyant Plume Distances to Toxic Endpoint for Release Rate Divided by Endpoint
60-Minute Release, Urban Conditions, F Stability, Wind Speed 1.5 Meters per Second

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
0 - 26	0.1
26 - 210	0.2
210 - 530	0.3
530 - 940	0.4
940 - 1,700	0.6
1,700 - 2,600	0.8
2,600 - 3,700	1.0
3,700 - 4,800	1.2
4,800 - 6,400	1.4
6,400 - 7,700	1.6
7,700 - 9,100	1.8
9,100 - 11,000	2.0
11,000 - 12,000	2.2
12,000 - 14,000	2.4
14,000 - 16,000	2.6
16,000 - 17,000	2.8
17,000 - 19,000	3.0
19,000 - 21,000	3.2
21,000 - 23,000	3.4
23,000 - 24,000	3.6
24,000 - 26,000	3.8
26,000 - 28,000	4.0
28,000 - 30,000	4.2
30,000 - 32,000	4.4
32,000 - 34,000	4.6
34,000 - 36,000	4.8
36,000 - 38,000	5.0
38,000 - 41,000	5.2
41,000 - 43,000	5.4
43,000 - 45,000	5.6
45,000 - 47,000	5.8
47,000 - 50,000	6.0
50,000 - 52,200	6.2
52,200 - 60,200	6.8
60,200 - 68,900	7.5
68,900 - 78,300	8.1
78,300 - 88,400	8.7
88,400 - 99,300	9.3
99,300 - 111,000	9.9
111,000 - 137,000	11
137,000 - 165,000	12
165,000 - 197,000	14
197,000 - 232,000	15
232,000 - 271,000	16
271,000 - 312,000	17
312,000 - 357,000	19
357,000 - 483,000	22
483,000 - 629,000	25
>629,000	>25*

*Report distance as 25 miles

Reference Table 5
Dense Gas Distances to Toxic Endpoint
10-minute Release, Rural Conditions, F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	**Toxic Endpoint (mg/L)**															
	0.0004	**0.0007**	**0.001**	**0.002**	**0.0035**	**0.005**	**0.0075**	**0.01**	**0.02**	**0.035**	**0.05**	**0.075**	**0.1**	**0.25**	**0.5**	**0.75**
	Distance (Miles)															
1	2.2	1.7	1.5	1.1	0.8	0.7	0.5	0.5	0.3	0.2	0.2	0.2	0.1	0.1	#	#
2	3.0	2.4	2.1	1.5	1.1	0.9	0.7	0.7	0.4	0.3	0.3	0.2	0.2	0.1	<0.1	<0.1
5	4.8	3.7	3.0	2.2	1.7	1.5	1.2	1.0	0.7	0.5	0.4	0.3	0.3	0.2	0.1	0.1
10	6.8	5.0	4.2	3.0	2.4	2.1	1.7	1.4	1.0	0.7	0.6	0.5	0.4	0.2	0.2	0.1
30	11	8.7	6.8	5.2	3.9	3.4	2.8	2.4	1.7	1.3	1.1	0.9	0.7	0.4	0.3	0.2
50	14	11	9.3	6.8	5.0	4.2	3.5	3.0	2.2	1.7	1.4	1.1	0.9	0.6	0.4	0.3
100	19	15	12	8.7	6.8	5.8	4.8	4.2	2.9	2.2	1.9	1.6	1.3	0.8	0.5	0.4
150	24	18	15	11	8.1	6.8	5.7	5.0	3.6	2.7	2.3	1.9	1.6	0.9	0.6	0.5
250	>25	22	19	14	11	8.7	7.4	6.2	4.5	3.4	2.8	2.3	2.0	1.2	0.8	0.6
500	*	>25	>25	19	14	12	9.9	8.7	6.2	4.7	3.8	3.1	2.7	1.6	1.1	0.9
750	*	*	*	23	17	15	12	11	7.4	5.5	4.5	3.7	3.2	1.9	1.3	1.0
1,000	*	*	*	>25	20	17	14	12	8.1	6.2	5.2	4.2	3.6	2.2	1.4	1.1
1,500	*	*	*	*	24	20	16	14	9.9	7.4	6.2	5.0	4.3	2.5	1.7	1.3
2,000	*	*	*	*	>25	23	19	16	11	8.7	6.8	5.6	4.8	2.9	1.9	1.5
2,500	*	*	*	*	*	>25	20	18	12	9.3	8.1	6.2	5.3	3.2	2.1	1.6
3,000	*	*	*	*	*	*	23	20	14	9.9	8.7	6.8	5.6	3.4	2.2	1.7
4,000	*	*	*	*	*	*	>25	22	16	11	9.3	7.4	6.2	3.8	2.5	2.0
5,000	*	*	*	*	*	*	*	25	17	13	11	8.7	6.8	4.2	2.7	2.1
7,500	*	*	*	*	*	*	*	>25	20	15	12	9.9	8.7	4.9	3.2	2.5
10,000	*	*	*	*	*	*	*	*	24	17	14	11	9.3	5.5	3.6	2.8
15,000	*	*	*	*	*	*	*	*	>25	20	17	13	11	6.2	4.2	3.2
20,000	*	*	*	*	*	*	*	*	*	23	19	15	12	7.4	4.7	3.7
50,000	*	*	*	*	*	*	*	*	*	>25	>25	21	18	10	6.6	5.0
75,000	*	*	*	*	*	*	*	*	*	*	*	>25	21	12	7.6	5.8
100,000	*	*	*	*	*	*	*	*	*	*	*	*	24	13	8.5	6.4
150,000	*	*	*	*	*	*	*	*	*	*	*	*	>25	15	9.8	7.4
200,000	*	*	*	*	*	*	*	*	*	*	*	*	*	17	11	8.2

* > 25 miles (report distance as 25 miles)

\# <0.1 mile (report distance as 0.1 mile)

Reference Table 6
Dense Gas Distances to Toxic Endpoint
60-minute Release, Rural Conditions, F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	Toxic Endpoint (mg/L)															
	0.0004	**0.0007**	**0.001**	**0.002**	**0.0035**	**0.005**	**0.0075**	**0.01**	**0.02**	**0.035**	**0.05**	**0.075**	**0.1**	**0.25**	**0.5**	**0.75**
	Distance (Miles)															
1	3.7	2.7	2.2	1.4	1.0	0.8	0.6	0.5	0.3	0.2	0.2	0.1	0.1	<0.1	#	#
2	5.3	4.0	3.2	2.2	1.6	1.2	1.0	0.8	0.5	0.4	0.3	0.2	0.2	0.1	<0.1	<0.1
5	8.7	6.8	5.3	3.7	2.7	2.2	1.7	1.4	0.9	0.6	0.5	0.4	0.3	0.2	0.1	0.1
10	12	9.3	8.1	5.3	4.0	3.3	2.7	2.2	1.4	1.0	0.8	0.6	0.5	0.3	0.2	0.1
30	22	16	14	9.9	7.4	6.1	4.9	4.1	2.9	2.1	1.6	1.2	1.0	0.5	0.3	0.2
50	>25	21	18	12	9.3	8.1	6.2	5.4	3.8	2.7	2.2	1.7	1.4	0.7	0.4	0.3
100	*	>25	>25	18	13	11	9.3	7.4	5.5	4.0	3.2	2.5	2.1	1.1	0.7	0.5
150	*	*	*	22	17	14	11	9.9	6.8	4.9	4.0	3.1	2.7	1.4	0.9	0.6
250	*	*	*	>25	22	18	14	12	8.7	6.2	5.2	4.1	3.5	1.9	1.2	0.9
500	*	*	*	*	>25	25	20	17	12	9.3	7.4	5.8	5.0	2.9	1.8	1.3
750	*	*	*	*	*	>25	25	22	15	11	9.3	7.4	6.1	3.5	2.2	1.7
1,000	*	*	*	*	*	*	>25	25	17	12	11	8.1	6.8	4.0	2.6	2.0
1,500	*	*	*	*	*	*	*	>25	20	16	12	9.9	8.7	5.0	3.2	2.5
2,000	*	*	*	*	*	*	*	*	24	17	14	11	9.9	5.7	3.7	2.9
2,500	*	*	*	*	*	*	*	*	>25	20	16	13	11	6.2	4.2	3.2
3,000	*	*	*	*	*	*	*	*	*	21	17	14	12	6.8	4.5	3.5
4,000	*	*	*	*	*	*	*	*	*	24	20	16	14	8.1	5.2	4.0
5,000	*	*	*	*	*	*	*	*	*	>25	22	17	15	8.7	5.7	4.4
7,500	*	*	*	*	*	*	*	*	*	*	>25	21	18	11	6.8	5.2
10,000	*	*	*	*	*	*	*	*	*	*	*	24	20	12	7.4	6.0
15,000	*	*	*	*	*	*	*	*	*	*	*	>25	24	14	9.3	6.8
20,000	*	*	*	*	*	*	*	*	*	*	*	*	>25	16	9.9	8.1
50,000	*	*	*	*	*	*	*	*	*	*	*	*	*	22	14	11
75,000	*	*	*	*	*	*	*	*	*	*	*	*	*	>25	17	13
100,000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	18	14
150,000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	21	16
200,000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	23	18

* > 25 miles (report distance as 25 miles)

\# <0.1 mile (report distance as 0.1 mile)

Reference Table 7
Dense Gas Distances to Toxic Endpoint
10-minute Release, Urban Conditions, F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	Toxic Endpoint (mg/L)															
	0.0004	**0.0007**	**0.001**	**0.002**	**0.0035**	**0.005**	**0.0075**	**0.01**	**0.02**	**0.035**	**0.05**	**0.075**	**0.1**	**0.25**	**0.5**	**0.75**
	Distance (Miles)															
1	1.6	1.2	1.1	0.7	0.6	0.4	0.4	0.3	0.2	0.2	0.1	0.1	0.1	#	#	#
2	2.2	1.7	1.4	1.1	0.8	0.6	0.5	0.4	0.3	0.2	0.2	0.1	0.1	<0.1	#	#
5	3.5	2.7	2.2	1.6	1.2	1.0	0.8	0.7	0.5	0.4	0.3	0.2	0.2	0.1	<0.1	#
10	4.9	3.8	3.1	2.2	1.7	1.4	1.2	1.0	0.7	0.5	0.4	0.3	0.2	0.1	0.1	<0.1
30	8.1	6.2	5.3	3.7	2.9	2.4	2.0	1.7	1.2	0.9	0.7	0.6	0.4	0.2	0.1	0.1
50	11	8.1	6.8	4.8	3.7	3.1	2.5	2.1	1.5	1.1	0.9	0.7	0.6	0.3	0.2	0.1
100	15	11	9.3	6.8	5.2	4.2	3.5	3.0	2.1	1.6	1.3	1.0	0.9	0.5	0.3	0.2
150	19	14	12	8.1	6.1	5.2	4.3	3.6	2.5	1.9	1.6	1.2	1.1	0.6	0.4	0.2
250	24	18	15	11	8.1	6.8	5.4	4.6	3.3	2.4	2.0	1.6	1.4	0.7	0.5	0.3
500	>25	>25	21	15	11	9.3	7.4	6.2	4.5	3.4	2.8	2.2	1.9	1.1	0.7	0.5
750	*	*	>25	18	14	11	9.3	8.1	5.5	4.1	3.3	2.6	2.2	1.3	0.8	0.6
1,000	*	*	*	21	16	13	11	9.3	6.2	4.6	3.8	3.0	2.5	1.5	0.9	0.7
1,500	*	*	*	>25	19	16	12	11	7.4	5.6	4.6	3.7	3.0	1.7	1.1	0.8
2,000	*	*	*	*	22	18	15	12	8.7	6.2	5.2	4.1	3.5	2.0	1.3	0.9
2,500	*	*	*	*	24	20	16	14	9.9	6.8	5.8	4.7	3.8	2.2	1.4	1.1
3,000	*	*	*	*	>25	22	18	16	11	7.4	6.2	5.0	4.2	2.4	1.6	1.2
4,000	*	*	*	*	*	25	20	17	12	8.7	6.8	5.6	4.8	2.7	1.7	1.3
5,000	*	*	*	*	*	>25	23	20	14	9.9	8.1	6.2	5.3	3.0	1.9	1.4
7,500	*	*	*	*	*	*	>25	24	16	12	9.9	7.4	6.2	3.6	2.3	1.7
10,000	*	*	*	*	*	*	*	>25	19	14	11	8.7	7.4	4.1	2.6	2.0
15,000	*	*	*	*	*	*	*	*	22	16	13	11	8.7	4.9	3.1	2.3
20,000	*	*	*	*	*	*	*	*	>25	19	15	12	9.9	5.5	3.5	2.7
50,000	*	*	*	*	*	*	*	*	*	>25	23	17	15	8.1	5.1	3.8
75,000	*	*	*	*	*	*	*	*	*	*	>25	21	17	9.6	6.0	4.5
100,000	*	*	*	*	*	*	*	*	*	*	*	24	20	11	6.8	5.1
150,000	*	*	*	*	*	*	*	*	*	*	*	>25	23	13	8.1	6.1
200,000	*	*	*	*	*	*	*	*	*	*	*	*	>25	14	8.9	6.7

* > 25 miles (report distance as 25 miles)

\# <0.1 mile (report distance as 0.1 mile)

Reference Table 8
Dense Gas Distances to Toxic Endpoint
60-minute Release, Urban Conditions, F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	**Toxic Endpoint (mg/L)**															
	0.0004	**0.0007**	**0.001**	**0.002**	**0.0035**	**0.005**	**0.0075**	**0.01**	**0.02**	**0.035**	**0.05**	**0.075**	**0.1**	**0.25**	**0.5**	**0.75**
	Distance (Miles)															
1	2.6	1.9	1.5	1.1	0.7	0.6	0.4	0.4	0.2	0.2	0.1	0.1	0.1	#	#	#
2	3.8	2.9	2.3	1.5	1.1	0.9	0.7	0.6	0.4	0.2	0.2	0.1	0.1	<0.1	#	#
5	6.2	4.7	3.9	2.6	1.9	1.5	1.2	0.9	0.6	0.4	0.3	0.2	0.2	0.1	<0.1	#
10	9.3	6.8	5.6	3.9	2.9	2.3	1.8	1.5	0.9	0.7	0.5	0.4	0.3	0.2	0.1	<0.1
30	16	12	9.9	7.4	5.3	4.3	3.4	2.9	1.9	1.3	1.0	0.7	0.6	0.3	0.2	0.1
50	22	16	14	9.3	6.8	5.7	4.5	3.8	2.6	1.8	1.4	1.1	0.9	0.4	0.2	0.2
100	>25	24	20	14	9.9	8.1	6.8	5.7	3.8	2.7	2.2	1.7	1.4	0.7	0.4	0.3
150	*	>25	24	17	12	11	8.1	6.8	4.8	3.5	2.8	2.2	1.8	0.9	0.5	0.3
250	*	*	>25	22	16	14	11	9.3	6.2	4.5	3.7	2.9	2.4	1.2	0.7	0.5
500	*	*	*	>25	24	19	16	13	9.3	6.8	5.4	4.2	3.5	1.9	1.1	0.7
750	*	*	*	*	>25	24	19	16	11	8.1	6.8	5.2	4.3	2.4	1.4	1.0
1,000	*	*	*	*	*	>25	22	19	13	9.3	7.4	6.0	5.0	2.8	1.6	1.2
1,500	*	*	*	*	*	*	>25	24	16	12	9.3	7.4	6.2	3.4	2.1	1.5
2,000	*	*	*	*	*	*	*	>25	19	13	11	8.7	7.4	4.0	2.5	1.8
2,500	*	*	*	*	*	*	*	*	20	15	12	9.3	8.1	4.5	2.8	2.1
3,000	*	*	*	*	*	*	*	*	22	16	13	11	8.7	4.9	3.0	2.2
4,000	*	*	*	*	*	*	*	*	>25	19	16	12	9.9	5.6	3.5	2.6
5,000	*	*	*	*	*	*	*	*	*	21	17	14	11	6.2	4.0	3.0
7,500	*	*	*	*	*	*	*	*	*	>25	20	16	14	7.4	4.8	3.6
10,000	*	*	*	*	*	*	*	*	*	*	24	19	16	8.7	5.5	4.2
15,000	*	*	*	*	*	*	*	*	*	*	>25	22	19	11	6.8	5.1
20,000	*	*	*	*	*	*	*	*	*	*	*	>25	21	12	7.4	5.8
50,000	*	*	*	*	*	*	*	*	*	*	*	*	>25	18	11	8.7
75,000	*	*	*	*	*	*	*	*	*	*	*	*	*	21	13	10
100,000	*	*	*	*	*	*	*	*	*	*	*	*	*	24	15	11
150,000	*	*	*	*	*	*	*	*	*	*	*	*	*	>25	18	14
200,000	*	*	*	*	*	*	*	*	*	*	*	*	*	*	20	15

* > 25 miles (report distance as 25 miles)

\# <0.1 mile (report distance as 0.1 mile)

Reference Table 9
Distances to Toxic Endpoint for Anhydrous Ammonia Liquefied Under Pressure
F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
1	0.1	<0.1*
2	0.1	0.1
5	0.1	0.1
10	0.2	0.1
15	0.2	0.2
20	0.3	0.2
30	0.3	0.2
40	0.4	0.3
50	0.4	0.3
60	0.5	0.3
70	0.5	0.3
80	0.5	0.4
90	0.6	0.4
100	0.6	0.4
150	0.7	0.5
200	0.8	0.6
250	0.9	0.6
300	1.0	0.7
400	1.2	0.8
500	1.3	0.9
600	1.4	0.9
700	1.5	1.0
750	1.6	1.0
800	1.6	1.1
900	1.7	1.2
1,000	1.8	1.2
1,500	2.2	1.5
2,000	2.6	1.7
2,500	2.9	1.9
3,000	3.1	2.0
4,000	3.6	2.3
5,000	4.0	2.6
6,000	4.4	2.8
7,000	4.7	3.1
7,500	4.9	3.2
8,000	5.1	3.3
9,000	5.4	3.4
10,000	5.6	3.6
15,000	6.9	4.4
20,000	8.0	5.0
25,000	8.9	5.6
30,000	9.7	6.1
40,000	11	7.0
50,000	12	7.8
75,000	15	9.5
100,000	18	10
150,000	22	13
200,000	**	15
250,000	**	17
750,000	**	**

*Report distance as 0.1 mile

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

Reference Table 10
Distances to Toxic Endpoint for Non-liquefied Ammonia, Ammonia Liquefied by Refrigeration, or Aqueous Ammonia
F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
1	0.1	<0.1*
2	0.1	
5	0.1	
10	0.2	0.1
15	0.2	0.1
20	0.3	0.1
30	0.3	0.1
40	0.4	0.1
50	0.4	0.1
60	0.4	0.2
70	0.5	0.2
80	0.5	0.2
90	0.5	0.2
100	0.6	0.2
150	0.7	0.2
200	0.8	0.3
250	0.8	0.3
300	0.9	0.3
400	1.1	0.4
500	1.2	0.4
600	1.3	0.4
700	1.4	0.5
750	1.4	0.5
800	1.5	0.5
900	1.5	0.6
1,000	1.6	0.6
1,500	2.0	0.7
2,000	2.2	0.8
2,500	2.5	0.9
3,000	2.7	1.0
4,000	3.1	1.1
5,000	3.4	1.2
6,000	3.7	1.3
7,000	4.0	1.4
7,500	4.1	1.5
8,000	4.2	1.5
9,000	4.5	1.6
10,000	4.7	1.7
15,000	5.6	2.0
20,000	6.5	2.4
25,000	7.2	2.6
30,000	7.8	2.8
40,000	8.9	3.3
50,000	9.8	3.6
75,000	12	4.4
100,000	14	5.0
150,000	16	6.1
200,000	19	7.0
250,000	21	7.8
750,000	**	13

*Report distance as 0.1 mile

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

Reference Table 11
Distances to Toxic Endpoint for Chlorine
F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
1	0.2	0.1
2	0.3	0.1
5	0.5	0.2
10	0.7	0.3
15	0.8	0.4
20	1.0	0.4
30	1.2	0.5
40	1.4	0.6
50	1.5	0.6
60	1.7	0.7
70	1.8	0.8
80	1.9	0.8
90	2.0	0.9
100	2.2	0.9
150	2.6	1.2
200	3.0	1.3
250	3.4	1.5
300	3.7	1.6
400	4.2	1.9
500	4.7	2.1
600	5.2	2.3
700	5.6	2.5
750	5.8	2.6
800	5.9	2.7
900	6.3	2.9
1,000	6.6	3.0
1,500	8.1	3.8
2,000	9.3	4.4
2,500	10	4.9
3,000	11	5.4
4,000	13	6.2
5,000	14	7.0
6,000	16	7.6
7,000	17	8.3
7,500	18	8.6
8,000	18	8.9
9,000	19	9.4
10,000	20	9.9
15,000	25	12
20,000	*	14
25,000	*	16
30,000	*	18
40,000	*	20
50,000	*	*

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

Reference Table 12
Distances to Toxic Endpoint for Anhydrous Sulfur Dioxide
F Stability, Wind Speed 1.5 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
1	0.2	0.1
2	0.2	0.1
5	0.4	0.2
10	0.6	0.2
15	0.7	0.3
20	0.9	0.4
30	1.1	0.5
40	1.3	0.5
50	1.4	0.6
60	1.6	0.7
70	1.8	0.7
80	1.9	0.8
90	2.0	0.8
100	2.1	0.9
150	2.7	1.1
200	3.1	1.3
250	3.6	1.4
300	3.9	1.6
400	4.6	1.9
500	5.2	2.1
600	5.8	2.3
700	6.3	2.5
750	6.6	2.6
800	6.8	2.7
900	7.2	2.9
1,000	7.7	3.1
1,500	9.6	3.8
2,000	11	4.5
2,500	13	5.0
3,000	14	5.6
4,000	17	6.5
5,000	19	7.3
6,000	21	8.1
7,000	23	8.8
7,500	24	9.1
8,000	25	9.5
9,000	*	10
10,000	*	11
15,000	*	13
20,000	*	16
25,000	*	18
30,000	*	19
40,000	*	23
50,000	*	*

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

Reference Table 13
Distance to Overpressure of 1.0 psi for Vapor Cloud Explosions of 500 - 2,000,000 Pounds of Regulated Flammable Substances
Based on TNT Equivalent Method, 10 Percent Yield Factor

	Quantity in Cloud (pounds)	**500**	**2,000**	**5,000**	**10,000**	**20,000**	**50,000**	**100,000**	**200,000**	**500,000**	**1,000,000**	**2,000,000**
CAS No.	**Chemical Name**	**Distance (Miles) to 1 psi Overpressure**										
75-07-0	Acetaldehyde	0.05	0.08	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8
74-86-2	Acetylene	0.07	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8	1.0
598-73-2	Bromotrifluoroethylene	0.02	0.04	0.05	0.06	0.08	0.1	0.1	0.2	0.2	0.3	0.4
106-99-0	1,3-Butadiene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
106-97-8	Butane	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
25167-67-3	Butene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
590-18-1	2-Butene-cis	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
624-64-6	2-Butene-trans	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
106-98-9	1-Butene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
107-01-7	2-Butene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
463-58-1	Carbon oxysulfide	0.04	0.06	0.08	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6
7791-21-1	Chlorine monoxide	0.02	0.03	0.04	0.05	0.06	0.08	0.1	0.1	0.2	0.2	0.3
590-21-6	1-Chloropropylene	0.05	0.08	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8
557-98-2	2-Chloropropylene	0.05	0.08	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8
460-19-5	Cyanogen	0.05	0.08	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8
75-19-4	Cyclopropane	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
4109-96-0	Dichlorosilane	0.04	0.06	0.08	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6
75-37-6	Difluoroethane	0.04	0.06	0.09	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6
124-40-3	Dimethylamine	0.06	0.09	0.1	0.2	0.2	0.3	0.3	0.4	0.6	0.7	0.9
463-82-1	2,2-Dimethylpropane	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
74-84-0	Ethane	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
107-00-6	Ethyl acetylene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
75-04-7	Ethylamine	0.06	0.09	0.1	0.2	0.2	0.3	0.3	0.4	0.6	0.7	0.9

Reference Table 13 (continued)

	Quantity in Cloud (pounds)	500	2,000	5,000	10,000	20,000	50,000	100,000	200,000	500,000	1,000,000	2,000,000
CAS No.	Chemical Name	Distance (Miles) to 1 psi Overpressure										
75-00-3	Ethyl chloride	0.05	0.08	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8
74-85-1	Ethylene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8	1.0
60-29-7	Ethyl ether	0.06	0.09	0.1	0.2	0.2	0.3	0.3	0.4	0.6	0.7	0.9
75-08-1	Ethyl mercaptan	0.05	0.09	0.1	0.2	0.2	0.2	0.3	0.4	0.5	0.7	0.9
109-95-5	Ethyl nitrite	0.05	0.07	0.1	0.1	0.2	0.2	0.3	0.3	0.5	0.6	0.7
1333-74-0	Hydrogen	0.09	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.9	1.1	1.4
75-28-5	Isobutane	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
78-78-4	Isopentane	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
78-79-5	Isoprene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
75-31-0	Isopropylamine	0.06	0.09	0.1	0.2	0.2	0.3	0.3	0.4	0.6	0.7	0.9
75-29-6	Isopropyl chloride	0.05	0.08	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8
74-82-8	Methane	0.07	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8	1.0
74-89-5	Methylamine	0.06	0.09	0.1	0.2	0.2	0.3	0.3	0.4	0.6	0.7	0.9
563-45-1	3-Methyl-1-butene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
563-46-2	2-Methyl-1-butene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
115-10-6	Methyl ether	0.05	0.09	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.7	0.9
107-31-3	Methyl formate	0.04	0.07	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.6	0.7
115-11-7	2-Methylpropene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
504-60-9	1,3-Pentadiene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
109-66-0	Pentane	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
109-67-1	1-Pentene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
646-04-8	2-Pentene, (E)-	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
627-20-3	2-Pentene, (Z)-	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
463-49-0	Propadiene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0

Reference Table 13 (continued)

	Quantity in Cloud (pounds)	500	2,000	5,000	10,000	20,000	50,000	100,000	200,000	500,000	1,000,000	2,000,000
CAS No.	**Chemical Name**	**Distance (Miles) to 1 psi Overpressure**										
74-98-6	Propane	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
115-07-1	Propylene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
74-99-7	Propyne	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
7803-62-5	Silane	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
116-14-3	Tetrafluoroethylene	0.02	0.03	0.04	0.05	0.07	0.09	0.1	0.1	0.2	0.2	0.3
75-76-3	Tetramethylsilane	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
10025-78-2	Trichlorosilane	0.03	0.04	0.06	0.08	0.1	0.1	0.2	0.2	0.3	0.4	0.4
79-38-9	Trifluorochloroethylene	0.02	0.03	0.05	0.06	0.07	0.1	0.1	0.2	0.2	0.3	0.3
75-50-3	Trimethylamine	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.6	0.8	1.0
689-97-4	Vinyl acetylene	0.06	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0
75-01-4	Vinyl chloride	0.05	0.08	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8
109-92-2	Vinyl ethyl ether	0.06	0.09	0.1	0.2	0.2	0.3	0.3	0.4	0.6	0.7	0.9
75-02-5	Vinyl fluoride	0.02	0.04	0.05	0.06	0.08	0.1	0.1	0.2	0.2	0.3	0.4
75-35-4	Vinylidene chloride	0.04	0.06	0.08	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6
75-38-7	Vinylidene fluoride	0.04	0.06	0.09	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6
107-25-5	Vinyl methyl ether	0.06	0.09	0.1	0.2	0.2	0.3	0.3	0.4	0.6	0.7	0.9

6 DETERMINING ALTERNATIVE RELEASE SCENARIOS

In Chapter 6

- Considerations for alternative release scenarios for regulated substances in Program 2 or Program 3 processes.
- Potential alternative scenarios for releases of flammable substances.

You are required to analyze at least one alternative release scenario for each listed toxic substance you have in a Program 2 or Program 3 process above its threshold quantity. You also are required to analyze one alternative release scenario for flammable substances in Program 2 or 3 processes as a class (i.e., you analyze one scenario involving a flammable substance as a representative scenario for all the regulated flammable substances you have on site in Program 2 or Program 3 processes). You do not need to analyze an alternative scenario for each flammable substance. For example, if you have five listed substances – chlorine, ammonia, hydrogen chloride, propane, and acetylene – above the threshold in Program 2 or 3 processes, you will need to analyze one alternative scenario each for chlorine, ammonia, and hydrogen chloride and a single alternative scenario to cover propane and acetylene (listed flammable substances). Even if you have a substance above the threshold in several processes or locations, you need only analyze one alternative scenario for it.

According to the rule (40 CFR 68.28), alternative scenarios should be more likely to occur than the worst-case scenario and should reach an endpoint offsite, unless no such scenario exists. Release scenarios considered should include, but are not limited to, the following:

- Transfer hose releases due to splits or sudden hose uncoupling;
- Process piping releases from failures at flanges, joints, welds, valves and valve seals, and drains or bleeds;
- Process vessel or pump releases due to cracks, seal failure, or drain, bleed, or plug failure;
- Vessel overfilling and spill, or overpressurization and venting through relief valves or rupture disks; and
- Shipping container mishandling or puncturing leading to a spill.

Alternative release scenarios for toxic substances should be those that lead to concentrations above the toxic endpoint beyond your fenceline. Scenarios for flammable substances should have the potential to cause substantial damage, including on-site damage. Those releases that have the potential to reach the public are of the greatest concern. You should consider unusual situations, such as start-up and shut-down, in selecting an appropriate alternative scenario.

For alternative release scenarios, you are allowed to consider active mitigation systems, such as interlocks, shutdown systems, pressure relieving devices, flares, emergency isolation systems, and fire water and deluge systems, as well as passive mitigation systems, as described in Sections 3.1.2 and 3.2.3.

For alternative release scenarios for regulated substances used in ammonia refrigeration, chemical distribution, propane distribution, warehouses, or POTWs, consult EPA's risk management program guidance documents for these industry sectors.

You have a number of options for selecting release scenarios for toxic or flammable substances.

- You may use your worst-case release scenario and apply your active mitigation system to limit the quantity released and the duration of the release.
- You may use information from your process hazards analysis, if you have conducted one, to select a scenario.
- You may review your accident history and choose an actual event as the basis of your scenario.
- If you have not conducted a process hazards analysis, you may review your operations and identify possible events and failures.

Whichever approach you select, the key information you need to define is the quantity to be released and the time over which it will be released; together, these allow you to estimate the release rate and use essentially the same methods you used for the worst-case analysis.

For flammable substances , the choice of alternative release scenarios is somewhat more complicated than for toxic substances, because the consequences of a release and the endpoint of concern may vary. For the flammable worst case, the consequence of concern is a vapor cloud explosion, with an overpressure endpoint. For alternative scenarios (e.g., fires), other endpoints (e.g., heat radiation) may need to be considered.

Possible scenarios involving flammable substances include:

- Vapor cloud fires (flash fires) may result from dispersion of a cloud of flammable vapor and ignition of the cloud following dispersion. Such a fire could flash back and could represent a severe heat radiation hazard to anyone in the area of the cloud. This guidance provides methods to estimate distances to a concentration equal to the lower flammability limit (LFL) for this type of fire. (See Sections 9.1, 9.2, and 10.1.)
- A pool fire, with potential radiant heat effects, may result from a spill of a flammable liquid. This guidance provides a simple method for estimating the distance from a pool fire to a radiant heat level that could cause second degree burns from a 40-second exposure. (See Section 10.2).
- A boiling liquid, expanding vapor explosion (BLEVE), leading to a fireball that may produce intense heat, may occur if a vessel containing flammable material ruptures explosively as a result of exposure to fire. Heat radiation from the fireball is the primary hazard; vessel fragments and overpressure from the explosion also can result. BLEVEs are generally considered unlikely events; however, if you think a BLEVE is possible at your site, this guidance provides a method to estimate the distance at which radiant heat effects might lead to second degree burns. (See Section 10.3.) You also may want to consider models or

calculation methods to estimate effects of vessel fragmentation. (See Appendix A for references that may provide useful information for estimating such effects.)

- For a vapor cloud explosion to occur, rapid release of a large quantity, turbulent conditions (caused by a turbulent release or congested conditions in the area of the release, or both), and other factors are generally necessary. Vapor cloud explosions generally are considered unlikely events; however, if conditions at your site are conducive to vapor cloud explosions, you may want to consider a vapor cloud explosion as an alternative scenario. This guidance provides methods you may use to estimate the distance to 1 psi overpressure for a vapor cloud detonation, based on less conservative assumptions than the worst-case analysis. (See Section 10.4.) A vapor cloud deflagration, involving lower flame speeds than a detonation and resulting in less damaging blast effects, is more likely than a detonation. This guidance does not provide methods for estimating the effects of a deflagration, but you may use other methods of analysis if you want to consider such events. (See Appendix A for references that may provide useful information.)

- A jet fire may result from the puncture or rupture of a tank or pipeline containing a compressed or liquefied gas under pressure. The gas discharging from the hole can form a jet that "blows" into the air in the direction of the hole; the jet then may ignite. Jet fires could contribute to BLEVEs and fireballs if they impinge on tanks of flammable substances. A large horizontal jet fire may have the potential to pose an offsite hazard. This guidance does not include a method for estimating consequence distances for jet fires. If you want to consider a jet fire as an alternative scenario, you should consider other models or methods for the consequence analysis. (See Appendix A for references that may provide useful information.)

If you carry out an alternative scenario analysis for a flammable mixture (i.e., a mixture that meets the criteria for NFPA 4), you need to consider all flammable components of the mixture, not just the regulated flammable substance or substances in the mixture (see Section 5.2 on flammable mixtures). If the mixture contains both flammable and non-flammable components, the analysis should be carried out considering only the flammable components.

Chapter 7 provides detailed information on calculating release rates for alternative release scenarios for toxic substances. If you can estimate release rates for the toxic gases and liquids you have on site based on readily available information, you may skip Chapter 7 and go to Chapter 8. Chapter 8 describes how to estimate distances to the toxic endpoint for alternative scenarios for toxic substances. Chapters 9 provides information on calculation release rates for flammable substances. Chapter 10 describes how to estimate distances to flammable endpoints.

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7 ESTIMATION OF RELEASE RATES FOR ALTERNATIVE SCENARIOS FOR TOXIC SUBSTANCES

For the alternative scenario analysis, you may use typical meteorological conditions and typical ambient temperature and humidity for your site. This guidance assumes D atmospheric stability and wind speed of 3.0 meters per second (6.7 miles per hour) as conditions likely to be applicable to many sites.

7.1 Release Rates for Toxic Gases

In Section 7.1

- 7.1.1 Methods for unmitigated releases of toxic gases, including:
  - Release of toxic gas from a hole in a tank or pipe (for choked flow conditions, or maximum flow rate),
  - Release of toxic gas from a pipe, based on the flow rate through the pipe, or based on a hole in the pipe (using the same method as for a hole in a tank),
  - Puff releases (no method is provided; users are directed to use other methods),
  - Gases liquefied under pressure, including gaseous releases from holes above the liquid level in the tank and releases from holes in the liquid space, and
  - Consideration of duration of releases of toxic gas.
- 7.1.2 Methods for adjusting the estimated release rate to account for active or passive mitigation, including:
  - Active mitigation to reduce the release duration (e.g., automatic shutoff valves),
  - Active mitigation to reduce the release rate to air, and
  - Passive mitigation (using the same method as for worst-case scenarios).

7.1.1 Unmitigated Releases of Toxic Gases

Gaseous Releases

Gaseous Release from Tank. Instead of assuming release of the entire contents of a vessel containing a toxic gas, you may decide to consider a more likely scenario as developed by the process hazards analysis, such as release from a hole in a vessel or pipe. To estimate a hole size you might assume, for example, the hole size that would result from shearing off a valve or pipe from a vessel containing a regulated substance. If you have a gas leak from a tank, you may use the following simplified equation to estimate a release rate based on hole size, tank pressure, and the properties of the gas. This equation applies to choked flow, or maximum gas flow rate. Choked flow generally would be expected for gases under pressure. (See Appendix D, Section D.6 for the derivation of this equation.)

$$QR = HA \times P_t \times \frac{1}{\sqrt{T_t}} \times GF \tag{7-1}$$

where:

QR = Release rate (pounds per minute)
HA = Hole or puncture area (square inches) (from hazard evaluation or best estimate)
P_t = Tank pressure (pounds per square inch absolute (psia)) (from process information; for liquefied gases, equilibrium vapor pressure at 25 °C is included in Exhibit B-1, Appendix B)
T_t = Tank temperature (K), where K is absolute temperature in kelvins; 25 °C (77 °F) is 298 K
GF = Gas Factor, incorporating discharge coefficient, ratio of specific heats, molecular weight, and conversion factors (listed for each regulated toxic gas in Exhibit B-1, Appendix B)

You can estimate the hole area from the size and shape of the hole. For a circular hole, you would use the formula for the area of a circle (area = πr^2, where π is 3.14 and r is the radius of the circle; the radius is half the diameter).

This equation will give an estimate of the initial release rate. It will overestimate the overall release rate, because it does not take into account the decrease in the release rate as the pressure in the tank decreases. You may use a computer model or another calculation method if you want a more realistic estimate of the release rate. As discussed below, you may use this equation for releases of gases liquefied under pressure if the release would be primarily gas (e.g., if the hole is in the head space of the tank, well above the liquid level).

Example 19. Release of Toxic Gas from Tank (Diborane)

You have a tank that contains diborane gas at a pressure of 30 psia. The temperature of the tank and its contents is 298 K (25°C). A valve on the side of the tank shears off, leaving a circular hole 2 ½ inches in diameter in the tank wall. You estimate the area from the formula for area of a circle (πr^2, where r is the radius). The radius of the hole is 1 1/4 inches, so the area is $\pi \times (1\ 1/4)^2$, or 5 square inches. From Exhibit B-1, the Gas Factor for diborane is 17. Therefore, the release rate, from Equation 7-1, is:

$$QR = 5 \times 30 \times 1/(298)^{1/2} \times 17 = 148 \text{ pounds per minute}$$

Gaseous Release from Pipe. If shearing of a pipe may be an alternative scenario for a toxic gas at your site, you could use the usual flow rate through the pipe as the release rate and carry out the estimation of distance as discussed in Chapter 8.

If you want to consider a release of toxic gas through a hole in a pipe as an alternative scenario, you may use the method described above for a gas release from a hole in a tank. This method neglects the effects of friction along the pipe and, therefore, provides a conservative estimate of the release rate.

Puff Releases. If a gaseous release from a hole in a tank or pipe is likely to be stopped very quickly (e.g., by a block valve), resulting in a puff of toxic gas that forms a vapor cloud rather than a plume, you may want to consider other methods for determining a consequence distance. A cloud of toxic gas resulting from a puff release will not exhibit the same behavior as a plume resulting from a longer release (e.g., a release over 10 minutes).

Liquefied Gases

Gases Liquefied Under Pressure. Gases liquefied under pressure may be released as gases, liquids, or a combination (two-phase), depending on a number of factors, including liquid level and the location of the hole relative to the liquid level. The resulting impact distances can vary greatly.

For releases from holes above the liquid level in a tank of gas liquefied under pressure, the release could be primarily gas, or the release may involve rapid vaporization of a fraction of the liquefied gas and possibly aerosolization (two-phase release). It is complex to determine which type of release (i.e., gas, two-phase) will occur and the likely mix of gases and liquids in a two-phase release. The methods presented in this guidance do not definitively address this situation. As a rule of thumb, if the head space is large and the distance between the hole and the liquid level is relatively large given the height of the tank or vessel, you could assume the release is gaseous and, therefore, use Equation 7-1 above. (Exhibit B-1, Appendix B, includes the equilibrium vapor pressure in psia for listed toxic gases liquefied under pressure at 25 ^{o}C; this pressure can be used in Equation 7-1.) However, use of this equation will not be conservative if the head space is small and the release from the hole is two-phased. In situations where you are unsure of whether the release would be gaseous or two-phase, you may want to consider other models or methods to carry out a consequence analysis.

For a hole in the liquid space of a tank, you may use Equation 7-2 below to estimate the release rate. Exhibit B-1 in Appendix B gives the equilibrium vapor pressure in psia for listed toxic gases at 25 ^{o}C; this is the pressure required to liquefy the gas at this temperature. You can estimate the gauge pressure in the tank from the equilibrium vapor pressure by subtracting the pressure of the ambient atmosphere (14.7 psi). Exhibit B-1 also gives the Density Factor (DF) for each toxic gas at its boiling point. This factor can be used to estimate the density of the liquefied gas (the density at 25 ^{o}C would not be significantly different from the density at the boiling point for most of the listed gases). The equation to estimate the release rate is (see Appendix D, Section D.7.1, for more information):

$$QR = HA \times 6.82 \sqrt{\frac{11.7}{DF^2} \times LH + \frac{669}{DF} \times P_g} \qquad \textbf{(7-2)}$$

where:
QR = Release rate (pounds per minute)
HA = Hole or puncture area (square inches) (from hazard evaluation or best estimate)
DF = Density Factor (listed for each regulated toxic gas in Exhibit B-1, Appendix B; 1/(DF x 0.033) is density in pounds per cubic foot)
LH = Height of liquid column above hole (inches) (from hazard evaluation or best estimate)
P_g = Gauge pressure of the tank pressure (pounds per square inch gauge (psig), from vapor pressure of gas (listed in Exhibit B-1, Appendix B) minus atmospheric pressure (14.7 psi)

This equation gives the rate of release of liquid through the hole. For a gas liquefied under pressure, assume that the released liquid will immediately flash into vapor (or a vapor/aerosol mixture) and the release rate to air is the same as the liquid release rate. This equation gives an estimate of the initial release rate. It will overestimate the overall release rate, because it does not take into account the decrease in the release rate as the pressure in the tank and the height of the liquid in the tank decrease. You may use a computer model or another calculation method if you want a more realistic estimate of the release rate.

For a release from a broken pipe of a gas liquefied under pressure, see equations 7-4 to 7-6 below for liquid releases from pipes. Assume the released liquid flashes into vapor upon release and use the calculated release rate as the release rate to air.

Gases Liquefied by Refrigeration. Gases liquefied by refrigeration alone may be treated as liquids. You may use the methods described in Section 7.2 for estimation of release rates.

Duration of Release

The duration of the release is used in choosing the appropriate generic reference table of distances, as discussed in Chapter 8. (You do not need to consider the duration of the release to use the chemical-specific reference tables.) You may calculate the maximum duration by dividing the quantity in the tank or the quantity that may be released from pipes by your calculated release rate. You may use 60 minutes as a default value for maximum release duration. If you know, and can substantiate, how long it is likely to take to stop the release, you may use that time as the release duration.

7.1.2 Mitigated Releases of Toxic Gases

For gases, passive mitigation may include enclosed spaces, as discussed in Section 3.1.2. Active mitigation for gases, which may be considered in analyzing alternative release scenarios, may include an assortment of techniques including automatic shutoff valves, rapid transfer systems (emergency deinventory), and water/chemical sprays. These mitigation techniques have the effect of reducing either the release rate or the duration of the release, or both.

Active Mitigation

Active Mitigation to Reduce Release Duration. An example of a mitigation technique to reduce the release duration is automatic shutoff valves. If you have an estimate of the rate at which the gas will be released and the time it will take to shut off the release, you may estimate the quantity potentially released (release rate times time). You must be able to substantiate the time it will take to shut off the release. If the release will take place over a period of 10 minutes or more, you may use the release rate to estimate the distance to the toxic endpoint, as discussed in Chapter 8. For releases stopped in less than 10 minutes, multiply the initial release rate by the duration of release to estimate the quantity released, then divide the new quantity by 10 minutes to estimate a mitigated release rate that you may apply to the reference tables described in Chapter 8 to estimate the consequence distance. If the release would be stopped very quickly, you might want to consider other methods that will estimate consequence distances for a puff release.

Active Mitigation to Directly Reduce Release Rate to Air. Examples of mitigation techniques to directly reduce the release rate include scrubbers and flares. Use test data, manufacturer design specifications, or past experience to determine the fractional reduction of the release rate by the mitigation technique. Apply this fraction to the release rate that would have occurred without the mitigation technique. The initial release rate, without mitigation, may be the release rate for the alternative scenario (e.g., a release rate estimated from the equations presented earlier in this section) or the worst-case release rate. The mitigated release rate is:

$$QR_R = (1 - FR) \times QR \tag{7-3}$$

where:
QR_R = Reduced release rate (pounds per minute)
FR = Fractional reduction resulting from mitigation
QR = Release rate without mitigation (pounds per minute)

Example 20. Water Spray Mitigation (Hydrogen Fluoride)

A bleeder valve on a hydrogen fluoride (HF) tank opens, releasing 660 pounds per minute of HF. Water sprays are applied almost immediately. Experimental field and laboratory test data indicate that HF vapors could be reduced by 90 percent. The reduced release rate is:

$$\begin{aligned} QR_R &= (1 - 0.9) \times (660 \text{ pounds per minute}) \\ &= 66 \text{ pounds per minute} \end{aligned}$$

In estimating the consequence distance for this release scenario, you would need to consider the release both before and after application of the water spray and determine which gives the greatest distance to the endpoint. You need to be able to substantiate the time needed to begin the water spray mitigation.

Passive Mitigation

The same simplified method used for worst-case releases may be used for alternative release scenarios to estimate the release rate to the outside air from a release in an enclosed space. For alternative scenarios, you may use a modified release quantity, if appropriate. You may also adjust the mitigation factor to account for the effects of ventilation, if appropriate for the alternative scenario you have chosen. Use the equations presented in Section 3.1.2 to estimate the release rate to the outside air.

Duration of Release

You should estimate the duration of the release either from your knowledge of the length of time it may take to stop the release (be prepared to substantiate your time estimate) or by dividing the quantity that may be released by your estimated release rate. (You do not need to consider the release duration to use the chemical-specific reference tables of distances.)

7.2 Release Rates for Toxic Liquids

In Section 7.2

- 7.2.1 Methods for estimating the liquid release rate and quantity released for toxic liquids released without mitigation, including:
    - Release of toxic liquid from a hole in a tank under atmospheric pressure (including toxic gases liquefied by refrigeration alone),
    - Release of toxic liquid from a hole in the liquid space of a pressurized tank (the user is referred to equations provided in the section on toxic gases or in the technical appendix), and
    - Release of toxic liquid from a broken pipe.
- 7.2.2 Methods for estimating the liquid release rate and quantity released for toxic liquids released with mitigation measures that reduce the duration of the liquid release or the quantity of liquid released (e.g., automatic shutoff valves),
- 7.2.3 Methods for estimating the evaporation rate of toxic liquids from pools, accounting for:
    - Ambient temperature,
    - Elevated temperature,
    - Diked areas,
    - Releases into buildings,
    - Active mitigation to reduce the evaporation rate of the liquid,
    - Temperatures between 25 °C and 50 °C, and
    - Duration of the release.
- 7.2.4 Methods for estimating the evaporation rate for common water solutions of regulated toxic substances and for oleum.

This section describes methods for estimating liquid release rates from tanks and pipes. The released liquid is assumed to form a pool, and the evaporation rate from the pool is estimated as for the worst-case scenario. For the alternative scenario, you may assume the average wind speed in your area in the calculation of evaporation rate, instead of the worst-case wind speed of 1.5 meters per second (3.4 miles per hour). For the reference tables in this guidance, the wind speed for alternative scenarios is assumed to be 3.0 meters per second (6.7 miles per hour).

If you have sufficient information to estimate the quantity of liquid that might be released to an undiked area under an alternative scenario, you may go directly to Section 7.2.3 to estimate the evaporation rate from the pool and the release duration. After you have estimated the evaporation rate and release duration, go to Chapter 8 for instructions on estimating distance to the toxic endpoint.

7.2.1 Liquid Release Rate and Quantity Released for Unmitigated Releases

Release from Tank

<u>Tank under Atmospheric Pressure</u>. If you have a liquid stored in a tank at atmospheric pressure (including gases liquefied by refrigeration alone), you may use the following simple equation to estimate the liquid release rate from a hole in the tank below the liquid level. (See Appendix D, Section D.7.1, for the derivation of this equation.)

$$QR_L = HA \times \sqrt{LH} \times LLF \qquad \textbf{(7-4)}$$

where:
QR_L = Liquid release rate (pounds per minute)
HA = Hole or puncture area (square inches) (from hazard evaluation or best estimate)
LH = Height of liquid column above hole (inches) (from hazard evaluation or best estimate)
LLF = Liquid Leak Factor incorporating discharge coefficient and liquid density (listed for each toxic liquid in Exhibit B-2, Appendix B).

Remember that this equation only applies to liquids in tanks under atmospheric pressure. This equation will give an overestimate of the release rate, because it does not take into account the decrease in the release rate as the height of the liquid above the hole decreases. You may use a computer model or another calculation method if you want a more realistic estimate of the liquid release rate.

You may estimate the quantity that might be released by multiplying the liquid release rate from the above equation by the time (in minutes) that likely would be needed to stop the release. You should be able to substantiate the time needed to stop the release. Alternatively, you may assume the release would stop when the level of liquid in the tank drops to the level of the hole. You may estimate the quantity of liquid above that level in the tank from the dimensions of the tank, the liquid level at the start of the leak, and the level of the hole. Assume the estimated quantity is released into a pool and use the method and equations in Section 7.2.3 below to determine the evaporation rate of the liquid from the pool and the duration of the release. As discussed in Section 7.2.3, if you find that your estimated evaporation rate is greater than estimated liquid release rate, you should use the liquid release rate as the release rate to air.

Example 21. Liquid Release from Atmospheric Tank (Allyl Alcohol)

You have a tank that contains 20,000 pounds of allyl alcohol at ambient temperature and pressure. A valve on the side of the tank shears, leaving a hole in the tank wall 5 square inches in area. The liquid column is 23 inches above the hole in the tank. From Exhibit B-2, the Liquid Leak Factor for allyl alcohol is 41. Therefore, from Equation 7-4, the liquid release rate is:

$$QR_L = 5 \times (23)^{1/2} \times 41 = 983 \text{ pounds per minute}$$

It takes 10 minutes to stop the release, so 10 minutes × 983 pounds per minute = 9,830 pounds of allyl alcohol released.

Pressurized Tank. If you have a liquid stored in a tank under pressure, you may estimate a release rate for liquid from a hole in the liquid space of the tank using the equation presented above for gases liquefied under pressure (Equation 7-2 in Section 7.1.1) or the equations in Appendix D, Section D.7.1.

Release from Pipe

If you have a liquid flowing through a pipe at approximately atmospheric pressure, and the pipeline remains at about the same height between the pipe inlet and the pipe break, you can estimate the quantity of liquid released from the flow rate in the pipe and the time it would take to stop the release by multiplying the flow rate by the time. For liquids at atmospheric pressure, assume the liquid is spilled into a pool and use the methods in Section 7.2.3 below to estimate the release rate to air.

For the release of a liquid under pressure from a long pipeline, you may use the equations below (see Appendix D, Section D.7.2 for more information on these equations). These equations apply both to substances that are liquid at ambient conditions and to gases liquefied under pressure. This method does not consider the effects of friction in the pipe. First estimate the initial operational flow velocity of the substance through the pipe using the initial operational flow rate as follows:

$$V_a = \frac{FR \times DF \times 0.033}{A_p} \tag{7-5}$$

where:
V_a = Initial operational flow velocity (feet per minute)
FR = Initial operational flow rate (pounds per minute)
DF = Density Factor (from Exhibit B-2, Appendix B)
A_p = Cross-sectional area of pipe (square feet)

You can estimate the cross-sectional area of the pipe from the diameter or radius (half the diameter of the pipe) using the formula for the area of a circle (area = πr^2, where r is the radius).

The release velocity is then calculated based on the initial operational flow, any gravitational acceleration or deceleration effects resulting from changes in the height of the pipeline, and the pressure difference between the pressure in the pipe and atmospheric pressure, using a form of the Bernoulli equation:

$$V_b = 197 \times \sqrt{[28.4 \times (P_T - 14.7) \times DF] + [5.97 \times (Z_a - Z_b)] + [2.58\times10^{-5} \times V_a^2]} \quad \textbf{(7-6)}$$

where: V_b = Release velocity (feet per minute)
P_T = Total pressure on liquid in pipe (psia)
DF = Density factor, see Exhibit B-1 or Exhibit B-2
Z_a = Height of pipeline at inlet (feet)
Z_b = Height of pipeline at break (feet)
V_a = Operational velocity (feet per minute), calculated from Equation 7-5

Please note that if the height of the pipe at the release point is higher than the initial pipe height, then Z_a-Z_b is negative, and the height term will cause the estimated release velocity to decrease.

The release velocity can then be used to calculate a release rate as follows:

$$QR_L = \frac{V_b \times A_p}{DF \times 0.033} \quad \textbf{(7-7)}$$

where: QR_L = Release rate (pounds per minute)
V_b = Release velocity (feet per minute)
DF = Density Factor
A_p = Cross-sectional area of pipe (square feet)

You may estimate the quantity released into a pool from the broken pipe by multiplying the liquid release rate (QR_L) from the equation above by the time (in minutes) that likely would be needed to stop the release (or to empty the pipeline). Assume the estimated quantity is released into a pool and use the method and equations described in Section 7.2.3 below to determine the evaporation rate of the liquid from the pool. You must be able to substantiate the time needed to stop the release.

As noted above in Section 7.1.1, for a release from a pipe of gas liquefied under pressure, assume that the released liquid is immediately vaporized, and use the calculated liquid release rate as the release rate to air. If the release duration would be very short (e.g., because of active mitigation measures), determine the total quantity of the release as the release rate times the duration, then estimate a new release rate as the quantity divided by 10. This will give you a release rate that you can use with the 10-minute reference tables of distances in this guidance to estimate a distance to the endpoint.

In the case of very long pipes, release rates from a shear or hole will be lower than the estimates from this method because of pipe roughness and frictional head loss. If friction effects are deemed considerable, an established method for calculating frictional head loss such as the Darcy formula may be used.

7.2.2 Liquid Release Rate and Quantity Released for Mitigated Releases

For alternative release scenarios, you are permitted to take credit for both passive and active mitigation systems, or a combination if both are in place. Active mitigation techniques that reduce the rate of liquid release or the quantity released into the pool are discussed in this section. Active and passive mitigation to reduce the evaporation rate of liquid from a pool are discussed in the next section.

Active Mitigation to Reduce Quantity Released

Examples of mitigation techniques to reduce the quantity released into the pool include automatic shutoff valves and emergency deinventory. You may use the equations in Section 7.2.1 above for calculating liquid release rate, if applicable. Estimate the approximate time needed to stop the release by the mitigation technique (you must be able to justify your estimate). Multiply the release rate times the duration of release to estimate quantity released. Assume the estimated quantity is released into a pool and use the method and equations described in Section 7.2.3 below to determine the evaporation rate of the liquid from the pool. You should also consider mitigation (active or passive) of evaporation from the pool, if applicable, as discussed in Section 7.2.3 below.

Example 22. Mitigated Liquid Release

A bromine injection system suffers a hose failure; the greatly lowered system pressure triggers an automatic shutoff valve within 30 seconds of the release. The flow rate out of the ruptured hose is approximately 330 pounds per minute. Because the release occurred for only 30 seconds (0.5 minutes), the total quantity spilled was 330 x 0.5, or 165 pounds.

7.2.3 Evaporation Rate from Liquid Pool

After you have estimated the quantity of liquid released, assume that the liquid forms a pool and calculate the evaporation rate from the pool as described below. You may account for both passive and active mitigation in estimating the release rate. Passive mitigation may include techniques already discussed in Section 3.2.3 such as dikes and trenches. Active mitigation to reduce the release rate of liquid in pools to the air may include an assortment of techniques including foam or tarp coverings and water or chemical sprays. Some methods of accounting for passive and active mitigation are discussed below.

If the calculated evaporation rate from the pool is greater than the liquid release rate you have estimated from the container, no pool would be formed, and calculating the release rate as the evaporation rate from a pool would not be appropriate. If the pool evaporation rate is greater than the liquid release rate, use the liquid release rate as the release rate to air. Consider this possibility particularly for relatively volatile liquids, gases liquefied by refrigeration, or liquids at elevated temperature that form pools with no mitigation.

Unmitigated

Ambient temperature. For pools with no mitigation, if the liquid is always at ambient temperature, find the Liquid Factor Ambient (LFA) and the Density Factor (DF) in Exhibit B-2 of Appendix B (see Appendix D, Section D.2.2 for the derivation of these factors). If your ambient temperature is between 25 °C and 50 °C, you may use this method to calculate the release rate, and then use the appropriate Temperature Correction Factor from Exhibit B-4, Appendix B, to adjust the release rate, as described below. For gases liquefied by refrigeration, use the Liquid Factor Boiling (LFB) and DF from Exhibit B-1. Calculate the release rate from the following equation for liquids at ambient temperature with no mitigation:

$$QR = QS \times 2.4 \times LFA \times DF \tag{7-8}$$

where:
QR = Release rate (pounds per minute)
QS = Quantity released (pounds)
2.4 = Wind speed factor = $3.0^{0.78}$, where 3.0 meters per second (6.7 miles per hour) is the wind speed for the alternative scenario for purposes of this guidance
LFA = Liquid Factor Ambient
DF = Density Factor

This method assumes that the total quantity of liquid released spreads out to form a pool one centimeter in depth; it does not take into account evaporation as the liquid is released.

Example 23. Evaporation from Pool Formed by Liquid Released from Hole in Tank (Allyl Alcohol)

In Example 21, 9,830 pounds of allyl alcohol were estimated to be released from a hole in a tank. From Exhibit B-2, the Density Factor for allyl alcohol is 0.58, and the Liquid Factor Ambient is 0.0046. Assuming that the liquid is not released into a diked area or inside a building, the evaporation rate from the pool of allyl alcohol, from Equation 7-8, is:

$$QR = 9{,}830 \times 2.4 \times 0.0046 \times 0.58 = 63 \text{ pounds per minute}$$

Elevated temperature. For pools with no mitigation, if the liquid is at an elevated temperature (above 50 °C or at or close to its boiling point), find the Liquid Factor Boiling (LFB) and the Density Factor (DF) in Exhibit B-2 of Appendix B (see Appendix D, Section D.2.2, for the derivation of these factors). For liquids at temperatures between 25 °C and 50 °C, you may use the method above for ambient temperature and apply the appropriate Temperature Correction Factor from Appendix B, Exhibit B-4, to the result, as discussed below. For liquids above 50 °C, or close to their boiling points, or with no Temperature Correction Factors available, calculate the release rate of the liquid from the following equation:

$$QR = QS \times 2.4 \times LFB \times DF \tag{7-9}$$

where: QR = Release rate (pounds per minute)
QS = Quantity released (pounds)
2.4 = Wind speed factor = $3.0^{0.78}$, where 3.0 meters per second (6.7 miles per hour) is the wind speed for the alternative scenario for purposes of this guidance
LFB = Liquid Factor Boiling
DF = Density Factor

Mitigated

Diked Areas. If the toxic liquid will be released into an area where it will be contained by dikes, compare the diked area to the maximum area of the pool that could be formed, as described in Section 3.2.3 (see Equation 3-6). Also verify that the quantity spilled will be totally contained by the dikes. The smaller of the two areas should be used in determination of the evaporation rate. If the maximum area of the pool is smaller than the diked area, calculate the release rate as described for pools with no mitigation (above). If the diked area is smaller, and the spill will be totally contained, go to Exhibit B-2 in Appendix B to find the Liquid Factor Ambient (LFA), if the liquid is at ambient temperature, or the Liquid Factor Boiling (LFB), if the liquid is at an elevated temperature. For temperatures between 25 °C and 50 °C, you may use the appropriate Temperature Correction Factor from Exhibit B-4, Appendix B, to adjust the release rate, as described below. For gases liquefied by refrigeration, use the LFB. Calculate the release rate from the diked area as follows for liquids at ambient temperature:

$$QR = 2.4 \times LFA \times A \qquad \textbf{(7-10)}$$

or, for liquids at elevated temperatures or gases liquefied by refrigeration alone:

$$QR = 2.4 \times LFB \times A \qquad \textbf{(7-11)}$$

where: QR = Release rate (pounds per minute)
2.4 = Wind speed factor = $3.0^{0.78}$, where 3.0 meters per second (6.7 miles per hour) is the wind speed for the alternative scenario for purposes of this guidance
LFA = Liquid Factor Ambient (listed in Exhibit B-2, Appendix B)
LFB = Liquid Factor Boiling (listed in Exhibit B-1 or B-2, Appendix B)
A = Diked area (square feet)

Releases Into Buildings. If a toxic liquid is released inside a building, compare the area of the building floor or any diked area that would contain the spill to the maximum area of the pool that could be formed; the smaller of the two areas should be used in determining the evaporation rate, as for the worst-case scenario. The maximum area of the pool is determined from Equation 3-6 in Section 3.2.3 for releases into diked areas. The area of the building floor is the length times width of the floor (in feet) (Equation 3-9).

If the floor area or diked area is smaller than the maximum pool size, estimate the outdoor evaporation rate from a pool the size of the floor area or diked area from Equation 7-10. If the maximum pool area is smaller, estimate the outdoor evaporation rate from a pool of maximum size from Equation 7-8.

Estimate the rate of release of the toxic vapor from the building as five percent of the calculated outdoor evaporation rate (multiply your evaporation rate by 0.05). See Appendix D, Section D.2.4 for more information on releases into buildings.

Active Mitigation to Reduce Evaporation Rate. Examples of active mitigation techniques to reduce the evaporation rate from the pool include water sprays and foam or tarp covering. Use test data, manufacturer design specifications, or past experience to determine the fractional reduction of the release rate by the mitigation technique. Apply this fraction to the release rate (evaporation rate from the pool) that would have occurred without the mitigation technique, as follows:

$$QR_{RV} = (1 - FR) \times QR \qquad \textbf{(7-12)}$$

where:
QR_{RV} = Reduced evaporation rate (release rate to air) from pool (pounds per minute)
FR = Fractional reduction resulting from mitigation
QR = Evaporation rate from pool without mitigation (pounds per minute)

Temperature Corrections for Liquids at Temperatures between 25 and 50 °C

If your liquid is at a temperature between 25 °C (77 °F) and 50 °C (122 °F), you may use the appropriate Temperature Correction Factor (TCF) from Exhibit B-4, Appendix B, to calculate a corrected release rate. Calculate the release rate (QR) of the liquid at 25 °C (77 °F) as described above for unmitigated releases or releases in diked areas and multiply the release rate by the appropriate TCF as described in Section 3.2.5.

Evaporation Rate Compared to Liquid Release Rate

If you estimated the quantity of liquid in the pool based on an estimated liquid release rate from a hole in a container or pipe, as discussed in Sections 7.2.1 and 7.2.2, compare the evaporation rate with the liquid release rate. If the evaporation rate from the pool is greater than the liquid release rate, use the liquid release rate as the release rate to air.

Duration of Release

After you have estimated a release rate as described above, determine the duration of the vapor release from the pool (the time it will take for the liquid pool to evaporate completely). To estimate the time in minutes, divide the total quantity released (in pounds) by the release rate (in pounds per minute) (see Equation 3-5 in Section 3.2.2). If you are using the liquid release rate as the release rate to air, as discussed in the preceding paragraph, estimate a liquid release duration as discussed in Section 7.2.1 or 7.2.2. The duration could be the time it would take to stop the release or the time it would take to empty the tank or to release all the liquid above the level of the leak. If you have corrected the release rate for a temperatures above 25 °C, use the corrected release rate to estimate the duration.

7.2.4 Common Water Solutions and Oleum

You may use the methods described above in Sections 7.2.1, 7.2.2, and 7.2.3 for pure liquids to estimate the quantity of a solution of a toxic substance or oleum that may be spilled into a pool. LFA, DF, and LLF values for several concentrations of ammonia, formaldehyde, hydrochloric acid, hydrofluoric acid, and nitric acid in water solution and for oleum are listed in Appendix B, Exhibit B-3. The LFA for a wind speed of 3.0 meters per second (6.7 miles per hour) should be used in the release rate calculations for alternative scenarios for pools of solutions at ambient temperature.

For unmitigated releases or releases with passive mitigation, follow the instructions in Section 7.2.3. If active mitigation measures are in place, you may estimate a reduced release rate from the instructions on active mitigation in Section 7.2.2. Use the total quantity of the solution as the quantity released from the vessel or pipeline (QS) in carrying out the calculation of the release rate to the atmosphere.

If the solution is at an elevated temperature, see Section 3.3. As discussed in Section 3.3, you may treat the release of the substance in solution as a release of the pure substance. Alternatively, if you have vapor pressure data for the solution at the release temperature, you may estimate the release rate from the equations in Appendix D, Sections D.2.1 and D.2.2.

If you estimated the quantity of solution in the pool based on an estimated liquid release rate from a hole in a container or pipe, as discussed in Sections 7.2.1 and 7.2.2, compare the evaporation rate with the liquid release rate. If the evaporation rate from the pool is greater than the liquid release rate, use the liquid release rate as the release rate to air.

8 ESTIMATION OF DISTANCE TO THE ENDPOINT FOR ALTERNATIVE SCENARIOS FOR TOXIC SUBSTANCES

In Chapter 8

- Reference tables of distances for alternative releases, including:
    - Generic reference tables (Exhibit 4), and
    - Chemical-specific reference tables (Exhibit 5).
- Considerations include:
    - Gas density (neutrally buoyant or dense),
    - Duration of release (10 minutes or 60 minutes),
    - Topography (rural or urban).

For estimating consequence distances for alternative scenarios for toxic substances, this guidance provides four generic reference tables for neutrally buoyant gases and vapors and four for dense gases. The generic reference tables of distances (Reference Tables 14-21) are found at the end of Chapter 10. The generic tables and the conditions for which each table is applicable are described in Exhibit 4. Four chemical-specific tables also are provided for ammonia, chlorine, and sulfur dioxide. The chemical-specific reference tables follow the generic reference tables at the end of Chapter 10. These tables, and the applicable conditions, are described in Exhibit 5.

All the reference tables of distances for alternative scenarios were developed assuming D stability and a wind speed of 3.0 meters per second (6.7 miles per hour) as representative of likely conditions for many sites. Many wind speed and atmospheric stability combinations may be possible at different times in different parts of the country. If D stability and 3.0 meters per second are not reasonable conditions for your site, you may want to use other methods to estimate distances.

For simplicity, this guidance assumes ground level releases. This guidance, therefore, may overestimate the consequence distance if your alternative scenario involves a release above ground level, particularly for neutrally buoyant gases and vapors. If you want to assume an elevated release, you may want to consider other methods to determine the consequence distance.

The generic reference tables should be used for all toxic substances other than ammonia, chlorine, and sulfur dioxide. To use the generic reference tables, you need to consider the release rates estimated for gases and evaporation from liquid pools and the duration of the release. For the alternative scenarios, the duration of toxic gas releases may be longer than the 10 minutes assumed for the worst-case analysis for gases. You need to determine the appropriate toxic endpoint and whether the gas or vapor is neutrally buoyant or dense, using the tables in Appendix B and considering the conditions of the release. You may interpolate between entries in the reference tables.

Exhibit 4
Generic Reference Tables of Distances for Alternative Scenarios

Applicable Conditions			Reference Table Number
Gas or Vapor Density	**Topography**	**Release Duration (minutes)**	
Neutrally buoyant	Rural	10	14
		60	15
	Urban	10	16
		60	17
Dense	Rural	10	18
		60	19
	Urban	10	20
		60	21

Exhibit 5
Chemical-Specific Reference Tables of Distances for Alternative Scenarios

Substance	Conditions of Release			Reference Table Number
	Gas or Vapor Density	**Release Duration (minutes)**	**Topography**	
Anhydrous ammonia liquefied under pressure	Dense	10-60	Rural, urban	22
Non-liquefied ammonia, ammonia liquefied by refrigeration, or aqueous ammonia	Neutrally buoyant	10-60	Rural, urban	23
Chlorine	Dense	10-60	Rural, urban	24
Sulfur dioxide (anhydrous)	Dense	10-60	Rural, urban	25

Note the following concerning the use of the chemical-specific reference tables for ammonia, chlorine, and sulfur dioxide:

- The table for anhydrous ammonia (Reference Table 22) applies only to flashing releases of ammonia liquefied under pressure. Use Table 23 for release of ammonia as a gas (e.g., evaporation from a pool or release from the vapor space of a tank).

- You may use these tables for releases of any duration.

To use the reference tables of distances, follow these steps:

For Regulated Toxic Substances Other than Ammonia, Chlorine, and Sulfur Dioxide

- Find the toxic endpoint for the substance in Appendix B (Exhibit B-1 for toxic gases or Exhibit B-2 for toxic liquids).

- Determine whether the table for neutrally buoyant or dense gases and vapors is appropriate from Appendix B (Exhibit B-1 for toxic gases or Exhibit B-2, column for alternative case, for toxic liquids). A toxic gas that is lighter than air may behave as a dense gas upon release if it is liquefied under pressure, because the released gas may be mixed with liquid droplets, or if it is cold. Consider the state of the released gas when you decide which table is appropriate.

- Determine whether the table for rural or urban conditions is appropriate.

  -- Use the rural table if your site is in an open area with few obstructions.

  -- Use the urban table if your site is in an urban or obstructed area.

- Determine whether the 10-minute table or the 60-minute table is appropriate.

  -- Use the 10-minute table for releases from evaporating pools of common water solutions and of oleum.

  -- If you estimated the release duration for gas release or pool evaporation to be 10 minutes or less, use the 10-minute table.

  -- If you estimated the release duration for gas release or pool evaporation to be more than 10 minutes, use the 60-minute table.

<u>Neutrally Buoyant Gases or Vapors</u>

- If Exhibit B-1 or B-2 indicates the gas or vapor should be considered neutrally buoyant, and other factors would not cause the gas or vapor to behave as a dense gas, divide the estimated release rate (pounds per minute) by the toxic endpoint (milligrams per liter).

- Find the range of release rate/toxic endpoint values that includes your calculated release rate/toxic endpoint in the first column of the appropriate table (Reference Table 14, 15, 16, or 17), then find the corresponding distance to the right.

  Dense Gases or Vapors

- If Exhibit B-1 or B-2 or consideration of other relevant factors indicates the substance should be considered a dense gas or vapor (heavier than air), find the distance in the appropriate table (Reference Table 18, 19, 20, or 21) as follows;
  - Find the toxic endpoint closest to that of the substance by reading across the top of the table. If the endpoint of the substance is halfway between two values on the table, choose the value on the table that is smaller (to the left). Otherwise, choose the closest value to the right or the left.
  - Find the release rate closest to the release rate estimated for the substance at the left of the table. If the calculated release rate is halfway between two values on the table, choose the release rate that is larger (farther down on the table). Otherwise, choose the closest value (up or down on the table).
  - Read across from the release rate and down from the endpoint to find the distance corresponding to the toxic endpoint and release rate for your substance.

For Ammonia, Chlorine, or Sulfur Dioxide

- Find the appropriate chemical-specific table for your substance (see the descriptions of Reference Tables 22-25 in Exhibit 5).
  - If you have ammonia liquefied by refrigeration alone, you may use Reference Table 23, even if the duration of the release is greater than 10 minutes.
  - If you have chlorine or sulfur dioxide liquefied by refrigeration alone, you may use the chemical-specific reference tables, even if the duration of the release is greater than 10 minutes.
- Determine whether rural or urban topography is applicable to your site.
  - Use the rural column in the reference table if your site is in an open area with few obstructions.
  - Use the urban column if your site is in an urban or obstructed area.
- Estimate the consequence distance as follows:
  - In the left-hand column of the table, find the release rate closest to your calculated release rate.

-- Read the corresponding distance from the appropriate column (urban or rural) to the right.

The development of the generic reference tables is discussed in Appendix D, Sections D.4.1 and D.4.2. The development of the chemical-specific reference tables is discussed in industry-specific risk management program guidance documents and a backup information document that are cited in Section D.4.3. If you think the results of the method presented here overstate the potential consequences of a your alternative release scenario, you may choose to use other methods or models that take additional site-specific factors into account.

Examples 24 and 25 below include the results of modeling using two other models, ALOHA and WHAZAN, for comparison with the results of the methods presented in this guidance. Appendix D, Section D.4.5 provides additional information on this modeling.

Example 24. Gas Release of Chlorine

Assume that you calculated a release rate of 500 pounds per minute of chlorine from a tank. A chemical-specific table is provided for chlorine, so you do not need to consult Appendix B for information on chlorine. The topography of your site is urban. For a release of chlorine under average meteorology (D stability and 3 meters per second wind speed), go to Reference Table 24. The estimated release rate of 500 pounds per minute, with urban topography, corresponds to a consequence distance of 0.4 miles.

Additional Modeling for Comparison

The ALOHA model gave a distance of 3.0 miles to the endpoint, using the same assumptions.

The WHAZAN model gave a distance of 3.2 miles to the endpoint, using the same assumptions and the dense cloud dispersion model.

Example 25. Allyl Alcohol Evaporating from Pool

In Example 23, the evaporation rate of allyl alcohol from a pool was calculated as 63 pounds per minute. The total quantity in the pool was estimated as 9,830 pounds; therefore, the pool would evaporate in 9,830/63 or 156 minutes. You would use a 60-minute reference table to estimate the distance to the endpoint. From Exhibit B-2 in Appendix B, the toxic endpoint for allyl alcohol is 0.036 mg/L, and the appropriate reference table for the alternative scenario analysis is a neutrally buoyant plume table. To find the distance from the neutrally buoyant plume tables, you need the release rate divided by the endpoint. In this case, it is 63/0.036, or 1,750. Assuming the release takes place in a rural location, you use Reference Table 15, applicable to neutrally buoyant plumes, 60-minute releases, and rural conditions. From this table, you estimate the distance as 0.4 mile.

Additional Modeling for Comparison

The ALOHA model gave a distance of 0.7 mile to the endpoint for a release rate of 63 pounds per minute, using the same assumptions and the dense gas model.

The WHAZAN model gave a distance of 0.5 mile to the endpoint for a release rate of 63 pounds per minute, using the same assumptions and the buoyant plume dispersion model.

9 ESTIMATION OF RELEASE RATES FOR ALTERNATIVE SCENARIOS FOR FLAMMABLE SUBSTANCES

In Chapter 9

- Methods to estimate a release rate to air for a flammable gas (9.1) or liquid (9.2).

9.1 Flammable Gases

Gaseous Release from Tank or Pipe

An alternative scenario for a release of a flammable gas may involve a leak from a vessel or piping. To estimate a release rate for flammable gases from hole size and storage conditions, you may use the method described above in Section 7.1.1 for toxic gases. This release rate may be used to determine the dispersion distance to the lower flammability limit (LFL), as described in Section 10.1. Exhibit C-2 in Appendix C includes Gas Factors (GF) that may be used in carrying out the calculations for each of the regulated flammable gases.

Example 26. Release Rate of Flammable Gas from Hole in Tank (Ethylene)

A pipe tears off a tank containing ethylene. The pipe is in the vapor space of the tank. The release rate from the hole can be estimated from Equation 7-1 in Section 7.1. You estimate that the pipe would leave a hole with an area (HA) of 5 square inches. The temperature inside the tank (T_t , absolute temperature, Kelvin) is 282 K, 9°C, and the square root of the temperature is 16.8. The pressure in the tank (P_t) is approximately 728 pounds per square inch absolute (psia). From Exhibit C-2, Appendix C, the gas factor (GF) for ethylene is 18. From Equation 7-1, the release rate (QR) is:

$$QR = 5 \times 728 \times (1/16.8) \times 18 = 3{,}900 \text{ pounds per minute}$$

Gases Liquefied Under Pressure

A vapor cloud fire is a possible result of a release of a gas liquefied under pressure. You may use the methods described in Section 7.1.1 for toxic gases liquefied under pressure to estimate the release rate from a hole in a tank for a flammable gas liquefied under pressure. The estimated release rate may be used to estimate the dispersion distance to the LFL for a vapor cloud fire.

Flammable gases that are liquefied under pressure may be released very rapidly, with partial vaporization of the liquefied gas and possible aerosol formation. Section 10.4 presents a method for estimating the consequences of a vapor cloud explosion from such a release of a gas liquefied under pressure.

Gases Liquefied by Refrigeration

Flammable gases liquefied by refrigeration alone can be treated as liquids for the alternative scenario analysis, as discussed in Section 9.2 and Section 10.2, below.

9.2 Flammable Liquids

You may estimate a release rate for flammable liquids by estimating the evaporation rate from a pool. Release rates also can be estimated for flammable gases liquefied by refrigeration alone by this method, if the liquefied gas is likely to form a pool upon release. You first need to estimate the quantity in the pool.

You may use the method discussed in Section 7.2.1 to estimate a rate of liquid release for flammable liquids into a pool from a hole in a tank or from a pipe shear. Exhibit C-3 in Appendix C includes liquid leak factors (LLF) for calculating release rate from a hole. Note that the LLF is appropriate only for atmospheric tanks. LLF values are not provided for liquefied flammable gases; you will need to estimate the quantity in the pool from other information for liquefied flammable gases.

Once you have an estimate of the quantity of flammable liquid in a pool, you may use the methods presented in Section 7.2.3 to estimate the evaporation rate from the pool. Liquid factors at ambient and boiling temperature (LFA and LFB) for liquids for the calculation are listed in Exhibit C-3 in Appendix C, and LFBs for liquefied gases are listed in Exhibit C-2. Both passive and active mitigation measures (discussed in Sections 7.2.2 and 7.2.3) may be taken into account. You do not need to estimate the duration of the release, because this information is not used to estimate distance to the LFL, as discussed in the next chapter.

As for toxic liquids, if the rate of evaporation of the liquid from the pool is greater than the rate of release of the liquid from the container, you should use the liquid release rate, not the pool evaporation rate, as the rate of release to the air. You should expect rapid evaporation rates for liquefied flammable gases from a pool. All of the regulated flammable liquids are volatile, so the evaporation rate from a pool may be expected to be relatively high, particularly without mitigation.

10 ESTIMATION OF DISTANCE TO THE ENDPOINT FOR ALTERNATIVE SCENARIOS FOR FLAMMABLE SUBSTANCES

In Chapter 10

- 10.1 Method to estimate the dispersion distance to the LFL for vapor cloud fires.
- 10.2 Method to estimate the distance to the heat radiation endpoint for a pool fire involving a flammable liquid, based on the pool area and factors provided in the appendix.
- 10.3 Method to estimate the distance to the heat radiation endpoint for a fireball from a BLEVE, using a reference table of distances.
- 10.4 Alternative scenario analysis for vapor cloud explosions, using less conservative assumptions than for worst-case vapor cloud explosions.

10.1 Vapor Cloud Fires

The distance to the LFL represents the maximum distance at which the radiant heat effects of a vapor cloud fire might have serious consequences. Exhibit C-2, Appendix C, provides LCL data (in volume percent and milligrams per liter) for listed flammable gases; Exhibit C-3 provides these data for flammable liquids. This guidance provides reference tables for the alternative scenario conditions assumed in this guidance (D stability and wind speed 3.0 meters per second, ground level releases) for estimating the distance to the LCL. Release rate is the primary factor for determining distance to the flammable endpoint. Because the methods used in this guidance assumes that the vapor cloud release is in a steady state and that vapor cloud fires are nearly instantaneous events, release duration is not a critical factor for estimating vapor cloud fire distances. Thus, the reference tables for flammable substances are not broken out separately by release duration (e.g., 10 minutes, 60 minutes). The development of these tables is discussed further in Appendix D, Section D.4. The reference tables for flammable substances (Reference Tables 26-29 at the end of Chapter 10) are listed in Exhibit 6.

To use the reference tables of distances to find the distance to the LFL from the release rate, follow these steps:

- Find the LFL endpoint for the substance in Appendix C (Exhibit C-2 for flammable gases or Exhibit C-3 for flammable liquids).
- Determine from Appendix C whether the table for neutrally buoyant or dense gases and vapors is appropriate (Exhibit C-2 for flammable gases or Exhibit C-3 for flammable liquids). A gas that is lighter than air may behave as a dense gas upon release if it is liquefied under pressure, because the released gas may be mixed with liquid droplets, or if it is cold. Consider the state of the released gas when you decide which table is appropriate.

- Determine whether the table for rural or urban conditions is appropriate.
  - Use the rural table if your site is in an open area with few obstructions.
  - Use the urban table if your site is in an urban or obstructed area.

Exhibit 6
Reference Tables of Distances for Vapor Cloud Fires of Flammable Substances

Applicable Conditions			**Reference Table Number**
Gas or Vapor Density	**Topography**	**Release Duration (minutes)**	
Neutrally buoyant	Rural	10 - 60	26
	Urban	10 - 60	27
Dense	Rural	10 - 60	28
	Urban	10 - 60	29

<u>Neutrally Buoyant Gases or Vapors</u>

- If Exhibit C-2 or C-3 indicates the gas or vapor should be considered neutrally buoyant, and other factors would not cause the gas or vapor to behave as a dense gas, divide the estimated release rate (pounds per minute) by the LFL endpoint (milligrams per liter).

- Find the range of release rate/LFL values that includes your calculated release rate/LFL in the first column of the appropriate table (Reference Table 26 or 27), then find the corresponding distance to the right.

<u>Dense Gases or Vapors</u>

- If Exhibit C-2 or C-3 or consideration of other relevant factors indicates the substance should be considered a dense gas or vapor (heavier than air), find the distance in the appropriate table (Reference Table 28 or 29) as follows:
  - Find the LFL closest to that of the substance by reading across the top of the table. If the LFL of the substance is halfway between two values on the table, choose the value on the table that is smaller (to the left). Otherwise, choose the closest value to the right or the left.
  - Find the release rate closest to the release rate estimated for the substance at the left of the table. If the calculated release rate is halfway between two values on the

table, choose the release rate that is larger (farther down on the table). Otherwise, choose the closest value (up or down on the table).

-- Read across from the release rate and down from the LFL to find the distance corresponding to the LFL and release rate for your substance.

Example 27. Flammable Gas Release (Ethylene)

In Example 26, you estimated a release rate for ethylene from a hole in a tank of 3,900 pounds per minute. You want to estimate the distance to the LFL for a vapor cloud fire resulting from this release.

From Exhibit C-2, Appendix C, the LFL for ethylene is 31 mg/L, and the appropriate table for distance estimation is a neutrally buoyant gas table for flammable substances. Your site is in a rural area, so you would use Reference Table 26.

To use the neutrally buoyant gas tables, you need to calculate release rate/endpoint. In this case, release rate/LFL = 3,900/31 or 126. On Reference Table 26, 126 falls in the range of release rate/LFL values corresponding to 0.2 miles.

Example 28. Vapor Cloud Fire from Evaporating Pool of Flammable Liquid

You have a tank containing 20,000 pounds of ethyl ether. A likely scenario for a release might be shearing of a pipe from the tank, with the released liquid forming a pool. You want to estimate the consequences of a vapor cloud fire that might result from evaporation of the pool and ignition of the vapor.

You first need to estimate the rate of release of the liquid from the tank. You can do this using Equation 7-4, Section 7.2.1. For this calculation, you need the area of the hole that would result from shearing the pipe (HA), the height of the liquid in the tank above the hole (LH), and the liquid leak factor (LLF) for ethyl ether, from Exhibit C-3 in Appendix C. The pipe diameter is 2 inches, so the cross sectional area of the hole would be 3.1 square inches. You estimate that the pipe is 2 feet, or 24 inches, below the level of the liquid when the tank is full. The square root of LH (24 inches) is 4.9. LLF for ethyl ether is 34. From Equation 7-4, the rate of release of the liquid from the hole is calculated as:

$$\begin{aligned} QR_L &= 3.1 \times 4.9 \times 34 \\ &= 520 \text{ pounds per minute} \end{aligned}$$

You estimate that the release of the liquid could be stopped in about 10 minutes. In 10 minutes, 10 × 520, or 5,200 pounds, would be released.

The liquid would be released into an area without dikes. To estimate the evaporation rate from the pool formed by the released liquid, you use Equation 7-8 from Section 7.2.3. To carry out the calculation, you need the Liquid Factor Ambient (LFA) and the Density Factor (DF) for ethyl ether. From Exhibit C-3, Appendix C, LFA for ethyl ether is 0.11 and DF is 0.69. The release rate to air is:

$$\begin{aligned} QR &= 5{,}200 \times 2.4 \times 0.11 \times 0.69 \\ &= 950 \text{ pounds per minute} \end{aligned}$$

The evaporation rate from the pool is greater than the estimated liquid release rate; therefore, you use the liquid release rate of 520 pounds per minute as the release rate to air. To estimate the maximum distance at which people in the area of the vapor cloud could suffer serious injury, estimate the distance to the lower flammability limit (LFL) (in milligrams per liter) for ethyl ether, from the appropriate reference table. From Exhibit C-3, Appendix C, LFL for ethyl ether is 57 mg/L, and the appropriate reference table is a dense gas table. Your site is in a rural area with few obstructions, so you use Reference Table 28.

From Reference Table 28, the closest LFL is 60 mg/L. The lowest release rate on the table is 1,500 pounds per minute, which is higher than the evaporation rate estimated for the pool of ethyl ether. For a release rate less than 1,500 pounds per minute, the distance to the LFL is less than 0.1 miles.

10.2 Pool Fires

Pool fires may be considered as potential alternative scenarios for flammable liquids, including gases liquefied by refrigeration alone. You may find, however, that other scenarios will give a greater distance to the endpoint and, therefore, may be more appropriate as alternative scenarios. A "Pool Fire Factor" (PFF) has been derived for each of the regulated flammable liquids and most of the flammable gases to aid in the consequence analysis. The derivation of these factors is discussed in Appendix D, Section D.9. The PFF, listed in Appendix C, Exhibit C-2 for flammable gases and C-3 for flammable liquids, may be used to estimate a distance from the center of a pool fire where people could potentially receive second degree burns from a 40-second exposure. The heat radiation endpoint for this analysis is 5 kilowatts per square meter (kW/m^2). Ambient temperature is assumed to be 25 °C (77 °F) for calculation of the PFF for flammable liquids.

To estimate a distance using the PFF, you first need to estimate the size of the pool, in square feet, that might be formed by the release of a flammable substance. You may use the methods described above for toxic liquids to estimate pool size. Density factors (DF) for the estimation of pool size in undiked areas may be found for flammable gases and flammable liquids in Exhibits C-2 and C-3 of Appendix C. For flammable gases, the DF is based on the density at the boiling point. You may want to consider whether the released substance may evaporate too quickly to form a pool of the maximum size, particularly for liquefied gases.

Distances may be estimated from the PFF and the pool area as follows:

$$d = PFF \times \sqrt{A} \qquad \textbf{(10-1)}$$

where:
d = Distance (feet)
PFF = Pool Fire Factor (listed for each flammable substance in Appendix C, Exhibits C-2 and C-3)
A = Pool area (square feet)

Example 29. Pool Fire of Flammable Liquid

For a tank containing 20,000 pounds of ethyl ether, you want to estimate the consequences of a pool fire. You estimate that 15,000 pounds would be released into an area without dikes, forming a pool. Assuming the liquid spreads to a depth of 1 centimeter (0.39 inches), you estimate the area of the pool formed from Equation 3-6, Section 3.2.3. For this calculation, you need the density factor (DF) for ethyl ether; from Exhibit C-3, Appendix C, DF for ethyl ether is 0.69. From Equation 3-6, the area of the pool is:

$$A = 15{,}000 \times 0.69 = 10{,}400 \text{ square feet}$$

You can use Equation 10-1 to estimate the distance from the center of the burning pool where the heat radiation level would reach 5 kW/m^2. For the calculation, you need the square root of the pool area (A) and the pool fire factor (PFF) for ethyl ether. The square root of A, 10,400 square feet, is 102 feet. From Exhibit C-3, Appendix C, PFF for ethyl ether is 4.3. From Equation 10-1, the distance (d) to 5 kW/m^2 is:

$$d = 4.3 \times 102 = 440 \text{ feet (about 0.08 miles)}$$

If you have a gas that is liquefied under pressure or under a combination of pressure and refrigeration, a pool fire is probably not an appropriate alternative scenario. A fire or explosion involving the flammable gas that is released to the air by a sudden release of pressure is likely to have the potential for serious effects at a greater distance than a pool fire (e.g., see the methods for analysis of BLEVEs and vapor cloud explosions in Sections 10.3 and 10.4 below, or see Appendix A for references that provide more information on consequence analysis for fires and explosions).

10.3 BLEVEs

If a fireball from a BLEVE is a potential release scenario at your site, you may use Reference Table 30 to estimate the distance to a potentially harmful radiant heat level. The table shows distances for a range of quantities to the radiant heat level that potentially could cause second degree burns to a person exposed for the duration of the fire. The quantity you use should be the total quantity in a tank that might be involved in a BLEVE. The equations used to derive this table of distances are presented in Appendix D, Section D.10. If you prefer, you may use the equations to estimate a distance for BLEVEs, or you may use a different calculation method or model.

10.4 Vapor Cloud Explosion

If you have the potential at your site for the rapid release of a large quantity of a flammable vapor, particularly into a congested area, a vapor cloud explosion may be an appropriate alternative release scenario. For the consequence analysis, you may use the same methods as for the worst case to estimate consequence distances to an overpressure endpoint of 1 psi (see Section 5.1 and the equation in Appendix C). Instead of assuming the total quantity of flammable substance released is in the vapor cloud, you may estimate a smaller quantity in the cloud. You could base your estimate of the quantity in the cloud on the release rate estimated as described above for gases and liquids multiplied by the time required to stop the release.

To estimate the quantity in the cloud for a gas liquefied under pressure (not refrigerated), you may use the equation below. This equation incorporates a "flash fraction factor" (FFF), listed in Appendix C, Exhibit C-2 for regulated flammable gases, to estimate the quantity that could be immediately flashed into vapor upon release. A factor of two is included to estimate the quantity that might be carried along as spray or aerosol. See Appendix D, Section D.11 for the derivation of this equation. The equation is:

$$QF = FFF \times QS \times 2 \tag{10-2}$$

where:
QF = Quantity flashed into vapor plus aerosol (pounds) (cannot be larger than QS)
FFF = Flash fraction factor (unitless) (listed in Appendix C, Exhibit C-2) (must be less than 1)
QS = Quantity spilled (pounds)
2 = Factor to account for spray and aerosol

For derivation of the FFF, the temperature of the stored gas was assumed to be 25 ^{o}C (77 ^{o}F) (except as noted in Exhibit C-2). You may estimate the flash fraction under other conditions using the equation presented in Appendix D, Section D.11.

You may estimate the distance to 1 psi for a vapor cloud explosion from the quantity in the cloud using Reference Table 13 (at the end of the worst-case analysis discussion) or from Equation C-1 in Appendix C. For the alternative scenario analysis, you may use a yield factor of 3 percent, instead of the yield factor of 10 percent used in the worst-case analysis. As discussed in Appendix D, Section D.11, the yield factor of 3 percent is representative of more likely events, based on data from past vapor cloud explosions. If you use the equation in Appendix C, use 0.03 instead of 0.1 in the calculation. If you use Reference Table 13, you can incorporate the lower yield factor by multiplying the distance you read from Reference Table 13 by 0.67.

Example 30. Vapor Cloud Explosion (Propane)

You have a tank containing 50,000 pounds of propane liquefied under pressure at ambient temperature. You want to estimate the consequence distance for a vapor cloud explosion resulting from rupture of the tank.

You use Equation 10-2 to estimate the quantity that might be released to form a cloud. You base the calculation on the entire contents of the tank (QS = 50,000 pounds). From Exhibit C-2 of Appendix C, the Flash Fraction Factor (FFF) for propane is 0.38. From Equation 10-2, the quantity flashed into vapor, plus the quantity that might be carried along as aerosol, (QF) is:

$$QF = 0.38 \times 50{,}000 \times 2 = 38{,}000 \text{ pounds}$$

You assume 38,000 pounds of propane is in the flammable part of the vapor cloud. This quantity falls between 20,000 pounds and 50,000 pounds in Reference Table 13; 50,000 pounds is the quantity closest to your quantity. From the table, the distance to 1 psi overpressure is 0.3 mile for 50,000 pounds of propane for a 10 percent yield factor. To change the yield factor to 3 percent, you multiply this distance by 0.67; then the distance becomes 0.2 mile.

Reference Table 14
Neutrally Buoyant Plume Distances to Toxic Endpoint for Release Rate Divided by Endpoint
10-Minute Release, Rural Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
0 - 64	0.1
64 - 510	0.2
510 - 1,300	0.3
1,300 - 2,300	0.4
2,300 - 4,100	0.6
4,100 - 6,300	0.8
6,300 - 8,800	1.0
8,800 - 12,000	1.2
12,000 - 16,000	1.4
16,000 - 19,000	1.6
19,000 - 22,000	1.8
22,000 - 26,000	2.0
26,000 - 30,000	2.2
30,000 - 36,000	2.4
36,000 - 42,000	2.6
42,000 - 47,000	2.8
47,000 - 54,000	3.0
54,000 - 60,000	3.2
60,000 - 70,000	3.4
70,000 - 78,000	3.6
78,000 - 87,000	3.8
87,000 - 97,000	4.0
97,000 - 110,000	4.2
110,000 - 120,000	4.4
120,000 - 130,000	4.6

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
130,000 - 140,000	4.8
140,000 - 160,000	5.0
160,000 - 180,000	5.2
180,000 - 190,000	5.4
190,000 - 210,000	5.6
210,000 - 220,000	5.8
220,000 - 240,000	6.0
240,000 - 261,000	6.2
261,000 - 325,000	6.8
325,000 - 397,000	7.5
397,000 - 477,000	8.1
477,000 - 566,000	8.7
566,000 - 663,000	9.3
663,000 - 769,000	9.9
769,000 - 1,010,000	11
1,010,000 - 1,280,000	12
1,280,000 - 1,600,000	14
1,600,000 - 1,950,000	15
1,950,000 - 2,340,000	16
2,340,000 - 2,770,000	17
2,770,000 - 3,240,000	19
3,240,000 - 4,590,000	22
4,590,000 - 6,190,000	25
>6,190,000	>25*

*Report distance as 25 miles

Reference Table 15
Neutrally Buoyant Plume Distances to Toxic Endpoint for Release Rate Divided by Endpoint
60-Minute Release, Rural Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
0 - 79	0.1
79 - 630	0.2
630 - 1,600	0.3
1,600 - 2,800	0.4
2,800 - 5,200	0.6
5,200 - 7,900	0.8
7,900 - 11,000	1.0
11,000 - 14,000	1.2
14,000 - 19,000	1.4
19,000 - 23,000	1.6
23,000 - 27,000	1.8
27,000 - 32,000	2.0
32,000 - 36,000	2.2
36,000 - 42,000	2.4
42,000 - 47,000	2.6
47,000 - 52,000	2.8
52,000 - 57,000	3.0
57,000 - 61,000	3.2
61,000 - 68,000	3.4
68,000 - 73,000	3.6
73,000 - 79,000	3.8
79,000 - 84,000	4.0
84,000 - 91,000	4.2
91,000 - 97,000	4.4
97,000 - 100,000	4.6

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
100,000 - 108,000	4.8
108,000 - 113,000	5.0
113,000 - 120,000	5.2
120,000 - 126,000	5.4
126,000 - 132,000	5.6
132,000 - 140,000	5.8
140,000 - 150,000	6.0
150,000 - 151,000	6.2
151,000 - 171,000	6.8
171,000 - 191,000	7.5
191,000 - 212,000	8.1
212,000 - 233,000	8.7
233,000 - 256,000	9.3
256,000 - 280,000	9.9
280,000 - 332,000	11
332,000 - 390,000	12
390,000 - 456,000	14
456,000 - 529,000	15
529,000 - 610,000	16
610,000 - 699,000	17
699,000 - 796,000	19
796,000 - 1,080,000	22
1,080,000 - 1,410,000	25
>1,410,000	>25*

*Report distance as 25 miles

Reference Table 16
Neutrally Buoyant Plume Distances to Toxic Endpoint for Release Rate Divided by Endpoint
10-Minute Release, Urban Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
0 - 160	0.1
160 - 1,400	0.2
1,400 - 3,600	0.3
3,600 - 6,900	0.4
6,900 - 13,000	0.6
13,000 - 22,000	0.8
22,000 - 31,000	1.0
31,000 - 42,000	1.2
42,000 - 59,000	1.4
59,000 - 73,000	1.6
73,000 - 88,000	1.8
88,000 - 100,000	2.0
100,000 - 120,000	2.2
120,000 - 150,000	2.4
150,000 - 170,000	2.6
170,000 - 200,000	2.8
200,000 - 230,000	3.0
230,000 - 260,000	3.2
260,000 - 310,000	3.4
310,000 - 340,000	3.6
340,000 - 390,000	3.8
390,000 - 430,000	4.0
430,000 - 490,000	4.2
490,000 - 540,000	4.4
540,000 - 600,000	4.6

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
600,000 - 660,000	4.8
660,000 - 720,000	5.0
720,000 - 810,000	5.2
810,000 - 880,000	5.4
880,000 - 950,000	5.6
950,000 - 1,000,000	5.8
1,000,000 - 1,100,000	6.0
1,100,000 - 1,220,000	6.2
1,220,000 - 1,530,000	6.8
1,530,000 - 1,880,000	7.5
1,880,000 - 2,280,000	8.1
2,280,000 - 2,710,000	8.7
2,710,000 - 3,200,000	9.3
3,200,000 - 3,730,000	9.9
3,730,000 - 4,920,000	11
4,920,000 - 6,310,000	12
6,310,000 - 7,890,000	14
7,890,000 - 9,660,000	15
9,660,000 - 11,600,000	16
11,600,000 - 13,800,000	17
13,800,000 - 16,200,000	19
16,200,000 - 23,100,000	22
23,100,000 - 31,300,000	25
>31,300,000	>25*

*Report distance as 25 miles

Reference Table 17
Neutrally Buoyant Plume Distances to Toxic Endpoint for Release Rate Divided by Endpoint
60-Minute Release, Urban Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
0 - 200	0.1
200 - 1,700	0.2
1,700 - 4,500	0.3
4,500 - 8,600	0.4
8,600 - 17,000	0.6
17,000 - 27,000	0.8
27,000 - 39,000	1.0
39,000 - 53,000	1.2
53,000 - 73,000	1.4
73,000 - 90,000	1.6
90,000 - 110,000	1.8
110,000 - 130,000	2.0
130,000 - 150,000	2.2
150,000 - 170,000	2.4
170,000 - 200,000	2.6
200,000 - 220,000	2.8
220,000 - 240,000	3.0
240,000 - 270,000	3.2
270,000 - 300,000	3.4
300,000 - 320,000	3.6
320,000 - 350,000	3.8
350,000 - 370,000	4.0
370,000 - 410,000	4.2
410,000 - 430,000	4.4
430,000 - 460,000	4.6
460,000 - 490,000	4.8
490,000 - 520,000	5.0
520,000 - 550,000	5.2
550,000 - 580,000	5.4
580,000 - 610,000	5.6
610,000 - 640,000	5.8
640,000 - 680,000	6.0
680,000 - 705,000	6.2
705,000 - 804,000	6.8
804,000 - 905,000	7.5
905,000 - 1,010,000	8.1
1,010,000 - 1,120,000	8.7
1,120,000 - 1,230,000	9.3
1,230,000 - 1,350,000	9.9
1,350,000 - 1,620,000	11
1,620,000 - 1,920,000	12
1,920,000 - 2,250,000	14
2,250,000 - 2,620,000	15
2,620,000 - 3,030,000	16
3,030,000 - 3,490,000	17
3,490,000 - 3,980,000	19
3,980,000 - 5,410,000	22
5,410,000 - 7,120,000	25
>7,120,000	>25*

*Report distance as 25 miles

Reference Table 18
Dense Gas Distances to Toxic Endpoint
10-minute Release, Rural Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate (lbs/min)	Toxic Endpoint (mg/L)															
	0.0004	0.0007	0.001	0.002	0.0035	0.005	0.0075	0.01	0.02	0.035	0.05	0.075	0.1	0.25	0.5	0.75
	Distance (Miles)															
1	0.6	0.4	0.4	0.2	0.2	0.1	0.1	0.1	<0.1	<0.1	#	#	#	#	#	#
2	0.9	0.6	0.5	0.4	0.3	0.2	0.2	0.1	0.1	0.1	<0.1	<0.1	#	#	#	#
5	1.4	1.1	0.9	0.6	0.4	0.4	0.3	0.2	0.2	0.1	0.1	0.1	<0.1	#	#	#
10	2.0	1.5	1.2	0.9	0.6	0.5	0.4	0.4	0.2	0.2	0.1	0.1	0.1	<0.1	<0.1	#
30	3.7	2.7	2.2	1.5	1.1	0.9	0.7	0.7	0.5	0.3	0.3	0.2	0.2	0.1	0.1	<0.1
50	5.0	3.7	3.0	2.1	1.9	1.2	1.0	0.9	0.6	0.4	0.4	0.3	0.2	0.2	0.1	0.1
100	7.4	5.3	4.3	3.0	2.3	1.7	1.4	1.2	0.9	0.6	0.6	0.4	0.4	0.2	0.2	0.1
150	8.7	6.8	5.5	3.8	2.8	2.3	1.9	1.6	1.1	0.8	0.7	0.6	0.5	0.3	0.2	0.2
250	12	8.7	7.4	5.0	3.7	3.0	2.4	2.1	1.4	1.1	0.9	0.7	0.5	0.4	0.3	0.2
500	17	13	11	7.4	5.3	4.5	3.6	3.0	2.1	1.6	1.3	1.1	0.9	0.6	0.4	0.3
750	22	16	13	9.3	6.8	5.6	4.5	3.8	2.7	1.9	1.6	1.3	1.1	0.7	0.5	0.4
1,000	>25	19	16	11	8.1	6.8	5.2	4.5	3.1	2.3	2.2	1.5	1.3	0.8	0.6	0.4
1,500	*	23	19	13	9.9	8.1	6.8	5.6	3.9	2.9	2.4	1.9	1.6	1.0	0.7	0.6
2,000	*	>25	22	15	12	9.3	7.4	6.8	4.5	3.4	2.7	2.2	1.9	1.2	0.8	0.6
2,500	*	*	25	17	13	11	8.7	7.4	5.2	3.8	3.2	2.5	2.1	1.3	0.9	0.7
3,000	*	*	>25	19	14	12	9.3	8.1	5.7	4.2	3.5	2.8	2.4	1.4	1.0	0.8
4,000	*	*	*	22	17	14	11	9.3	6.8	4.9	4.1	3.3	2.8	1.7	1.1	0.9
5,000	*	*	*	>25	19	16	12	11	7.4	5.6	4.7	3.7	3.1	2.1	1.3	1.1
7,500	*	*	*	*	24	19	16	13	9.3	6.8	5.8	4.7	4.0	2.4	1.6	1.3
10,000	*	*	*	*	>25	22	18	16	11	8.1	6.8	5.3	4.6	2.8	1.9	1.5
15,000	*	*	*	*	*	>25	22	19	13	9.9	8.1	6.8	5.7	3.5	2.4	1.9
20,000	*	*	*	*	*	*	>25	22	16	11	9.3	7.4	6.8	4.0	2.8	2.2
50,000	*	*	*	*	*	*	*	>25	24	18	15	12	10	6.5	4.5	3.6
75,000	*	*	*	*	*	*	*	*	>25	22	18	15	13	7.8	5.4	4.4
100,000	*	*	*	*	*	*	*	*	*	>25	21	17	14	8.9	6.3	5.0
150,000	*	*	*	*	*	*	*	*	*	*	>25	20	17	11	7.4	6.0
200,000	*	*	*	*	*	*	*	*	*	*	*	23	19	12	8.5	6.8

* > 25 miles (report distance as 25 miles)

\# <0.1 mile (report distance as 0.1 mile)

Reference Table 19
Dense Gas Distances to Toxic Endpoint
60-minute Release, Rural Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate (lbs/min)	Toxic Endpoint (mg/L)															
	0.0004	**0.0007**	**0.001**	**0.002**	**0.0035**	**0.005**	**0.0075**	**0.01**	**0.02**	**0.035**	**0.05**	**0.075**	**0.1**	**0.25**	**0.5**	**0.75**
	Distance (Miles)															
1	0.5	0.4	0.3	0.2	0.2	0.1	0.1	0.1	<0.1	#	#	#	#	#	#	#
2	0.8	0.6	0.5	0.3	0.2	0.2	0.2	0.1	0.1	<0.1	<0.1	<0.1	#	#	#	#
5	1.6	1.0	0.8	0.5	0.4	0.3	0.2	0.2	0.2	0.1	0.1	0.1	<0.1	#	#	#
10	2.0	1.4	1.2	0.8	0.6	0.5	0.4	0.3	0.2	0.2	0.1	0.1	0.1	<0.1	<0.1	#
30	4.0	2.8	2.2	1.5	1.1	0.9	0.7	0.6	0.4	0.3	0.2	0.2	0.2	0.1	0.1	<0.1
50	5.5	3.9	3.1	2.1	1.5	1.2	1.0	0.8	0.6	0.4	0.3	0.3	0.2	0.1	0.1	0.1
100	8.7	6.1	4.8	3.2	2.2	1.8	1.4	1.2	0.8	0.6	0.5	0.4	0.3	0.2	0.1	0.1
150	12	8.1	6.2	4.1	2.9	2.3	1.8	1.6	1.1	0.7	0.6	0.5	0.4	0.3	0.2	0.1
250	17	11	8.7	5.6	4.0	3.2	2.5	2.1	1.4	1.1	0.9	0.7	0.6	0.4	0.2	0.2
500	>25	19	14	9.3	6.2	5.0	3.9	3.3	2.2	1.6	1.3	1.0	0.9	0.5	0.4	0.3
750	*	25	19	12	8.7	6.8	5.1	4.2	2.8	2.0	1.6	1.3	1.1	0.6	0.4	0.4
1,000	*	>25	24	15	11	8.1	6.1	5.2	3.4	2.4	1.9	1.5	1.3	0.7	0.5	0.4
1,500	*	*	>25	20	14	11	8.1	6.8	4.3	3.0	2.5	1.9	1.7	1.0	0.7	0.5
2,000	*	*	*	24	17	13	9.9	8.1	5.2	3.7	2.9	2.3	1.9	1.2	0.7	0.6
2,500	*	*	*	>25	19	15	12	9.3	6.0	4.3	3.4	2.7	2.2	1.3	0.9	0.7
3,000	*	*	*	*	22	17	13	11	6.8	4.8	3.8	3.0	2.5	1.5	1.0	0.8
4,000	*	*	*	*	>25	21	16	14	8.7	5.8	4.7	3.6	3.0	1.7	1.2	0.9
5,000	*	*	*	*	*	25	19	16	9.9	6.8	5.3	4.1	3.5	2.0	1.4	1.1
7,500	*	*	*	*	*	>25	25	20	13	9.3	6.8	5.4	4.5	2.6	1.7	1.4
10,000	*	*	*	*	*	*	>25	25	16	11	8.7	6.8	5.4	3.1	2.1	1.6
15,000	*	*	*	*	*	*	*	>25	21	14	11	8.7	7.4	4.0	2.6	2.1
20,000	*	*	*	*	*	*	*	*	25	17	14	11	8.7	4.8	3.1	2.5
50,000	*	*	*	*	*	*	*	*	>25	>25	25	19	16	8.8	5.6	4.3
75,000	*	*	*	*	*	*	*	*	*	*	>25	25	20	11	7.3	5.6
100,000	*	*	*	*	*	*	*	*	*	*	*	>25	24	14	9.4	6.8
150,000	*	*	*	*	*	*	*	*	*	*	*	*	>25	17	11	8.7
200,000	*	*	*	*	*	*	*	*	*	*	*	*	*	20	13	10

* > 25 miles (report distance as 25 miles)

\# <0.1 mile (report distance as 0.1 mile)

Reference Table 20
Dense Gas Distances to Toxic Endpoint
10-minute Release, Urban Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate (lbs/min)	Toxic Endpoint (mg/L)															
	0.0004	0.0007	0.001	0.002	0.0035	0.005	0.0075	0.01	0.02	0.035	0.05	0.075	0.1	0.25	0.5	0.75
	Distance (Miles)															
1	0.5	0.3	0.2	0.2	0.1	0.1	0.1	0.1	<0.1	#	#	#	#	#	#	#
2	0.7	0.5	0.4	0.3	0.2	0.2	0.1	0.1	0.1	<0.1	<0.1	#	#	#	#	#
5	1.1	0.8	0.6	0.5	0.3	0.3	0.2	0.2	0.1	0.1	0.1	<0.1	<0.1	#	#	#
10	2.1	1.2	1.0	0.7	0.5	0.4	0.3	0.3	0.2	0.1	0.1	0.1	0.1	<0.1	#	#
30	3.0	2.2	1.9	1.2	0.9	0.8	0.6	0.6	0.4	0.3	0.2	0.2	0.1	0.1	<0.1	#
50	4.1	3.0	2.5	1.6	1.2	1.0	0.8	0.7	0.5	0.3	0.3	0.2	0.2	0.1	0.1	<0.1
100	5.8	4.3	3.5	2.7	1.8	1.4	1.2	1.0	0.7	0.6	0.4	0.4	0.3	0.2	0.1	0.1
150	7.4	5.5	4.5	3.1	2.2	1.9	1.4	1.2	0.9	0.7	0.6	0.4	0.4	0.2	0.2	0.1
250	9.9	7.4	5.8	4.1	3.0	2.5	2.0	1.7	1.1	0.9	0.7	0.6	0.5	0.3	0.2	0.1
500	14	11	8.7	5.9	4.3	3.6	2.9	2.5	1.7	1.2	1.0	0.8	0.7	0.4	0.3	0.2
750	17	13	11	7.4	5.5	4.5	3.6	3.1	2.1	1.6	1.2	1.0	0.9	0.5	0.4	0.3
1,000	20	15	12	8.7	6.2	5.3	4.3	3.5	2.5	1.8	1.5	1.2	1.0	0.6	0.4	0.3
1,500	>25	19	16	11	8.1	6.2	5.2	4.5	3.0	2.2	1.8	1.5	1.2	0.7	0.5	0.4
2,000	*	22	18	12	9.3	7.4	6.2	5.2	3.7	2.7	2.2	1.7	1.4	0.9	0.6	0.5
2,500	*	24	20	14	11	8.7	6.8	6.0	3.8	3.0	2.2	1.9	1.7	1.0	0.7	0.6
3,000	*	>25	22	16	11	9.3	7.4	6.8	4.5	3.3	2.7	2.1	1.9	1.1	0.7	0.6
4,000	*	*	>25	18	14	11	8.7	7.4	5.3	4.0	3.2	2.6	2.1	1.2	0.9	0.7
5,000	*	*	*	20	15	12	9.9	8.7	5.8	4.4	3.6	2.9	2.4	1.4	0.9	0.7
7,500	*	*	*	>25	19	16	12	11	7.4	5.5	4.5	3.6	3.0	1.8	1.2	0.9
10,000	*	*	*	*	22	18	14	12	8.7	6.2	5.2	4.2	3.6	2.1	1.4	1.1
15,000	*	*	*	*	>25	22	18	16	11	8.1	6.8	5.2	4.4	2.6	1.7	1.3
20,000	*	*	*	*	*	>25	20	18	12	9.3	7.4	6.0	5.2	3.0	2.0	1.6
50,000	*	*	*	*	*	*	>25	>25	20	15	12	9.7	8.3	5.0	3.3	2.6
75,000	*	*	*	*	*	*	*	*	25	18	15	12	10	6.1	4.1	3.1
100,000	*	*	*	*	*	*	*	*	>25	21	17	14	12	7.0	4.7	3.7
150,000	*	*	*	*	*	*	*	*	*	>25	21	17	14	8.5	5.7	4.5
200,000	*	*	*	*	*	*	*	*	*	*	24	19	16	9.7	6.5	5.1

* > 25 miles (report distance as 25 miles)

\# <0.1 mile (report distance as 0.1 mile)

Reference Table 21
Dense Gas Distances to Toxic Endpoint
60-minute Release, Urban Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate (lbs/min)	Toxic Endpoint (mg/L)															
	0.0004	**0.0007**	**0.001**	**0.002**	**0.0035**	**0.005**	**0.0075**	**0.01**	**0.02**	**0.035**	**0.05**	**0.075**	**0.1**	**0.25**	**0.5**	**0.75**
	Distance (Miles)															
1	0.4	0.3	0.2	0.2	0.1	0.1	0.1	<0.1	#	#	#	#	#	#	#	#
2	0.7	0.5	0.4	0.2	0.2	0.2	0.1	0.1	<0.1	<0.1	#	#	#	#	#	#
5	1.1	0.8	0.7	0.4	0.3	0.2	0.2	0.2	0.1	0.1	<0.1	<0.1	<0.1	#	#	#
10	1.7	1.2	1.0	0.7	0.5	0.4	0.3	0.3	0.2	0.1	0.1	0.1	0.1	<0.1	#	#
30	3.3	2.4	1.9	1.3	0.9	0.7	0.6	0.5	0.3	0.2	0.2	0.2	0.1	0.1	<0.1	#
50	4.7	3.3	2.6	1.7	1.2	1.0	0.8	0.7	0.4	0.3	0.3	0.2	0.2	0.1	0.1	<0.1
100	7.4	5.2	4.1	2.7	1.9	1.5	1.2	1.0	0.7	0.5	0.4	0.3	0.3	0.2	0.1	0.1
150	9.9	6.8	5.3	3.4	2.4	1.9	1.5	1.3	0.9	0.6	0.5	0.4	0.3	0.2	0.1	0.1
250	14	9.3	7.4	4.7	3.4	2.7	2.1	1.7	1.1	0.8	0.7	0.5	0.4	0.3	0.2	0.1
500	22	16	12	7.4	5.2	4.2	3.2	2.7	1.7	1.2	1.0	0.8	0.7	0.4	0.2	0.2
750	>25	20	16	9.9	6.8	5.4	4.2	3.5	2.2	1.6	1.3	1.0	0.9	0.5	0.3	0.3
1,000	*	24	19	12	8.1	6.8	5.0	4.2	2.7	1.8	1.6	1.2	1.0	0.6	0.4	0.3
1,500	*	>25	>25	16	11	8.7	6.8	5.5	3.5	1.9	2.0	1.6	1.3	0.7	0.5	0.4
2,000	*	*	*	19	14	11	8.1	6.8	4.2	3.0	2.2	1.9	1.6	0.9	0.6	0.4
2,500	*	*	*	23	16	12	9.3	7.4	4.9	3.4	2.7	2.1	1.7	1.0	0.6	0.5
3,000	*	*	*	>25	18	14	11	8.7	5.5	3.8	3.0	2.4	2.0	1.1	0.7	0.6
4,000	*	*	*	*	22	17	13	11	6.8	4.7	3.1	2.8	2.4	1.3	0.9	0.7
5,000	*	*	*	*	>25	20	16	12	8.1	5.3	4.3	3.3	2.7	1.5	1.0	0.7
7,500	*	*	*	*	*	25	20	17	11	6.8	5.6	4.3	3.5	2.0	1.2	0.9
10,000	*	*	*	*	*	>25	24	20	13	8.7	6.8	5.2	4.3	2.4	1.5	1.1
15,000	*	*	*	*	*	*	>25	>25	17	11	8.7	6.8	5.6	3.0	1.9	1.5
20,000	*	*	*	*	*	*	*	*	20	14	11	8.1	6.8	3.6	2.3	1.7
50,000	*	*	*	*	*	*	*	*	>25	>25	20	15	13	6.6	4.0	3.1
75,000	*	*	*	*	*	*	*	*	*	*	>25	20	16	8.7	5.3	3.9
100,000	*	*	*	*	*	*	*	*	*	*	*	24	20	10	6.3	4.7
150,000	*	*	*	*	*	*	*	*	*	*	*	>25	>25	14	8.2	6.1
200,000	*	*	*	*	*	*	*	*	*	*	*	*	*	16	9.9	7.3

* > 25 miles (report distance as 25 miles)

\# <0.1 mile (report distance as 0.1 mile)

Reference Table 22
Distances to Toxic Endpoint for Anhydrous Ammonia Liquefied Under Pressure
D Stability, Wind Speed 3.0 Meters per Second

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

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

* Report distance as 0.1 mile

Reference Table 23
Distances to Toxic Endpoint for Non-liquefied Ammonia, Ammonia Liquefied by Refrigeration, or Aqueous Ammonia
D Stability, Wind Speed 3.0 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
<8	<0.1*	<0.1*
8	0.1	
10	0.1	
15	0.1	
20	0.1	
30	0.1	
40	0.1	
50	0.2	0.1
60	0.2	0.1
70	0.2	0.1
80	0.2	0.1
90	0.2	0.1
100	0.2	0.1
150	0.3	0.1
200	0.3	0.1
250	0.4	0.2
300	0.4	0.2
400	0.4	0.2
500	0.5	0.2
600	0.6	0.2
700	0.6	0.2
750	0.6	0.2

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
800	0.7	0.2
900	0.7	0.3
1,000	0.8	0.3
1,500	1.0	0.4
2,000	1.2	0.4
2,500	1.2	0.4
3,000	1.5	0.5
4,000	1.8	0.6
5,000	2.0	0.7
7,500	2.2	0.7
10,000	2.5	0.8
15,000	3.1	1.0
20,000	3.6	1.2
25,000	4.1	1.3
30,000	4.4	1.4
40,000	5.1	1.6
50,000	5.8	1.8
75,000	7.1	2.2
100,000	8.2	2.5
150,000	10	3.1
200,000	12	3.5

* Report distance as 0.1 mile

Reference Table 24
Distances to Toxic Endpoint for Chlorine
D Stability, Wind Speed 3.0 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
1	<0.1*	<0.1*
2	0.1	
5	0.1	
10	0.2	0.1
15	0.2	0.1
20	0.2	0.1
30	0.3	0.1
40	0.3	0.1
50	0.3	0.1
60	0.4	0.2
70	0.4	0.2
80	0.4	0.2
90	0.4	0.2
100	0.5	0.2
150	0.6	0.2
200	0.6	0.3
250	0.7	0.3
300	0.8	0.3
400	0.8	0.4
500	1.0	0.4
600	1.0	0.4
700	1.1	0.4
750	1.2	0.4
800	1.2	0.5
900	1.2	0.5
1,000	1.3	0.5
1,500	1.6	0.6
2,000	1.8	0.6
2,500	2.0	0.7
3,000	2.2	0.8
4,000	2.5	0.8
5,000	2.8	0.9
7,500	3.4	1.2
10,000	3.9	1.3
15,000	4.6	1.6
20,000	5.3	1.8
25,000	5.9	2.0
30,000	6.4	2.1
40,000	7.3	2.4
50,000	8.1	2.7
75,000	9.8	3.2
100,000	11	3.6
150,000	13	4.2
200,000	15	4.8

* Report distance as 0.1 mile

Reference Table 25
Distances to Toxic Endpoint for Sulfur Dioxide
D Stability, Wind Speed 3.0 Meters per Second

Release Rate (lbs/min)	Distance to Endpoint (miles)	
	Rural	Urban
1	<0.1*	<0.1*
2	0.1	
5	0.1	
10	0.2	0.1
15	0.2	0.1
20	0.2	0.1
30	0.2	0.1
40	0.3	0.1
50	0.3	0.1
60	0.4	0.2
70	0.4	0.2
80	0.4	0.2
90	0.4	0.2
100	0.5	0.2
150	0.6	0.2
200	0.6	0.2
250	0.7	0.3
300	0.8	0.3
400	0.9	0.4
500	1.0	0.4
600	1.1	0.4
700	1.2	0.4
750	1.3	0.5
800	1.3	0.5
900	1.4	0.5
1,000	1.5	0.5
1,500	1.9	0.6
2,000	2.2	0.7
2,500	2.3	0.8
3,000	2.7	0.8
4,000	3.1	1.0
5,000	3.3	1.1
7,500	4.0	1.3
10,000	4.6	1.4
15,000	5.6	1.7
20,000	6.5	1.9
25,000	7.3	2.1
30,000	8.0	2.3
40,000	9.2	2.6
50,000	10	2.9
75,000	13	3.5
100,000	14	4.0
150,000	18	4.7
200,000	20	5.4

* Report distance as 0.1 mile

Reference Table 26
Neutrally Buoyant Plume Distances to Lower Flammability Limit (LFL) For Release Rate Divided by LFL
Rural Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
0 - 28	0.1
28 - 40	0.1
40 - 60	0.1
60 - 220	0.2
220 - 530	0.3
530 - 860	0.4
860 - 1,300	0.5
1,300 - 1,700	0.6
1,700 - 2,200	0.7
2,200 - 2,700	0.8
2,700 - 3,300	0.9
3,300 - 3,900	1.0
3,900 - 4,500	1.1
4,500 - 5,200	1.2
5,200 - 5,800	1.3
5,800 - 6,800	1.4
6,800 - 8,200	1.6
8,200 - 9,700	1.8
9,700 - 11,000	2.0
11,000 - 13,000	2.2

Reference Table 27
Neutrally Buoyant Plume Distances to Lower Flammability Limit (LFL) For Release Rate Divided by LFL
Urban Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate/Endpoint [(lbs/min)/(mg/L)]	Distance to Endpoint (miles)
0 - 68	0.1
68 - 100	0.1
100 - 150	0.1
150 - 710	0.2
710 - 1,500	0.3
1,500 - 2,600	0.4
2,600 - 4,000	0.5
4,000 - 5,500	0.6
5,500 - 7,300	0.7
7,300 - 9,200	0.8
9,200 - 11,000	0.9
11,000 - 14,000	1.0
14,000 - 18,000	1.2
18,000 - 26,000	1.4
26,000 - 31,000	1.6
31,000 - 38,000	1.8

Reference Table 28
Dense Gas Distances to Lower Flammability Limit
Rural Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate (lbs/min)	Lower Flammability Limit (mg/L)									
	27	30	35	40	45	50	60	70	100	>100
	Distance (Miles)									
<1,500	#	#	#	#	#	#	#	#	#	#
1,500	<0.1	<0.1	#	#	#	#	#	#	#	#
2,000	0.1	0.1	<0.1	#	#	#	#	#	#	#
2,500	0.1	0.1	0.1	<0.1	#	#	#	#	#	#
3,000	0.1	0.1	0.1	0.1	<0.1	<0.1	#	#	#	#
4,000	0.1	0.1	0.1	0.1	0.1	0.1	<0.1	#	#	#
5,000	0.1	0.1	0.1	0.1	0.1	0.1	0.1	<0.1	#	#
7,500	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	<0.1	#
10,000	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	<0.1

< 0.1 mile (report distance as 0.1 mile)

Reference Table 29
Dense Gas Distances to Lower Flammability Limit
Urban Conditions, D Stability, Wind Speed 3.0 Meters per Second

Release Rate (lbs/min)	**Lower Flammability Limit (mg/L)**				
	27	**30**	**35**	**40**	**>40**
	Distance (Miles)				
<5,000	#	#	#	#	#
5,000	<0.1	<0.1	#	#	#
7,500	0.1	0.1	<0.1	#	#
10,000	0.1	0.1	0.1	<0.1	#

< 0.1 mile (report distance as 0.1 mile)

Reference Table 30

Distance to Radiant Heat Dose at Potential Second Degree Burn Threshold Assuming Exposure for Duration of Fireball from BLEVE

(Dose = [5 kW/m^2]$^{4/3}$ x Exposure Time)

Quantity in Fireball (pounds)		**1,000**	**5,000**	**10,000**	**20,000**	**30,000**	**50,000**	**75,000**	**100,000**	**200,000**	**300,000**	**500,000**
Duration of Fireball (seconds)		**3.5**	**5.9**	**7.5**	**9.4**	**10.8**	**12.7**	**14.8**	**15.5**	**17.4**	**18.7**	**20.3**
CAS No.	**Chemical Name**	**Distance (miles) at which Exposure for Duration of Fireball May Cause Second Degree Burns**										
75-07-0	Acetaldehyde	0.04	0.08	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6
74-86-2	Acetylene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
598-73-2	Bromotrifluoroethylene	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.1	0.2
106-99-0	1,3-Butadiene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
106-97-8	Butane	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
106-98-9	1-Butene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
107-01-7	2-Butene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
25167-67-3	Butene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
590-18-1	2-Butene-cis	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
624-64-6	2-Butene-trans	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
463-58-1	Carbon oxysulfide	0.02	0.05	0.06	0.09	0.1	0.1	0.2	0.2	0.2	0.3	0.3
7791-21-1	Chlorine monoxide	0.01	0.02	0.02	0.03	0.03	0.04	0.05	0.06	0.08	0.09	0.1
557-98-2	2-Chloropropylene	0.03	0.07	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.5
590-21-6	1-Chloropropylene	0.03	0.07	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.5
460-19-5	Cyanogen	0.03	0.07	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.5
75-19-4	Cyclopropane	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
4109-96-0	Dichlorosilane	0.02	0.04	0.06	0.08	0.1	0.1	0.2	0.2	0.2	0.3	0.3
75-37-6	Difluoroethane	0.02	0.05	0.07	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4
124-40-3	Dimethylamine	0.04	0.09	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.7
463-82-1	2,2-Dimethylpropane	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
74-84-0	Ethane	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
107-00-6	Ethyl acetylene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8

Reference Table 30 (continued)

	Quantity in Fireball (pounds)	1,000	5,000	10,000	20,000	30,000	50,000	75,000	100,000	200,000	300,000	500,000
	Duration of Fireball (seconds)	**3.5**	**5.9**	**7.5**	**9.4**	**10.8**	**12.7**	**14.8**	**15.5**	**17.4**	**18.7**	**20.3**
CAS No.	**Chemical Name**	**Distance (miles) at which Exposure for Duration of Fireball May Cause Second Degree Burns**										
75-04-7	Ethylamine	0.04	0.09	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.7
75-00-3	Ethyl chloride	0.03	0.07	0.09	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.5
74-85-1	Ethylene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
60-29-7	Ethyl ether	0.04	0.09	0.1	0.2	0.2	0.2	0.3	0.3	0.5	0.5	0.7
75-08-1	Ethyl mercaptan	0.04	0.08	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.6
109-95-5	Ethyl nitrite	0.03	0.06	0.09	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5
1333-74-0	Hydrogen	0.08	0.2	0.2	0.3	0.4	0.5	0.6	0.6	0.9	1.0	1.2
75-28-5	Isobutane	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
78-78-4	Isopentane	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
78-79-5	Isoprene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.7
75-31-0	Isopropylamine	0.04	0.09	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.7
75-29-6	Isopropyl chloride	0.04	0.07	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5
74-82-8	Methane	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.6	0.6	0.8
74-89-5	Methylamine	0.04	0.08	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.6
563-45-1	3-Methyl-1-butene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
563-46-2	2-Methyl-1-butene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.7
115-10-6	Methyl ether	0.04	0.08	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.6
107-31-3	Methyl formate	0.03	0.06	0.08	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4
115-11-7	2-Methylpropene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
504-60-9	1,3-Pentadiene	0.05	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.7
109-66-0	Pentane	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
109-67-1	1-Pentene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
646-04-8	2-Pentene, (E)-	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8

Reference Table 30 (continued)

Quantity in Fireball (pounds)		1,000	5,000	10,000	20,000	30,000	50,000	75,000	100,000	200,000	300,000	500,000
Duration of Fireball (seconds)		**3.5**	**5.9**	**7.5**	**9.4**	**10.8**	**12.7**	**14.8**	**15.5**	**17.4**	**18.7**	**20.3**
CAS No.	**Chemical Name**	**Distance (miles) at which Exposure for Duration of Fireball May Cause Second Degree Burns**										
627-20-3	2-Pentene, (Z)-	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
463-49-0	Propadiene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
74-98-6	Propane	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
115-07-1	Propylene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
74-99-7	Propyne	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
7803-62-5	Silane	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.7
116-14-3	Tetrafluoroethylene	0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.1	0.1
75-76-3	Tetramethylsilane	0.05	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.7
10025-78-2	Trichlorosilane	0.01	0.03	0.04	0.06	0.07	0.08	0.1	0.1	0.2	0.2	0.2
79-38-9	Trifluorochloroethylene	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.1	0.1	0.2
75-50-3	Trimethylamine	0.04	0.09	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.7
689-97-4	Vinyl acetylene	0.05	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.8
75-01-4	Vinyl chloride	0.03	0.07	0.09	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.5
109-92-2	Vinyl ethyl ether	0.04	0.09	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.6
75-02-5	Vinyl fluoride	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.1	0.1	0.2
75-35-4	Vinylidene chloride	0.02	0.05	0.07	0.09	0.1	0.1	0.2	0.2	0.3	0.3	0.4
75-38-7	Vinylidene fluoride	0.02	0.05	0.07	0.09	0.1	0.1	0.2	0.2	0.3	0.3	0.4
107-25-5	Vinyl methyl ether	0.04	0.08	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.6

11 ESTIMATING OFFSITE RECEPTORS

In Chapter 11

- How to estimate the number of offsite receptors potentially affected by your worst-case and alternative scenarios.
- Where to find the data you need.

The rule requires that you estimate residential populations within the circle defined by the endpoint for your worst-case and alternative release scenarios. In addition, you must report in the RMP whether certain types of public receptors and environmental receptors are within the circles.

To estimate residential populations, you may use the most recent Census data or any other source of data that you believe is more accurate. Local authorities may be able to provide information on offsite receptors. You are not required to update Census data or conduct any surveys to develop your estimates. Census data are available in public libraries and in the LandView system, which is available on CD-ROM (see box below). The rule requires that you estimate populations to two significant digits. For example, if there are 1,260 people within the circle, you may report 1,300 people. If the number of people is between 10 and 100, estimate to the nearest 10. If the number of people is less than 10, provide the actual number.

How to obtain Census data and LandView

Census data can be found in publications of the Bureau of the Census, available in public libraries, including *County and City Data Book.*

LandView ®III is a desktop mapping system that includes database extracts from EPA, the Bureau of the Census, the U.S. Geological Survey, the Nuclear Regulatory Commission, the Department of Transportation, and the Federal Emergency Management Agency. These databases are presented in a geographic context on maps that show jurisdictional boundaries, detailed networks of roads, rivers, and railroads, census block group and tract polygons, schools, hospitals, churches, cemeteries, airports, dams, and other landmark features.

CD-ROM for IBM-compatible PCS
CD-TGR95-LV3-KIT $99 per disc (by region) or $549 for 11 disc set

U.S. Department of Commerce
Bureau of the Census
P.O. Box 277943
Atlanta, GA 30384-7943
Phone: 301-457-4100 (Customer Services -- orders)
Fax: (888) 249-7295 (toll-free)
Fax: (301) 457-3842 (local)
Phone: (301) 457-1128 (Geography Staff -- content)
http://www.census.gov/ftp/pub/geo/www/tiger/

Further information on LandView and other sources of Census data is available at the Bureau of the Census web site at www.census.gov.

Census data are presented by Census tract. If your circle covers only a portion of the tract, you should develop an estimate for that portion. The easiest way to do this is to determine the population density per square mile (total population of the Census tract divided by the number of square miles in the tract) and apply that density figure to the number of square miles within your circle. Because there is likely to be considerable variation in actual densities within a Census tract, this number will be approximate. The rule, however, does not require you to correct the number.

Other public receptors must be noted in the RMP. If there are any schools, residences, hospitals, prisons, public recreational areas, or commercial, office, or industrial areas within the circle, you must report that. Any of these locations inhabited or occupied by the public at any time without restriction by the source is a public receptor. You are not required to develop a list of all institutions and areas; you must simply check off which types of receptors are within the circle. Most of these institutions or areas can be identified from local street maps. Recreational areas include public swimming pools, public parks, and other areas that are used for recreational activities (e.g., baseball fields). Commercial and industrial areas include shopping malls, strip malls, downtown business areas, industrial parks, etc. See EPA's *General Guidance for Risk Management Programs (40 CFR part 68)* for further information on identifying public receptors.

Environmental receptors are defined as national or state parks, forests, or monuments; officially designated wildlife sanctuaries, preserves, or refuges; and Federal wilderness areas. All of these can be identified on local U.S. Geological Survey (USGS) maps (see box below). You are not required to locate each of these specifically. You are only required to check off in the RMP that these specific types of areas are within the circle. If any part of one of these receptors is within your circles, you must note that in the RMP.

Important: The rule does not require you to assess the likelihood, type, or severity of potential impacts on either public or environmental receptors. Identifying them as within the circle simply indicates that they could be adversely affected by the release.

How to obtain USGS maps

The production of digital cartographic data and graphic maps comprises the largest component of the USGS National Mapping Program. The USGS's most familiar product is the 1:24,000-scale Topographic Quadrangle Map. This is the primary scale of data produced, and depicts greater detail for a smaller area than intermediate-scale (1:50,000 and 1:100,000) and small-scale (1:250,000, 1:2,000,000 or smaller) products, which show selectively less detail for larger areas.

U.S. Geological Survey
508 National Center
12201 Sunrise Valley Drive
Reston, VA 20192
Phone: (703) 648-4000
http://mapping.usgs.gov

To order USGS maps by fax, select, print, and complete one of the online forms and fax to 303-202-4693.

A list of the nearest commercial dealers is available at: http://mapping.usgs.gov/esic/usimage/dealers.html

For more information or ordering assistance, call 1-800-HELP-MAP, or write:

USGS Information Services
Box 25286
Denver, CO 80225

For additional information, contact any USGS Earth Science Information Center or call 1-800-USA-MAPS.

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12 SUBMITTING OFFSITE CONSEQUENCE ANALYSIS INFORMATION FOR RISK MANAGEMENT PLAN

In Chapter 12

- 12.1 Information you are required to submit for worst-case scenarios for toxic substances.
- 12.2 Information you are required to submit for alternative scenarios for toxic substances.
- 12.3 Information you are required to submit for worst-case scenarios for flammable substances.
- 12.4 Information you are required to submit for alternative scenarios for flammable substances.

For the offsite consequence analysis (OCA) component of the RMP you must provide information on your worst-case and alternative release scenario(s) for toxic and flammable regulated chemicals held above the threshold quantity. The requirements for what information you must submit differ if your source has Program 1, Program 2, or Program 3 processes.

If your source has Program 1 processes, you must submit information on a worst-case release scenario for each Program 1 process. If your source has Program 2 or Program 3 processes, you must provide information on one worst-case release for all toxic regulated substances present above the threshold quantity and one worst-case release scenario for all flammable regulated substances present above the threshold quantity. You may need to submit an additional worst-case scenario if a worst-case release from another part of the source would potentially affect public receptors different from those potentially affected by the initial worst-case scenario(s) for flammable and toxic regulated substances.

In addition to a worst-case release scenario, sources with Program 2 and Program 3 processes must also provide information on alternative release scenarios. Alternative releases are releases that could occur, other than the worst-case, that may result in concentrations, overpressures, or radiant heat that reach endpoints offsite. You must present information on one alternative release scenario for each regulated toxic substance, including the substance used for the worst-case release, held above the threshold quantity and one alternative release scenario to represent all flammable substances held above the threshold quantity. The types of documentation to submit are presented below for worst-case scenarios involving toxic substances, alternative scenarios involving toxic substances, worst-case scenarios involving flammable substances, and alternative scenarios involving flammable substances.

12.1 RMP Data Required for Worst-Case Scenarios for Toxic Substances

For worst-case scenarios involving toxic substances, you will have to submit the following information. See the RMP*eSubmit User Manual for complete instructions.

- Chemical name;
- Percentage weight of the regulated liquid toxic substance (if present in a mixture);

- Physical state of the chemical released (gas, liquid, refrigerated gas, gas liquefied by pressure);
- Model used (OCA or industry-specific guidance reference tables or modeling; name of other model used);
- Scenario (gas release or liquid spill and vaporization);
- Quantity released (pounds);
- Release rate (pounds per minute);
- Duration of release (minutes) (10 minutes for gases; if you used OCA guidance for liquids, indicate either 10 or 60 minutes);
- Wind speed (meters per second) and stability class (1.5 meters per second and F stability unless you can show higher minimum wind speed or less stable atmosphere at all times during the last three years);
- Topography (rural or urban);
- Distance to endpoint (miles, rounded to two significant digits);
- Population within distance to endpoint (residential population rounded to two significant digits);
- Public receptors within the distance to endpoint (schools, residences, hospitals, prisons, recreation areas, commercial, office or industrial areas);
- Environmental receptors within the distance to endpoint (national or state parks, forests, or monuments; officially designated wildlife sanctuaries, preserves, or refuges; Federal wilderness areas); and
- Passive mitigation measures considered (dikes, enclosures, berms, drains, sumps, other).

12.2 RMP Data Required for Alternative Scenarios for Toxic Substances

For alternative scenarios involving toxic substances held above the threshold quantity in a Program 2 or Program 3 process, you will have to submit the following information. See the Risk Management Plan Data Elements Guide for complete instructions.

- Chemical name;
- Percentage weight of the regulated liquid toxic substance (if present in a mixture);
- Physical state of the chemical released (gas, liquid, refrigerated gas, gas liquefied by pressure);
- Model used (OCA or industry-specific guidance reference tables or modeling; name of other model used);
- Scenario (transfer hose failure, pipe leak, vessel leak, overfilling, rupture disk/relief valve, excess flow valve, other);
- Quantity released (pounds);
- Release rate (pounds per minute);
- Duration of release (minutes) (if you used OCA guidance, indicate either 10 or 60 minutes);
- Wind speed (meters per second) and stability class (3.0 meters per second and D stability if you use OCA guidance, otherwise use typical meteorological conditions at your site);
- Topography (rural or urban);
- Distance to endpoint (miles, rounded to two significant digits);
- Population within distance to endpoint (residential population rounded to two significant digits);

- Public receptors within the distance to endpoint (schools, residences, hospitals, prisons, recreation areas, commercial, office, or industrial areas);
- Environmental receptors within the distance to endpoint (national or state parks, forests, or monuments; officially designated wildlife sanctuaries, preserves, or refuges; Federal wilderness areas);
- Passive mitigation measures considered (dikes, enclosures, berms, drains, sumps, other); and
- Active mitigation measures considered (sprinkler system, deluge system, water curtain, neutralization, excess flow valve, flares, scrubbers, emergency shutdown system, other).

12.3 RMP Data Required for Worst-Case Scenarios for Flammable Substances

For worst-case scenarios involving flammable substances, you will have to submit the following information. See the Risk Management Plan Data Elements Guide for complete instructions.

- Chemical name;
- Model used (OCA or industry-specific guidance reference tables or modeling; name of other model used);
- Scenario (vapor cloud explosion);
- Quantity released (pounds);
- Endpoint used (for vapor cloud explosions use 1 psi);
- Distance to endpoint (miles, rounded to two significant digits);
- Population within distance to endpoint (residential population rounded to two significant digits);
- Public receptors within the distance to endpoint (schools, residences, hospitals, prisons, recreation areas, commercial, office, or industrial areas);
- Environmental receptors within the distance to endpoint (national or state parks, forests, or monuments, officially designated wildlife sanctuaries, preserves, or refuges, Federal wilderness areas); and
- Passive mitigation measures considered (blast walls, other).

12.4 RMP Data Required for Alternative Scenarios for Flammable Substances

For alternative scenarios involving flammable substances held above the threshold quantity in a Program 2 or Program 3 process, you will have to submit the following information. See the Risk Management Plan Data Elements Guide for complete instructions.

- Chemical name;
- Model used (OCA or industry-specific guidance reference tables or modeling; name of other model used);
- Scenario (vapor cloud explosion, fireball, BLEVE, pool fire, jet fire, vapor cloud fire, other);
- Quantity released (pounds);
- Endpoint used (for vapor cloud explosions, the endpoint is 1 psi overpressure; for a fireball the endpoint is 5 kw/m^2 for 40 seconds. A lower flammability limit (expressed as a percentage) may be listed as specified in NFPA documents or other generally recognized sources; these are listed in the OCA Guidance);
- Distance to endpoint (miles, rounded to two significant digits);

- Population within distance to endpoint (residential population rounded to two significant digits);
- Public receptors within the distance to endpoint (schools, residences, hospitals, prisons, recreation areas, commercial, office, or industrial areas);
- Environmental receptors within the distance to endpoint (national or state parks, forests, or monuments, officially designated wildlife sanctuaries, preserves, or refuges, Federal wilderness areas);
- Passive mitigation measures considered (e.g., dikes, fire walls, blast walls, enclosures, other); and
- Active mitigation measures considered (e.g., sprinkler system, deluge system, water curtain, excess flow valve, other).

12.5 Submitting RMPs

EPA has made RMP*eSubmit available to complete and file your RMP. RMP*eSubmit does the following:

- Provides a user-friendly, web-based RMP Submission System via EPA's secure Central Data Exchange (CDX).
- Performs data quality checks, accepts limited graphics, and provides on-line help including defining data elements and providing instructions.
- Online reporting simplifies the process. It saves you time, and improves data quality and security.
- EPA uses industry-standard technology, including encryption used by most commercial banks, as well as stringent user ID and password protocols to protect your information.
- You will be able to access your RMP online at any time.
- For a facility to submit their RMP, the certifier will first be required to set up a CDX account (or use their current one if the facility already submits data via CDX). Instructions for obtaining a CDX account and using RMP*eSubmit can be found at: www.epa.gov/emergencies/rmp.
- Upon approval of the document in submission, a confirmation e-mail will be sent to the certifier.

12.6 Other Required Documentation

Besides the information you are required to submit in your RMP, you must maintain other records of your offsite consequence analysis on site. Under 40 CFR 68.39, you must maintain the following records:

- For worst-case scenarios, a description of the vessel or pipeline and substance selected as the worst case, the assumptions and parameters used, and the rationale for selection. Assumptions include any administrative controls and any passive mitigation systems that were used to limit the quantity that could be released. You must document that anticipated effects of these controls and systems on the release quantity and rate.

- For alternative release scenarios, a description of the scenarios identified the assumptions and parameters used, and the rationale for selection of the specific scenarios. Assumptions include any administrative controls and any passive mitigation systems that were used to limit the quantity that could be released. You must document that anticipated effects of these controls and systems on the release quantity and rate.
- Documentation of estimated quantity released, release rate, and duration of the release.
- Methodology used to determine distance to an endpoint.
- Data used to estimate populations and environmental receptors potentially affected.

You are required to maintain these records for five years.

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