CHAPTER 4: OFFSITE CONSEQUENCE ANALYSIS

You are required to conduct an offsite consequence analysis to provide information to the government and the public about the potential consequences of an accidental chemical release at your facility. The offsite consequence analysis (OCA) consists of two elements:

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

To simplify the analysis and ensure a common basis for comparisons, 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 are no longer likely.

This chapter gives guidance on how to perform the OCA for regulated substances that are typically found at chemical distribution facilities.

Section 68.130 lists 77 toxic substances and 63 flammable substances that are subject to regulation. The National Association of Chemical Distributors (NACD) conducted an informal poll of its members to determine which regulated chemicals might be on-site in quantities above the threshold. The results of the survey are shown on Exhibits 4-1 and 4-2. This guidance focuses on the substances identified in these exhibits. For substances that are not currently included in this guidance, consult and use the EPA's *RMP Offsite Consequence Analysis Guidance* (OCAG) or other models or methods.

To estimate consequence distance, this guidance provides a sequence of equations based on the references tables of distances in the OCAG (see Appendix 4A for the derivation of these equations. You may use the OCAG reference tables to estimate distances, if you prefer.

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 Internet website at http://www.epa.gov/swercepp/tools/rmp-comp/rmp-comp.html.

EXHIBIT 4-1
INFORMATION GATHERED BY NACD SURVEY - TOXIC SUBSTANCES

Chemical Name	Typical Amount on Site (lb)[a]	Liquid or Gas	Toxic Endpoint (mg/L)	Vapor Pressure @ 25EC	Liquid Density (lb/ft^3)
Allyl alcohol	Not specified	Toxic liquid	0.036	26.1 mm Hg	52.2
Anhydrous ammonia	20,000 - 180,000	Toxic gas	0.14	145 psia	43.8
Aqueous ammonia (> 20%)	10,000 - 180,000	Toxic liquid	0.14	332 mm Hg	55.1
Bromine	10,000 - 35,000	Toxic liquid	0.0065	212 mm Hg	189
Carbon disulfide	20,000 - 120,000	Toxic liquid	0.16	359 mm Hg	77.7
Chlorine	20,000 - 330,000	Toxic gas	0.0087	113 psia	101
Chloroform	20,000	Toxic liquid	0.49	196 mm Hg	91.8
Cyclohexylamine	20,000	Toxic liquid	0.16	10.1 mm Hg	54.1
Epichlorohydrin	20,000	Toxic liquid	0.076	16.5 mm Hg	73.9
Ethylenediamine	20,000	Toxic liquid	0.49	12.2 mm Hg	56.1
Ethylene oxide	10,000 - 200,000	Toxic gas	0.09	25.4 psia	89.81
Formaldehyde (37%)[b]	15,000 - 55,000	Toxic liquid	0.012	Concentration Dependent	68.9
Hydrazine - pure	15,000 - 55,000	Toxic liquid	0.011	14.4 mm Hg	63.1
Aqueous hydrochloric acid (> 30%:38%)	15,000 - 330,000	Toxic liquid	0.03	Concentration Dependent	73.9
Hydrofluoric acid (70%)	1,000 - 100,000	Toxic liquid	0.016	Concentration Dependent	77.7
Methyl chloride	20,000 - 25,000	Toxic gas	0.82	83.2 psia	83.34
Methyl isocyanate	10,000 - 45,000	Toxic liquid	0.0012	457 mm Hg	58.3
Nitric acid (80%)	20,000	Toxic liquid	0.026	10 mm Hg	91.8
Phosgene	2,000+	Toxic gas	0.00081	27.4 psia	79.9
Phosphorus oxychloride	5,000 - 25,000	Toxic liquid	0.003	35.8 mm Hg	104.5
Phosphorus trichloride	20,000	Toxic liquid	0.028	120 mm Hg	97.8
Propylene oxide	10,000 - 200,000	Toxic liquid	0.59	533 mm Hg	51.4
Sulfur dioxide	10,000 - 400,000	Toxic gas	0.0078	58 psia	94.7
Sulfur trioxide	10,000 - 170,000	Toxic liquid	0.01	263 mm Hg	117
Toluene 2,4-diisocyanate	10,000 - 45,000	Toxic liquid	0.007	0.013 mm Hg	75.8
Toluene 2,6-diisocyanate[c]	10,000 - 115,000	Toxic liquid	0.007	0.05 mm Hg	75.8

[a]Range provided if there was more than one respondent and they provided different estimates
[b]The vapor pressure of formaldehyde in a 37% solution is less than 10 mm Hg. It is, therefore, not covered by the regulation.
[c]Toluene diisocyanate is also available as a mixture of 2,4- and 2,6-diisocyanate.

EXHIBIT 4-2
INFORMATION GATHERED BY NACD SURVEY - FLAMMABLE SUBSTANCES

Chemical Name	Typical Amount on Site (lb)	Liquid or Gas	Lower Flammable Limit (mg/L)	Vapor Pressure @ 25EC	Liquid Density (lb/ft³)
Acetaldehyde	Not specified	Flammable gas	72	21 psia	49
Dimethylamine	2,500	Flammable gas	52	102 psia	42
Ethyl ether	10,000 - 40,000	Flammable liquid	57	440 mm Hg	43.9
Isopropyl chloride	5,000	Flammable liquid	90	325 mm Hg	53.1
Isopropylamine	5,000	Flammable liquid	48	248 mm Hg	42.7
Methane	Not specified	Flammable gas	33	1,080 psia	28
Propane	Not specified	Flammable gas	36	138 psia	37
Trimethylamine	10,000 - 115,000	Flammable gas	48	31.9 psia	41

The methodology and data 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 other models, you should review the rule and Chapter 4 of the *General Guidance for Risk Management Programs*, which outline required conditions for use of other models.

Some of the results obtained using the methods in this document may be conservative (i.e., they may overestimate the distance to endpoints). Complex models that can account for many site-specific factors may give less conservative estimates of offsite consequences than the simple methods used 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.

This chapter discusses worst-case scenarios and presents methods for determining the worst-case distance to the endpoint for substances listed in Exhibits 4-1 and 4-2 (section 4.1), followed by discussions and methods for alternative scenarios for these substances (section 4.2). Section 4.3 briefly discusses methods for estimating the mitigating effects of buildings. The remaining sections provide guidance on defining offsite impacts (section 4.4) and documentation (section 4.5).

4.1   WORST-CASE RELEASE SCENARIOS

This section provides guidance on how to analyze worst-case scenarios. Information is provided on the general requirements of the regulations, followed by sections on toxic gases, toxic liquids, and flammable substances, focusing on those substances likely to be found at chemical distribution facilities. Exhibit 4-3 presents the parameters that must be used in worst-case and alternative release scenarios.

EXHIBIT 4-3
REQUIRED PARAMETERS FOR MODELING (40 CFR 68.22)

WORST CASE	ALTERNATIVE SCENARIO
Endpoints (§68.22(a))	
Toxic endpoints are listed in part 68 Appendix A.	Toxic endpoints are listed 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: gOverpressure of 1 psi for vapor cloud explosions gRadiant heat level of 5 kilowatts per square meter (kW/m^2) for 40 seconds for heat from fires (or equivalent dose) gLower flammability limit (LFL) as specified in NFPA documents or other generally recognized sources for vapor cloud fires.
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 may use typical meteorological conditions for your site.
Ambient temperature/humidity (§68.22(c))	
This guidance assumes 25EC (77EF) 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 25EC 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.	Tables or models used for dispersion must appropriately account for gas density.
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.	Substances may be considered to be released at a process or ambient temperature that is appropriate for the scenario.

GENERAL REQUIREMENTS FOR TOXIC SUBSTANCES

The following information is required for worst-case release analysis of toxic substances:

g   The *worst-case release quantity* Q (lb) is the greater of the following:

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

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

An example of an administrative control is a procedure that limits the total amount of a substance that you can have in a vessel. For example, you should have procedures for vessels containing anhydrous ammonia liquefied under pressure, limiting the volume of ammonia to 85% of the volume of the vessel, because ammonia has a large coefficient of volumetric expansion.

For vessels, you need only consider the largest amount in the vessel, regardless of interconnections with pipes and other vessels. Similarly, if the largest quantity is contained in a pipe, you need not add the quantity in vessels at the end of the pipelines. You may be able to think of scenarios in which a quantity greater than Q as defined above can be released, but EPA does not require you to model such scenarios as worst-case (you may want to consider modeling them as alternative scenarios).

g   *Weather conditions.* The rule allows anyone who conducts his or her OCA based on this guidance to use specific default weather conditions for wind speed, stability class, average temperature, and humidity.

g   *Temperature of released substance.* Liquids other than gases liquefied by refrigeration should be considered to be released at the highest daily maximum temperature, based on local data for the previous three years, or at process temperature, whichever is the higher. Gases liquefied by refrigeration alone (e.g., refrigerated chlorine or ammonia) should be considered to be released at their atmospheric boiling points. You can obtain weather data from local weather stations. You can also obtain temperature and wind speed data from the National Climatic Data Center at (828) 271-4800.

g   For the worst-case scenario, the release must be assumed to take place at *ground level.*

g   *Toxic endpoints* for toxic substances commonly found at chemical distribution facilities are listed in Exhibit 4-1. These endpoints are specified in 40 CFR Part 68, Appendix A. The endpoints are intended to correspond to maximum airborne concentrations below which it is believed that nearly

all individuals can be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.

g   *Rural vs. urban sites*. The regulations require you to take account of whether your site is rural or urban. To decide whether the site is rural or urban, the rule offers the following: "Urban means that there are many obstacles in the immediate area; obstacles include buildings or trees. Rural means that there are no buildings in the immediate area and the terrain is generally flat or unobstructed." Some areas outside of cities may still be considered urban if they are forested.

The distinction between urban and rural sites is important because the atmosphere at urban sites is generally more turbulent than at rural sites, causing more rapid dilution of the cloud as it travels downwind. Therefore, for ground-level releases, predicted distances to toxic endpoints are always smaller at urban sites than at rural sites.

g   *Gas density*. The regulations require you to use tables or models that appropriately account for gas density. This guidance provides methods that are based on modeling carried out for dense and neutrally buoyant gases or vapors (i.e., for gases that are denser-than-air or for gases that have the same density as air, respectively), as appropriate.

g   *Mitigation*. You are only allowed to take account of passive mitigation systems, not active ones. Passive mitigation systems could include:

-        Diked areas that confine a liquid pool and reduce the surface area available for evaporation
-        Buildings, provided that the building can be shown to withstand the events that caused the release (see Section 4.3 for more information)

Active mitigation systems include:

-        Automatically closing or remotely operated valves
-        Sprays and deluge systems
-        Relief valves
-        Check valves
-        Excess flow valves
-        Scrubbers

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g   The predicted frequency of occurrence of the worst-case scenario is not an allowable consideration. You are not required to determine a possible cause of the failure of the vessel.

TOXIC GASES

For toxic gases, the worst-case scenario is release of the contents of the largest vessel or pipeline over 10 minutes. For toxic gases listed in Exhibit 4-1, distance to which

the cloud will travel before falling below the toxic endpoint can be estimated from the following equation:

$$D = A1 \, (QR)^{A2} \tag{1}$$

where D (mi) is the distance to which the vapor cloud travels before its concentration falls below the toxic endpoint, QR (lb/min) is the release rate, or the total quantity released divided by 10, and A1 and A2 are constants with values that depend upon the particular chemical and whether the site is urban or rural. The derivation of Equation 1 is fully explained in Appendix 4A.

Values of A1 and A2 for the toxic gases listed in Exhibit 4-1 are given on Exhibit 4-4. For calculated distances less than 10 mi, round the results up or down to the nearest tenth of a mile. For distances from 10 to 25 mi, round the results to the nearest mile. For distances exceeding 25 mi, present the results as 25 mi. For distances less than 0.1 mi, present the results as 0.1 mi.

EXHIBIT 4-4
WORST-CASE SCENARIO—CONSTANTS A1 AND A2 FOR TOXIC GASES
(For a 10-minute Duration of Release)

Chemical Name	Rural		Urban	
	A1	**A2**	**A1**	**A2**
Anhydrous Ammonia	0.0607	0.4923	0.0443	0.4782
Chlorine	0.227	0.4879	0.0878	0.5134
Ethylene Oxide	0.181	0.4311	0.0877	0.4775
Methyl Chloride	0.0518	0.4397	0.0270	0.4571
Phosgene	1.79	0.4503	1.21	0.4860
Sulfur Dioxide	0.165	0.5562	0.0726	0.5419

Example 1. For sulfur dioxide at a rural site, A1 = 0.165 and A2 = 0.5562 (see Exhibit 4-4). For a 20,000-lb release, at 2,000 lb/min:

$$D = (0.165)(2,000)^{0.5562} = 11.3 \text{ mi} \sim 11 \text{ mi}$$

For an urban site, A1 = 0.0726 and A2 = 0.5419, so that:

$$D = (0.0726)(2,000)^{0.5419} = 4.46 \text{ mi} \sim 4.5 \text{ mi}$$

TOXIC LIQUIDS

The worst-case scenario for toxic liquids is a spill of the total quantity in the largest vessel. The quantity spilled is assumed to spread instantaneously to a depth of one centimeter in an undiked area or to cover a diked area instantaneously. The distance to the endpoint is estimated based on evaporation from the pool and downwind dispersion of the vapor. Two cases are considered here:

g   The pool is unconfined, in which case it spreads out until it has a depth of one centimeter, or

g   The pool is limited in area by a dike

RATE OF EVAPORATION - UNDIKED AREA

For an undiked area, the rate of evaporation QR (lb/min) for a spill at ambient temperature is given by:

$$QR = 1.4 \times LFA \times DF \times QS \qquad (2)$$

where QS is the total quantity (lb) spilled, LFA is the "Liquid Factor Ambient," and DF is the "density factor." The values of LFA and DF are provided in Exhibits 4-5a and 4-5b. LFA is calculated for a 25EC spillage. If you wish, you may apply a correction factor that takes account of the fact that LFA is proportional to the vapor pressure. Exhibit 4-6 gives values for a temperature correction factor (TCF) over a range of temperatures for toxic liquids. You can correct the LFA for temperatures above 25EC as follows:

$$LFA(T) = TCF \times LFA(25EC) \qquad (3)$$

where: LFA(T) = Corrected Liquid Factor Ambient at temperature T
         TCF = Temperature Correction Factor at temperature T, from Exhibit 4-6
         (use the factor given for temperature closest to T)
         LFA(25EC) = LFA at 25EC, from Exhibit 4-5a or 4-5b

For a liquid in a process in which the temperature of the process exceeds 25EC, the release rate to air from an evaporating pool in an undiked area is given by the following formula:

$$QR = 1.4 \times LFB \times DF \times QS \qquad (4)$$

where LFB is the "Liquid Factor Boiling." Values of LFB are also provided in Exhibit 4-5a. You may replace LFB by LFA(T), using Equation 3, where TEC is now the temperature of the process. LFA(T) will give a less conservative result.

EXHIBIT 4-5a
VALUES OF LFA, LFB, DF AND VAPOR PRESSURE FOR TOXIC LIQUIDS[1]

Material	LFA	LFB	DF	Vapor Pressure @ 25EC (mm Hg)
Allyl Alcohol	0.0046	0.11	0.58	26.1
Bromine	0.073	0.23	0.16	212
Carbon disulfide	0.075	0.15	0.39	359
Chloroform	0.055	0.19	0.33	196
Cyclohexylamine	0.0025	0.14	0.56	10
Epichlorohydrin	0.0040	0.14	0.42	17
Ethylenediamine	0.0022	0.10	0.54	12
Hydrazine	0.0017	0.069	0.48	14.4
Methyl Isocyanate	0.079	0.13	0.52	457
Phosphorus oxychloride	0.012	0.20	0.29	35.8
Phosphorus trichloride	0.037	0.20	0.31	120
Propylene oxide	0.093	0.13	0.59	533
Sulfur trioxide	0.057	0.15	0.26	263
Toluene 2,4-diisocyanate	0.000006	0.16	0.40	0.017
Toluene 2,6-diisocyanate	0.000018	0.16	0.40	0.05

EXHIBIT 4-5b
VALUES OF LFA, DF AND VAPOR PRESSURE FOR AQUEOUS SOLUTIONS[1]

Material	LFA at 25EC		Vapor Pressure at 25EC (mm Hg)[2]		DF
	Wind Speed 1.5 m/s	Wind Speed 3.0 m/s	Wind Speed 1.5 m/s	Wind Speed 3.0 m/s	
Aqueous Ammonia 30%	0.026	0.019	332	248	0.55
Aqueous Ammonia 24%	0.019	0.014	241	184	0.54
Aqueous Ammonia 20%	0.015	0.011	190	148	0.53
Formaldehyde 37%	0.0002	0.0002	1.5	1.4	0.44
Hydrochloric Acid 38%	0.010	0.0070	78	55	0.41
Hydrochloric Acid 37%	0.0085	0.0062	67	48	0.42
Hydrochloric Acid 36%[3]	0.0072	0.0053	56	42	0.42
Hydrochloric Acid 34%[3]	0.0048	0.0037	38	29	0.42
Hydrochloric Acid 30%[3]	0.0016	0.0015	13	12	0.42
Hydrofluoric Acid 70%	0.011	0.010	124	107	0.39
Hydrofluoric Acid 50%	0.0014	0.0013	16	15	0.41
Nitric Acid 90%	0.0046	0.0040	25	22	0.33
Nitric Acid 85%	0.0032	0.0029	17	16	0.33
Nitric Acid 80%	0.0019	0.0018	10.2	10	0.33

[1]LFB is not tabulated for solutions.
[2]Vapor pressure averaged over 10 minutes.
[3]Hydrochloric acid in concentrations below 37% is not regulated.

EXHIBIT 4-6
TEMPERATURE CORRECTION FACTORS FOR LIQUIDS EVAPORATING FROM POOLS
AT TEMPERATURES BETWEEN 25EC AND 50EC (77EF AND 122EF)[1]

CAS Number	Chemical Name	Boiling Point (EC)	Temperature Correction Factor (TCF)				
			30EC (86EF)	35EC (95EF)	40EC (104EF)	45EC (113EF)	50EC (122EF)
107-18-6	Allyl alcohol	97.08	1.3	1.7	2.2	2.9	3.6
7726-95-6	Bromine	58.75	1.2	1.5	1.7	2.1	2.5
75-15-0	Carbon disulfide	46.22	1.2	1.4	1.6	1.9	LFB
67-66-3	Chloroform	61.18	1.2	1.5	1.8	2.1	2.5
108-91-8	Cyclohexylamine	134.50	1.3	1.7	2.1	2.7	3.4
106-89-8	Epichlorohydrin	118.50	1.3	1.7	2.1	2.7	3.4
107-15-3	Ethylenediamine	117.41	1.3	1.8	2.3	3.0	3.8
302-01-2	Hydrazine	113.50	1.3	1.7	2.2	2.9	3.6
624-83-9	Methyl isocyanate	38.85	1.2	1.4	LFB	LFB	LFB
7697-37-2	Nitric acid	83.00	1.3	1.6	2.0	2.5	3.1
10025-87-3	Phosphorus oxychloride	105.50	1.3	1.6	1.9	2.4	2.9
7719-12-2	Phosphorus trichloride	76.10	1.2	1.5	1.8	2.1	2.5
75-56-9	Propylene oxide	33.90	1.2	LFB	LFB	LFB	LFB
7446-11-9	Sulfur trioxide	44.75	1.3	1.7	LFB	LFB	LFB
584-84-9	Toluene 2,4-diisocyanate	251.00	1.6	2.4	3.6	5.3	7.7
91-08-7	Toluene 2,6-diisocyanate	244.85	ND	ND	ND	ND	ND

Notes:
[1]Taken from OCAG, Exhibit B-4
ND: No data available.
LFB: Chemical above boiling point at this temperature; use LFB for analysis.

OCAG did not develop temperature correction factors for aqueous solutions, such as aqueous ammonia.

You may want to use LFA(T) especially in cases where the liquid is at a temperature significantly below its boiling point.   Assuming the liquid spreads to form a pool 1 centimeter deep, the area A (ft^2) of the spill is:

$$A = DF \times QS \qquad (5)$$

where DF is assumed to be independent of temperature.

Example 2 To calculate the rate of evaporation of an undiked spill of 10,000 lb of epichlorohydrin spilled at ambient temperature, use Equation 2 and Exhibit 4-5a:

$$QR = (1.4)(0.0040)(0.42)(10,000) = 23.5 \text{ lb/min}$$

If the spill takes place from a process at a higher temperature than 25EC, using Equation 4 and Exhibit 4-5a:

$$QR = (1.4)(0.14)(0.42)(10,000) \sim 820 \text{ lb/min}$$

Clearly, this is an example in which you might want to consider replacing LFB in Equation 4 by LFA(T) from Equation 3. For example, at 35EC, TCF for epichlorohydrin (from Exhibit 4-6) is 1.7. The release rate is:

$$QR = 23.5 \times 1.7 = 40 \text{ lb/min}$$

RATE OF EVAPORATION - DIKED AREA

If the pool is confined within a diked area of A_d ft^2, the rate of evaporation is independent of the total quantity spilled and is given by:

$$QR = 1.4 \times LFA \times A_d \qquad (6)$$

for a spill at ambient temperature, and

$$QR = 1.4 \times LFB \times A_d \qquad (7)$$

for a spill from a process at a temperature exceeding 25EC. You may replace LFB by LFA(T) from Equation 3 if you wish.

To calculate the rate of evaporation QR:

g   Calculate the area A to which the spill will spread, using Equation 5

g   Compare A and A_d

g   If A is smaller than A_d, calculate QR using Equation 2 or Equation 4 (this is appropriate for a small spill that spreads to a depth of 1 cm before it encounters the walls of the diked area), or

g   If A_d is smaller, calculate the release rate using Equation 6 or 7.

Example 3 Suppose that 10,000 lb of cyclohexylamine at ambient temperature spills into a diked area (A_d) of 4,000 ft^2. From Equation 5 and Exhibit 4-4:

$$A = (0.56)(10,000) = 5,600 \text{ ft}^2$$

A_d is the smaller of the two areas, so that, using Equation 6 and Exhibit 4-4a:

$$QR = 1.4 \times 0.0025 \times 4,000 = 14 \text{ lb/min}$$

DISTANCE TO TOXIC ENDPOINT

For each of the toxic liquids and aqueous solutions listed in Exhibits 4-5a and 4-5b, the distance to the endpoint can be estimated from the following equation (see Appendix 4A for the derivation of this equation):

$$D = B1 \, (QR)^{B2} \tag{8}$$

where D (mi) is the distance to which the vapor cloud travels before its concentration falls below the toxic endpoint, QR (lb/min) is the rate of evaporation, and B1 and B2 are constants with values that depend upon the particular chemical and whether the site is urban or rural.

Values of B1 and B2 are given on Exhibit 4-7a for a 10-minute release and on Exhibit 4-7b for a 60-minute release. B1 and B2 values for 10-minute releases should be used for pools that evaporate in 10 minutes or less, and values for 60-minute releases should be used for longer evaporation times. For solutions, always use the 10-minute values.

For distances less than 10 mi, round the results up or down to the nearest tenth of a mile. For distances from 10 to 25 mi, round the results to the nearest mile. For distances exceeding 25 mi, present the results as 25 mi. For distances less than 0.1 mi, present the results as 0.1 mi.

Example 4, 60-minute release. In Example 3, an evaporation rate of 14 lb/min was estimated for a 10,000-lb spill of cyclohexylamine. At this rate of evaporation, the pool would take 10,000/14, or more than 700 minutes, to evaporate. Therefore, you would use B1 and B2 for a 60-minute release to estimate the distance to the endpoint. From Exhibit 4-7b, for a rural site, B1 = 0.143 and B2 = 0.5440. For the 14 lb/min release rate predicted in Example 3,

$$D = (0.143)(14)^{0.5440} = \ 0.6 \text{ mi at a rural site}$$

For an urban site, B1 = 0.0844 and B2 = 0.5789, so that:

$$D = (0.0844)(14)^{0.5789} = 0.39 \text{ mi} \sim 0.4 \text{ mi.}$$

EXHIBIT 4-7a
**WORST-CASE SCENARIO—CONSTANTS B1 & B2 FOR TOXIC LIQUIDS
AND AQUEOUS SOLUTIONS, 10-MINUTE RELEASE**

Chemical Name	Rural		Urban	
	B1	B2	B1	B2
Allyl Alcohol	0.233	0.4871	0.162	0.4806
Aqueous Ammonia	0.0667	0.4617	0.0221	0.4712
Bromine	0.550	0.4704	0.377	0.4807
Carbon Disulfide	0.181	0.4311	0.0877	0.4775
Chloroform	0.0703	0.4326	0.0274	0.4916
Cyclohexylamine	0.181	0.4311	0.0877	0.4775
Epichlorohydrin	0.212	0.4320	0.108	0.4747
Ethylenediamine	0.0703	0.4326	0.0274	0.4916
Formaldehyde	0.271	0.5389	0.140	0.5072
Hydrazine	0.284	0.5389	0.147	0.5072
Hydrochloric Acid	0.233	0.4871	0.162	0.4806
Hydrofluoric Acid	0.232	0.5389	0.121	0.5072
Methyl Isocyanate	1.49	0.4572	1.04	0.4820
Nitric Acid	0.326	0.4782	0.220	0.4835
Phosphorus Oxychloride	0.809	0.4638	0.563	0.4804
Phosphorus Trichloride	0.233	0.4871	0.162	0.4806
Propylene Oxide	0.0703	0.4326	0.0274	0.4916
Sulfur Trioxide	0.475	0.4696	0.319	0.4829
Toluene 2,4-diisocyanate	0.362	0.5389	0.184	0.5072
Toluene 2,6-diisocyanate	0.362	0.5389	0.184	0.5072

EXHIBIT 4-7b
WORST-CASE SCENARIO—CONSTANTS B1 & B2 FOR TOXIC LIQUIDS[1]
60-MINUTE RELEASE

Chemical Name	Rural		Urban	
	B1	B2	B1	B2
Allyl Alcohol	0.266	0.5715	0.169	0.5894
Bromine	0.693	0.5505	0.456	0.5808
Carbon Disulfide	0.143	0.5540	0.0844	0.5789
Chloroform	0.0473	0.5665	0.0249	0.5936
Cyclohexylamine	0.143	0.5540	0.0844	0.5789
Epichlorohydrin	0.174	0.5468	0.105	0.5769
Ethylenediamine	0.0473	0.5665	0.0249	0.5936
Hydrazine	0.220	0.6951	0.107	0.6317
Methyl Isocyanate	2.25	0.5320	1.55	0.5531
Phosphorus Oxychloride	1.12	0.5315	0.744	0.5618
Phosphorus Trichloride	0.266	0.5715	0.169	0.5894
Propylene Oxide	0.0473	0.5665	0.249	0.5936
Sulfur Trioxide	0.576	0.5540	0.381	0.5724
Toluene 2,4-diisocyanate	0.302	0.6951	0.142	0.6317
Toluene 2,6-diisocyanate	0.302	0.6951	0.142	0.6317

Footnotes:
[1]Aqueous solutions are omitted from this table. The evaporation rates from aqueous solutions are averaged over the first ten minutes, so the 60-minute release table is not applicable.

RELEASE OF TOXIC GASES LIQUEFIED BY REFRIGERATION

If a material such as chlorine or ammonia is handled as a refrigerated liquid and spills onto an undiked area, spreading to a depth of 1 cm or less, the regulation requires that the owner or operator assume that it is released as a gas in 10 minutes. That is, it is modeled in the same way as a worst-case release scenario from a vessel in which the material is a liquid under pressure, as for the toxic gases listed in Exhibit 4-3.

If the material is confined in a diked area, forming a pool more than 1 cm deep, then you can assume the liquid is at its boiling point and use Equation 7, for a spill into a diked area, to estimate the rate of evaporation from the pool. The LFB (Liquid Factor Boiling) is listed below for toxic gases.

Toxic Gas	LFB
Anhydrous Ammonia	0.073
Chlorine	0.19
Ethylene Oxide	0.12
Methyl Chloride	0.14
Phosgene	0.20
Sulfur Dioxide	0.16

Use of Equation 7 is a simple approach; however, other methods are available to estimate the release rate for refrigerated liquefied gases. Appendix 4A provides an equation (Equation A-2) for estimating the evaporation rate that takes into account a number of additional factors, including the thermal conductivity and diffusivity of the surface under the pool, the temperature of the ground and the pool, and the heat of vaporization of the spilled substance. You are free to use this more complex equation (or other methods), instead of Equation 7, to estimate the evaporation rate.

Example 5 Refrigerated chlorine is spilled into a diked area with $A_d = 400$ ft^2. The LFB of chlorine is 0.19. Using Equation 7,

$$QR = 1.4 \times 0.19 \times 400 = 106 \text{ lb/min}$$

Appendix 4A provides an estimate of the evaporation rate for this example using the more complex equation discussed above (see Example A-1 in the appendix).

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 substance in the mixture is below 10 millimeters of mercury (mm Hg). In case of a

spill of a liquid mixture containing a regulated toxic substance with partial vapor
pressure of 10 mm Hg or higher, you should carry out a worst-case analysis. The
information provided by NACD in Exhibit 4-1 does not include any mixtures of
toxic liquids; therefore, mixtures are not considered in this guidance. If you do have
mixtures that would be covered by the RMP rule, you should refer to the OCAG or
use other models or methods.

FLAMMABLE GASES AND LIQUIDS

For regulated flammable substances, the regulation requires that the distance D (mi)
to the 1 psi overpressure endpoint should be calculated for a vapor cloud explosion
of the greatest quantity in a vessel or pipeline.

g   If the flammable substance is normally a gas at ambient temperature and
         handled as gas or liquid under pressure or if the flammable substance is a gas
         handled as a refrigerated liquid and is not contained when released or the
         contained pool is one centimeter or less deep, you must assume the total
         quantity is released as a gas and is involved in a vapor cloud explosion.

g   If the flammable substance is a liquid or a refrigerated gas released into a
         containment area with a depth greater than one centimeter, you may assume
         that the quantity that volatilizes in 10 minutes is involved in a vapor cloud
         explosion.

A simple method of obtaining an approximate answer is to use the TNT equivalency
method, which states that:

$$D = 0.0037(Q \times H/H_{TNT})^{1/3} \tag{9}$$

where Q (lb) is the quantity of flammable material released, H is the heat of
combustion of the flammable substance and H_{TNT} is the heat of combustion of
trinitrotoluene (TNT). As required by the rule, the yield factor is 10% (i.e, 10% of
the released quantity participates in the explosion) when the TNT equivalency model
is used, and this assumption is incorporated into the constant 0.0037. (This equation
is valid for both volatile flammable liquids and flammable gases.) Equation 9 can be
rewritten as:

$$D = 8 \, (Q)^{1/3} \tag{10}$$

where $8 = 0.0037 \times (H/H_{TNT})^{1/3}$

The values of 8 for the flammable substances listed in Exhibit 4-2 are given below:

	8
Acetaldehyde	0.0065
Dimethylamine	0.0073
Ethyl ether	0.0072
Isopropyl chloride	0.0064
Isopropylamine	0.0073
Methane	0.0082

Propane   0.0080
Trimethylamine   0.0074

Example 5 If 10,000 lb of propane explodes:

$$D = 0.008 \, (10{,}000)^{1/3} = 0.17 \text{ mi}$$

4.2   ALTERNATIVE SCENARIOS

GENERAL REQUIREMENTS

The requirements that differ from those for the worst-case scenarios are as follows:

g   You can take into account active as well as passive mitigation systems, as long as these systems are expected to withstand the causes of the accident.

g   The alternative scenario should reach an endpoint offsite, unless no such scenario exists.

g   If you are doing your own modeling, you should use "typical meteorological conditions for the stationary source." You may obtain these data from local weather stations. You can obtain wind speed and temperature data from the National Climatic Data Center at (828) 271-4800. This guidance uses an "average" weather condition of wind speed 3 m/s and D stability class with an ambient temperature of 25EC.

g   The release is not necessarily restricted to ground level. It can be elevated, if appropriate.

g   The number of alternative scenarios you are required to develop is as follows:

-        At least one scenario for each regulated toxic substance held in Program 2 and Program 3 processes
-        At least one scenario to represent all flammables held in Program 2 and Program 3 processes

CHOICE OF ALTERNATIVE SCENARIOS

Your alternative scenario for a covered process must be one that is more likely to occur than the worst-case scenario and that reaches an endpoint offsite, unless no such scenario exists. You do not need to demonstrate greater likelihood of occurrence or carry out any analysis of probability of occurrence; you only need to use reasonable judgement and knowledge of the process. If, using a combination of reasonable assumptions, modeling of a release of a regulated substance from a process shows that the relevant endpoint is not reached offsite, you can use the modeling results to demonstrate that a scenario does not exist for the process that will give an endpoint offsite. You must report an alternative scenario, however.

Release scenarios you should consider include, but are not limited to, the following, where applicable:

g   Transfer hose releases due to splits or sudden hose uncoupling;

g   Releases from piping failures at flanges, joints, welds, valves and valve seats, and drains or bleeds;

g   Releases from pumps or vessels due to cracks, seal failure, or drain, bleed, or plug failure;

g   Vessel overfilling and spill, or overpressurization and venting through relief valves or rupture disks; and

g   Shipping container mishandling and breakage or puncturing leading to a spill.

For alternative release scenarios, you may 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. Mitigation systems considered must be capable of withstanding the event that triggers the release while remaining functional.

You must consider your five-year accident history and failure scenarios identified in your hazard review or process hazards analysis in selecting alternative release scenarios for regulated toxic or flammable substances (e.g., you might choose an actual event from your accident history as the basis of your scenario). You may also consult your trade organization (NACD). You may consider any other reasonable scenarios.

The alternative scenarios you choose to analyze should be scenarios that you consider possible at your site. Although EPA requires no explanation of your choice of scenario, you should choose a scenario that you think you can explain to emergency responders and the public as a reasonable alternative to the worst-case scenario. For example, you could pick a scenario based on an actual event, or you could choose a scenario that you worry about, because circumstances at your site might make it a possibility. If you believe that there is no reasonable scenario that could lead to offsite consequences, you may use a scenario that has no offsite impacts for your alternative analysis. You should be prepared to explain your choice of such a scenario to the public, should questions arise.

TOXIC GASES - ALTERNATIVE SCENARIO

CHOICE OF SCENARIO

For the six toxic gases considered in this guidance (anhydrous ammonia, chlorine, ethylene oxide, methyl chloride, phosgene and sulfur dioxide), it is possible to envisage liquid, vapor, or two-phase releases. Methods are presented below for

estimation of the release rate for liquid and vapor releases of gases liquefied under pressure. See Appendix 4A a method for two-phase releases.

RATE OF RELEASE - GASES LIQUEFIED UNDER PRESSURE

For the current guidance, the conservative case is considered of a liquid release that, upon release to the external atmosphere, flashes to a mixture of fine liquid droplets and vapor such that the whole release remains airborne. To estimate the release rate, the following equation can be used (see Appendix 4A for more information on this equation):

$$QR_L = 4{,}630 \times a \times (D_L)^{1/2} \times (P_g)^{1/2} \tag{11}$$

where: QR_L =   Liquid release rate (lb/min)
        a   =   Area of hole (ft^2)
        D_L =   Liquid density (lb/ft^3), listed in Exhibit 4-1
        P_g =   Tank gauge pressure (psig) (can be estimated from the equilibrium vapor pressure given in Exhibit 4-1 by subtracting 14.7 from the vapor pressure in psia)

The liquid release rate is assumed to be the release rate to air.

Example 6 Liquid chlorine at 25EC is released through a 1/4-inch hole (a = 0.00034 ft^2) in the liquid space of the tank. The density of chlorine is 101 lb/ft^3; the pressure in the vessel is 103 psig. The liquid release rate, calculated from Equation 11, is:

$$QR_L = 4{,}630 \times 0.0034 \times (101)^{1/2} \times (103)^{1/2} = 160 \text{ lb/min}$$

The release rate to air, QR, is assumed to be the same as the liquid release rate, 160 lb/min. This is the initial rate of release. It may decline with time or the opening may become uncovered and vapor may escape instead of liquid. Therefore, using the initial rate of release, and assuming that the release continues until the vessel is empty is conservative.

RATE OF RELEASE - VAPOR RELEASE FROM PRESSURIZED TANK

If you have a gas leak from a tank (e.g., from a hole in the vapor space of the 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.

$$QR = a_h \times p_a \times GF/(T_t + 273)^{1/2} \tag{12}$$

where: QR = Release rate (pounds per minute)
       a_h = Hole or puncture area (square inches)
       p_a = Tank pressure (pounds per square inch absolute [psia])
       T_t = Tank temperature (EC); the addition of 273 converts EC to K (Kelvin)

GF = Gas Factor, incorporating discharge coefficient, ratio of specific heats, molecular weight and conversion factors

For the toxic gases on Tables 4-1 and 4-2, the values of GF and p_a are as follows:

Gas	p_a(psia)	GF
Anhydrous Ammonia	145	14
Chlorine	113	29
Ethylene Oxide	25.4	22
Methyl Chloride	83.2	24
Phosgene	27.4	33
Sulfur Dioxide	58	27

Example 7. You have a tank that contains chlorine liquefied under pressure at 25EC (298 K). There is a rupture of a 1-inch pipe in the vapor space, so that $a = B(½)^2 = 0.786$ in^2. From Equation 12 and the above table:

$$QR = (0.786)(113)(29)/(298)^{0.5} = 149 \text{ lb/min}$$

DISTANCE TO TOXIC ENDPOINT FOR ALTERNATIVE SCENARIOS - TOXIC GASES

The distance to the endpoint for toxic gases can be calculated from the following equation:

$$D = D1 \, (QR)^{D2} \tag{13}$$

where D (mi) is the distance to which the vapor cloud travels before its concentration falls below the toxic endpoint, QR (lb/min) is the rate of release, and D1 and D2 are constants with values that depend upon the particular chemical and whether the site is urban or rural.

Values of D1 and D2 are given on Exhibits 4-8a and 4-8b for 10-minute and 60-minute releases, respectively.

For distances less than 10 mi, round the results up or down to the nearest tenth of a mile. For distances from 10 to 25 mi, round the results to the nearest mile. For distances exceeding 25 mi, present the results as 25 mi. For distances less than 0.1 mi, present the results as 0.1 mi.

Example 8, 10-minute release. For sulfur dioxide at a rural site, D1 = 0.047 and D2 = 0.4961. For a 160-lb/min release rate:

$$D = (0.047)(160)^{0.4961} = 0.58 \text{ mi} \sim 0.6 \text{ mi}$$

For an urban site, D1 = 0.025 and D2 = 0.4407, so that:

$$D = (0.025)(160)^{0.4407} = 0.23 \text{ mi} \sim 0.2 \text{ mi}$$

EXHIBIT 4-8a
ALTERNATIVE CASE SCENARIO—CONSTANTS D1 AND D2 FOR TOXIC GASES
10-MINUTE RELEASE

Chemical Name	Rural		Urban	
	D1	D2	D1	D2
Anhydrous Ammonia	0.0222	0.4780	0.0131	0.4164
Chlorine	0.0530	0.4647	0.0260	0.4263
Ethylene Oxide	0.0289	0.5445	0.0241	0.5383
Methyl Chloride	0.0105	0.5381	0.0103	0.5043
Phosgene	0.441	0.5407	0.340	0.5518
Sulfur Dioxide	0.0470	0.4961	0.025	0.4407

EXHIBIT 4-8b
ALTERNATIVE CASE SCENARIO—CONSTANTS D1 AND D2 FOR TOXIC GASES
60-MINUTE RELEASE

Chemical Name	Rural		Urban	
	D1	D2	D1	D2
Anhydrous Ammonia[1]	0.0222	0.4780	0.0130	0.4164
Chlorine[1]	0.0530	0.4647	0.0260	0.4263
Ethylene Oxide	0.0203	0.6085	0.0144	0.6214
Methyl Chloride	0.00680	0.5971	0.00480	0.5958
Phosgene	0.360	0.6232	0.298	0.6250
Sulfur Dioxide[1]	0.0470	0.4961	0.0250	0.4407

Footnotes:

[1]For anhydrous ammonia, chlorine, and sulfur dioxide, the 10-minute and 60-minute scenarios have the same predictions for the distance to the toxic endpoints. The reasons for this approximation are explained in the Backup Document, *Backup Information for the Hazards Assessments in the RMP Offsite Consequence Analysis Guidance, the Guidance for Wastewater Treatment Facilities and the Guidance for Ammonia Refrigeration - Anhydrous Ammonia, Aqueous Ammonia, Chlorine and Sulfur Dioxide*. This document is available from EPA.

TOXIC LIQUIDS - ALTERNATIVE SCENARIOS

For an undiked area, the rate of evaporation QR (lb/min) for a spill at ambient temperature in typical weather conditions is given by:

$$QR = 2.4 \times LFA \times DF \times QS \tag{14}$$

For a spill from a process operating at a temperature exceeding 25EC, the equation is:

$$QR = 2.4 \times LFB \times DF \times QS \tag{15}$$

where LFA, LFB, and DF are given in Exhibits 4-4a and 4-4b. You are free to replace LFA in Equation 14 or LFB in Equation 15 by LFA(T) from Equation 3 to correct for your vapor pressure at temperature TEC. Equation 5 remains unchanged for the area of the spill, i.e., $A = DF \times QS$.

To fully address alternative scenario spills of toxic liquids, the following possibilities are discussed below:

> P1   Rapid, undiked spill, pool spreads out to a depth of 1 cm
> P2   Spillage of prolonged duration, undiked, pool spreads out until rate of evaporation equals rate of spillage
> P3   Rapid spill into a diked area
> P4   Prolonged spill into a diked area

P1: UNDIKED AREA, SPILL OF SHORT DURATION

Estimate the total quantity spilled, QS (lb). Use Equation 14 or 15 with LFA, LFB, and DF from Exhibits 4-4a and 4-4b.

Example 9. For carbon disulfide, with a spill of 500 lb at 25 °C:

$$QR = 2.4 \times 0.075 \times 0.39 \times 500 = 35 \text{ lb/min}$$

The duration of evaporation is predicted to be $500/35 \sim 14$ min > 10 min.

P2: UNDIKED AREA, RATE OF SPILL EQUALS RATE OF EVAPORATION

For this case, it is first necessary to calculate the rate of spillage of the toxic liquid. The rate of release of a liquid through a hole in a tank under atmospheric pressure can be calculated from the following equation (see Appendix 4A for the derivation of this equation):

$$QR_L = 385 \times D_L \times a \times (h)^{\frac{1}{2}} \tag{16}$$

where: D_L = the density of the liquid in the vessel (lb/ft^3)
   a = the area of the hole (ft^2) - for example, the area of a hole of diameter 1 in is 0.0055 ft^2
   h = the static head (ft)

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

Example 10. Suppose that 38% aqueous hydrochloric acid is kept under atmospheric pressure in a vessel with a static head of 10 ft. A leak develops at the bottom of the vessel with a diameter of 1/4 in, so that a $= B(d/2)^2 = B(1/8)^2/144 = 0.00034$ ft^2, where the factor 1/144 converts from in^2 to ft^2. The initial rate of release of the liquid, QR_L, using Equation 16 with $D_L = 73.9$ lb/ft^3 (from Exhibit 4-1), is given by:

$$QR_L = 385 \times 73.9 \times 0.00034 \times (10)^{1/2} = 30.6 \text{ lb/min}$$

If the tank contains (say) 20,000 lb, the duration of release would be 20,000/30.6 min ~ 11 hr. Furthermore, the rate of release would decline as the static head decreases, so the actual duration of release would be considerably greater than 11 hr, if not stopped sooner by emergency actions. This can certainly be regarded as a prolonged release. Therefore, in this case, the rate of evaporation would conservatively stabilize at a value equal to the rate of release, 30.6 lb/min. If you wish to develop a more sophisticated model that takes account of this decrease in the static head, you are free to do so.

P3: *DIKED AREA, SPILL OF SHORT DURATION*

For a spillage of a toxic liquid into a diked area A_d at ambient temperature, the rate of evaporation QR is given by:

$$QR = 2.4 \times LFA \times A_d \tag{17}$$

For a spillage from a process at a temperature above 25EC,

$$QR = 2.4 \times LFB \times A_d \tag{18}$$

Again, you are at liberty to replace LFA in Equation 17 or LFB in Equation 18 by the vapor pressure corrected quantity LFA(T) from Equation 3.

Use Equations 17 or 18 as follows: if a quantity QS lb is rapidly spilled, calculate the area A of an undiked spillage from Equation 5, using DF from Exhibit 4-5a or 4-5b. Compare this with the diked area and select the smaller of the two. Then substitute that area into Equation 17 or Equation 18, using LFA or LFB from Exhibits 4-5a or 4-5b, to calculate the rate of evaporation.

Example 11. There is a sudden spill of 500 lb of phosphorus oxychloride at 35 EC into a diked area A_d of 400 ft^2. From Equation 5 and Exhibit 4-5a, the area of a pool 1 cm deep would be:

$$A = (0.29)(500) = 145 \text{ ft}^2$$

A is smaller than A_d. Therefore, from Equation 18 and Exhibit 4-5a, the rate of evaporation is:

$$QR = 2.4 \times 0.20 \times 145 = 69.6 \text{ lb/min}$$

The duration of release in this case would be 500/69.6 ~ 7 min < 10 min.

P4: PROLONGED SPILL INTO A DIKED AREA

For a liquid spill from a hole in a tank under ambient pressure, calculate the rate of spillage QR_L from Equation 16—see the example given above of 30.6 lb/min for 38% aqueous hydrochloric acid. Assume that the temperature is ambient. Then calculate the equilibrium area A_e from:

$$A_e = QR_L/(2.4 \times LFA) \tag{19}$$

which is obtained from Equation 17 by equating the rate of spillage to the rate of evaporation.

If A_e is smaller than A_d, then the rate of evaporation $QR = QR_L$. If A_e is larger than A_d, substitute A_d into Equation 17 or Equation 18 with LFA or LFB from Exhibits 4-5a or 4-5b.

Example 12. For the spill of 38% aqueous hydrochloric acid in Example 10, which had a predicted release rate of 30.6 lb/min, using Equation 19 and Exhibit 4-5b gives:

$$A_e = 30.6/(2.4 \times 0.01) = 1,275 \text{ ft}^2$$

If the spill is into a diked area of 800 ft^2, A_d is smaller than A_e. Using Equation 17 and Exhibit 4-5b gives:

$$QR = 2.4 \times 0.01 \times 800 = 19.2 \text{ lb/min}$$

DISTANCE TO TOXIC ENDPOINT FOR ALTERNATIVE SCENARIOS - TOXIC LIQUIDS

For each of the toxic liquids listed in Exhibits 4-1, 4-5a, and 4-5b, the distance to the endpoint can be estimated from the following equation:

$$D = C1 \, (QR)^{C2} \tag{20}$$

where D (mi) is the distance to which the vapor cloud travels before its concentration falls below the toxic endpoint, QR (lb/min) is the rate of evaporation, and C1 and C2 are constants with values that depend upon the particular chemical and whether the site is urban or rural.

Values of C1 and C2 are given on Exhibit 4-9a for a 10-minute release and on Exhibit 4-9b for a one-hour release.

For distances less than 10 mi, round the results up or down to the nearest tenth of a mile. For distances from 10 to 25 mi, round the results to the nearest mile. For

distances exceeding 25 mi, present the results as 25 mi. For distances less than 0.1 mi, present the results as 0.1 mi.

Example 13a, 10-minute release. For 38% aqueous hydrogen chloride at a rural site, C1 = 0.0495 and C2 = 0.5342. For the 19.2 lb/min release rate predicted above:

$$D = (0.0495)(19.2)^{0.5342} = 0.24 \text{ mi} \sim 0.2 \text{ mi at a rural site}$$

For an urban site, C1 = 0.0313 and C2 = 0.5008, so that:

$$D = (0.0313)(19.2)^{0.5008} = 0.14 \text{ mi} \sim 0.1 \text{ mi.}$$

Example 13b, 60-minute release. Assume a release of 40 lb/min allyl alcohol at a rural site, for which C1 = 0.0188 and C2 = 0.6736. The distance to the endpoint is:

$$D = (0.0188)(40)^{0.6736} = 0.23 \text{ mi} \sim 0.2 \text{ mi.}$$

For an urban site, C1 = 0.0111 and C2 = 0.6210, so that:

$$D = (0.0111)(40)^{0.6210} = 0.11 \text{ mi} \sim 0.1 \text{ mi.}$$

EXHIBIT 4-9a
ALTERNATIVE CASE SCENARIO—CONSTANTS C1 AND C2 FOR TOXIC LIQUIDS
AND AQUEOUS SOLUTIONS, 10-MINUTE RELEASE

Chemical Name	Rural		Urban	
	C1	C2	C1	C2
Allyl Alcohol	0.0449	0.5342	0.0285	0.5008
Aqueous Ammonia	0.0200	0.5174	0.0107	0.4748
Bromine	0.117	0.5475	0.0871	0.5568
Carbon Disulfide	0.0289	0.5445	0.0241	0.5383
Chloroform	0.0132	0.5364	0.0150	0.4898
Cyclohexylamine	0.0202	0.5342	0.0135	0.5008
Epichlorohydrin	0.0301	0.5342	0.0196	0.5008
Ethylenediamine	0.0111	0.5342	0.00772	0.5008
Formaldehyde	0.0807	0.5342	0.0495	0.5008
Hydrazine	0.0845	0.5342	0.0517	0.5008
Hydrochloric Acid	0.0495	0.5342	0.0313	0.5008
Hydrofluoric Acid	0.0692	0.5342	0.0428	0.5008
Methyl Isocyanate	0.367	0.5397	0.272	0.5529
Nitric Acid	0.0534	0.5342	0.0335	0.5008
Phosphorus Oxychloride	0.182	0.5462	0.138	0.5521
Phosphorus Trichloride	0.0547	0.5339	0.0400	0.5498
Propylene Oxide	0.0132	0.5364	0.0150	0.4898
Sulfur Trioxide	0.110	0.5267	0.0739	0.5604
Toluene 2,4-diisocyanate	0.108	0.5342	0.0648	0.5008
Toluene 2,6-diisocyanate	0.108	0.5342	0.0648	0.5008

EXHIBIT 4-9b
ALTERNATIVE CASE SCENARIO—CONSTANTS C1 AND C2 FOR TOXIC LIQUIDS[1]
60-MINUTE RELEASE

Chemical Name	Rural		Urban	
	C1	C2	C1	C2
Allyl Alcohol	0.0188	0.6736	0.0111	0.6210
Bromine	0.0905	0.6164	0.0695	0.6263
Carbon Disulfide	0.0203	0.6085	0.0144	0.6214
Chloroform	0.00840	0.6006	0.00590	0.6034
Cyclohexylamine	0.00687	0.6736	0.00437	0.6210
Epichlorohydrin	0.0113	0.6736	0.00694	0.6210
Ethylenediamine	0.00320	0.6736	0.00218	0.6210
Hydrazine	0.0417	0.6736	0.0230	0.6210
Methyl Isocyanate	0.297	0.6157	0.238	0.6288
Phosphorus Oxychloride	0.141	0.6217	0.111	0.6289
Phosphorus Trichloride	0.0381	0.6069	0.0283	0.6133
Propylene Oxide	0.00840	0.6006	0.00590	0.6034
Sulfur Trioxide	0.0797	0.6099	0.0591	0.6227
Toluene 2,4-diisocyanate	0.0566	0.6736	0.0305	0.6210
Toluene 2,6-diisocyanate	0.0566	0.6736	0.0305	0.6210

[1]Aqueous solutions are omitted from this table. In the OCAG, the evaporation rates from aqueous solutions are averaged over the first ten minutes, so the 60-minute release table is not applicable.

ALTERNATIVE SCENARIOS - FLAMMABLE SUBSTANCES

The potential alternative scenarios for flammable substances include:

g   Vapor cloud fires (flash fires) that may result from dispersion of a flammable vapor cloud and subsequent ignition. Such a fire could flash back and present a severe heat radiation hazard to anyone in the vicinity. The endpoint distance for such a fire is the predicted distance to which the vapor cloud travels before falling below its lower flammable limit (LFL).

g   A pool fire - in the event of such a fire, the endpoint distance is that at which radiant heat could cause second degree burns over a period of 40 s.

g A boiling liquid, expanding vapor explosion (BLEVE), leading to a fireball that may produce intense heat, may occur if a vessel containing material such as propane ruptures as a result of exposure to a fire. The radiant heat from such an event is generally considered to be the principal hazard, but in addition, portions of the vessel can be thrown a considerable distance and there are shock waves generated by the explosive rupture of the vessel.

g A vapor cloud explosion, such as that considered for the worst-case, but presumably containing a smaller amount of flammable material.

g A jet fire from the puncture of a vessel containing a flammable material under pressure.

ESTIMATION OF RELEASE RATE

You can estimate release rates for flammable gases and liquids using the same methods described for toxic gases and liquids. See the equations and discussion in the previous sections.

To use Equation 11 for liquid releases of gases liquefied under pressure, you can find the liquid density in Exhibit 4-2. The equilibrium vapor pressure (absolute) for these gases liquefied under their vapor pressure is listed below in psia. To estimate the gauge pressure in the tank in psig, for equation 11, subtract 14.7 from the pressure in psia.

If you use Equation 12 for vapor releases from a pressurized tank, the values of GF and p_a for the flammable gases on Table 4-2 are as follows:

Gas	p_a(psia)	GF
Acetaldehyde	21	22
Dimethylamine	102	22
Methane	1,080	14
Propane	138	22
Trimethylamine	31.9	25

ESTIMATION OF DISTANCE TO LFL

For the maximum distance for a vapor cloud fire, you estimate the distance to the LFL, that is, the distance to which the cloud propagates before diluting below the lower flammable limit, and assume the vapor cloud then ignites. Exhibit 4-10 below gives distances to the LFL for ranges of release rates for the flammable substances listed in Exhibit 4-2.

EXHIBIT 4-10
DISTANCE TO LFL FOR FLAMMABLE SUBSTANCES

Chemical Name	Rural		Urban	
	Release Rate (lb/min)	Distance (mi)	Release Rate (lb/min	Distance (mi)
Acetaldehyde	0 - 5,000 7,500-10,000	<0.1 0.1	0 - 10,000	<0.1
Dimethylamine	0 - 3,000 4,000 - 10,000	<0.1 0.1	0 - 10,000	<0.1
Ethyl ether	0 - 4,000 5,000 - 10,000	<0.1 0.1	0 - 10,000	<0.1
Isopropyl chloride	0 - 7,500 10,000	<0.1 0.1	0 - 10,000	<0.1
Isopropylamine	0 - 3,000 4,000 - 10,000	<0.1 0.1	0 - 10,000	<0.1
Methane	0 - 2,000 2,000 - 7,300 7,300 - 17,500	0.1 0.2 0.3	0 - 5,000 5,000 - 23,000	0.1 0.2
Propane	0 - 1,500 2,500 - 10,000	<0.1 0.1	0 - <10,000 10,000	<0.1 0.1
Trimethylamine	0 - 3,000 4,000 - 10,000	<0.1 0.1	0 - 10,000	<0.1

VAPOR CLOUD EXPLOSIONS

You can use Equation 10 to estimate the distance to the endpoint for the explosion of a known quantity of the flammable substances that are listed in Exhibit 4-2. You are not required to use a yield factor of 10% for alternative scenario vapor cloud explosions. For example, you could use a yield factor of 3%, which is considered representative of more likely events, based on data from past vapor cloud explosions. For a yield factor of 3%, multiply the distance you calculate from Equation 10 by 0.67.

Example 14. Example 5 was a worst-case vapor cloud explosion of 10,000 pounds of propane. The calculated distance to the 1 psi overpressure endpoint was 0.17 mi. You can also use a vapor cloud explosion of 10,000 pounds of propane as an alternative scenario, but you can use a smaller yield factor. Assuming a yield factor of 3%, the distance to the endpoint would be $0.17 \times 0.67 = 0.1$ mile.

POOL FIRES

For pool fires involving spills of flammable liquids, Equation 21 below gives an estimate of the distance d (ft) from a pool fire at which people could potentially receive a second-degree burn after 40 seconds:

$$d = PFF \ (A_d)^{0.5} \tag{21}$$

where PFF is the "Pool Fire Factor" and A_d (ft^2) is the area of the pool. For the flammable liquids on Exhibit 4-2, the PFFs are as follows:

Flammable Liquid	**PFF**
Ethyl Ether	4.3
Isopropylamine	4.1
Isopropylchloride	3.1

Example 15. Ethyl ether spills into a diked area of 100 ft^2 and burns. From Equation 21, d = 4.3(100)$^{0.5}$ = 43 ft (0.008 mi).

4.3   BUILDINGS

In chemical distribution facilities, some chemical operations may take place indoors, and the building may provide mitigation for releases. Unless your containers of regulated substances are delivered directly into the building (i.e., they are not unloaded outdoors and moved inside later), you should not consider buildings in your worst-case scenario, because there will be some time when the vessels are outdoors. If your containers are delivered indoors or if your largest vessel is indoors, you may want to analyze the mitigating effects of the building when you do your worst-case analysis. You may also want to consider buildings as mitigation systems for alternative scenarios . However, the buildings at chemical distribution facilities vary over a wide range in their strength of construction, the surface area of ventilation outlets and their purpose. At one end of the spectrum, there are strong, leaktight buildings that are designed to contain accidentally released vapors. Some of them contain scrubbers that activate upon release of certain hazardous materials and would ensure that any release to the external atmosphere would be very small indeed. At the other end of the spectrum, there may be a building that is intended to do no more than keep the rain off.

If you have a building that is expected to contain or mitigate a release, you are entitled to explain that the worst-case scenario is extremely unlikely and that the building will ensure that there will be no or minimal offsite consequences.

For toxic liquids, EPA has provided simple building release rate reduction factors for indoor releases of 10% for worst-case scenarios and 5% for alternative scenarios (i.e., the predicted rate of release is 10% or 5% of that for the same accident if it should occur outdoors). The factors are applicable to releases in a fully enclosed,

non-airtight space that is directly adjacent to the outside air. They do not apply to a space that has doors or windows that could be open during a release. (See Appendix D of the OCAG for more discussion of the mitigation factors.)

For toxic gases, the EPA's reduction factor is 55%, for both worst-case and alternative scenarios. It is applicable to releases in the same type of enclosure as the factors for liquids. (See Appendix D of the OCAG for more discussion.)

Example 16. Example 4 considers a worst-case release of 14 lb/min of cyclohexylamine over 60 minutes that travels ~ 0.6 mi to a toxic endpoint at a rural site and ~ 0.3 mi at an urban site. Using the building mitigation factor of 0.1 cited above, the new release rate is 1.4 lb/min. In worst-case weather conditions, and using Equation 8 and Exhibit 4-7b, the predicted distance to the toxic endpoint is reduced from ~ 0.6 mi to 0.18 mi ~ 0.2 mi at a rural site and from ~ 0.4 mi to 0.1 mi at an urban site. You could present this mitigated worst-case scenario as an alternative scenario with a mitigation factor of 0.05, in which case the mitigated rate of release is 0.7 lb/min The predicted distances to the toxic endpoint, using Equation 20 and Exhibit 4-9, are < 0.1 mi at a rural site and < 0.1 mi at an urban site.

The consequences of explosions inside buildings are extremely dependent upon the nature of the congestion in the building. Simple guidance is not readily available. However, if you keep flammable material in a building, there should be explosion venting per NFPA requirements. This should prevent excessive buildup of pressure inside the building and should ensure that pressure waves are vented in directions favorable to mitigation.

4.4   ESTIMATING OFFSITE RECEPTORS

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

RESIDENTIAL POPULATIONS

To estimate residential populations, you may use the most recent Census data or any other source of data that you believe is more accurate. 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. 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

Other public receptors must be noted in the RMP (see the discussion of public receptors in Chapter 2). If there are any schools, residences, hospitals, prisons, public recreational areas or arenas, or commercial or industrial areas within the circle, you must report that. You are not required to develop a list of all public receptors; you must simply check off that one or more such areas is within the circle. Most receptors can be identified from local street maps.

ENVIRONMENTAL RECEPTORS

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

Besides the results you are required to report in the RMP, you may want to consider submitting to EPA or providing your local community with a map showing the distances to the endpoint. Figure 4-1 is one suggested example of how the consequences of worst-case and alternative scenarios might be presented. It is a simplified map that shows the radius to which the vapor cloud might extend, given the worst-case release in worst-case weather conditions (the owner or operator should use a real map of the area surrounding the site). Organizations that have already begun to prepare Risk Management Programs and Plans have used this form of presentation (for example, in the Kanawha Valley or in Tampa Bay).

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.

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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.

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
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 commercial dealers also 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.
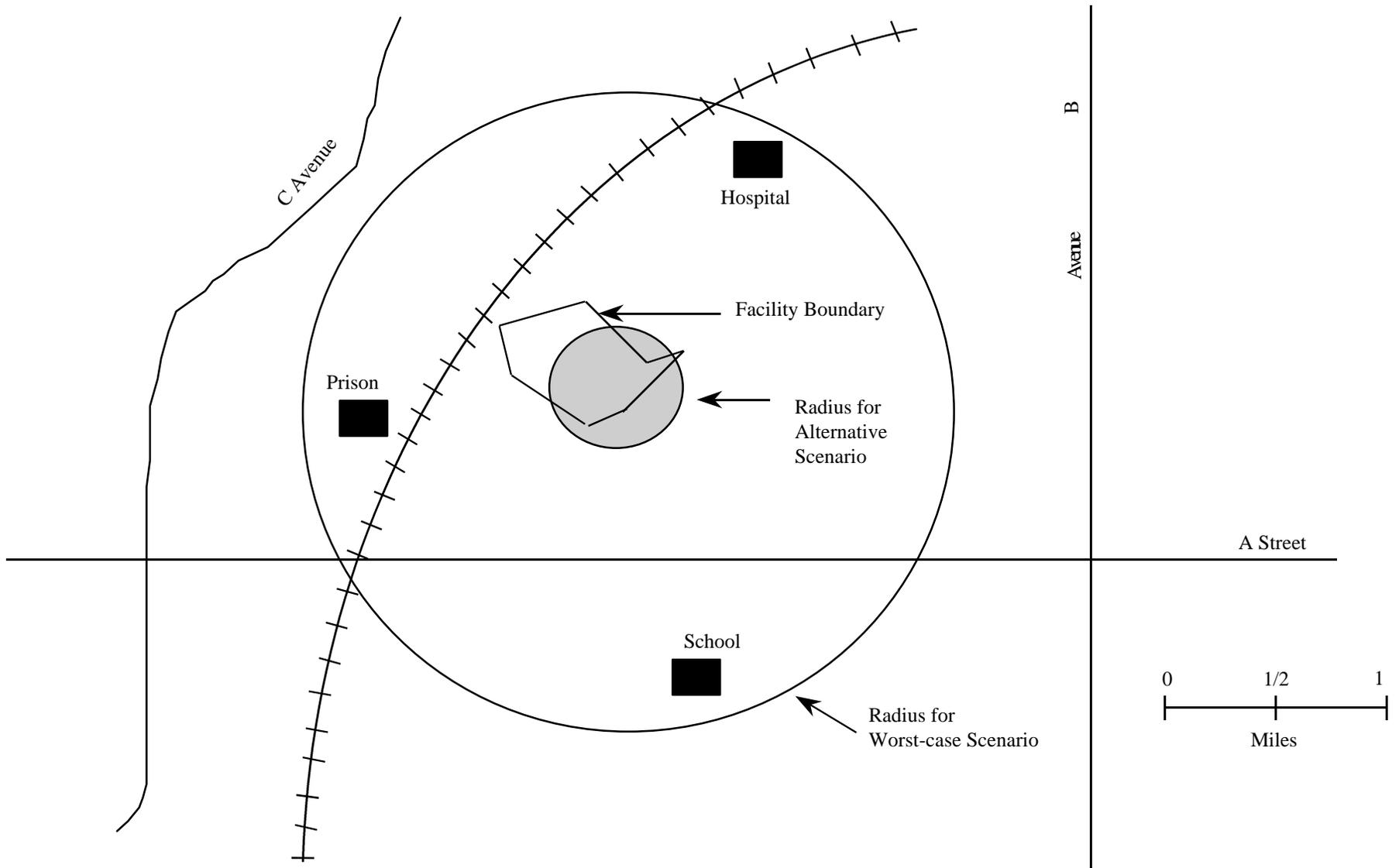
4.5   DOCUMENTATION

You need to maintain onsite the following records on the offsite consequence analyses:

g   For the worst-case scenario, a description of the vessel or pipeline selected as worst-case, assumptions and parameters used and the rationale for selection; assumptions include use of any administrative controls and any passive mitigation systems that you assumed to limit the quantity that could be released.

g   For alternative release scenarios, a description of the scenarios identified, assumptions and parameters used and the rationale for the selection of specific scenarios; assumptions include use of any administrative controls and any mitigation that were assumed to limit the quantity that could be released. Documentation includes the effect of the controls and mitigation on the release quantity and rate. Section 4-3 can be referenced here if you use any of the "canned" scenarios described there.

Other data that you should provide includes:

g   Documentation of estimated quantity released, release rate and duration of release.

g   Methodology used to determine distance to endpoints (it will be sufficient to reference this guidance).

g   Data used to identify potentially affected population and environmental receptors.

Figure 4-1 Simplified Presentation of Worst-Case and Alternative Scenario on a Local Map

C Avenue

B Avenue

Hospital

Facility Boundary

Prison

Radius for Alternative Scenario

A Street

School

Radius for Worst-case Scenario

0   1/2   1

Miles

APPENDIX 4A

TECHNICAL BACKGROUND FOR CHAPTER 4

METHODS AND EQUATIONS FROM EPA'S *RMP OFFSITE CONSEQUENCE ANALYSIS GUIDANCE* (OCAG)

Data for Analysis

The chemical data presented in the text for the worst-case and alternative scenario analysis are from the tables of data in the OCAG. Appendix B of the OCAG provides information on regulated toxic substances. Data for toxic gases are found in Exhibit B-1 of Appendix B, data for toxic liquids are in Exhibit B-2, data for common water solutions of toxic substances are in Exhibit B-3, and temperature correction factors are in Exhibit B-4. Appendix C provides information on regulated flammable substances. Heats of combustion for flammable substances are in Exhibit C-1, additional data for flammable gases can be found in Exhibit C-2, and Exhibit C-3 provides additional data for flammable liquids.

Methods of Analysis from OCAG

Toxic Substances. The method for estimating the release rate from an evaporating pool is from the OCAG. This method and the derivation of the factors used are discussed in Appendix D, Section D.2 of the OCAG. Equations 2 and 4 in the text, for the worst-case evaporation rate, are the same as Equations 3-3 and 3-4 from the OCAG. Equations 14 and 15, for alternative scenario evaporation rates, are the same as Equations 7-9 and 7-10 from the OCAG.

Equation 3 in the text is based on the following equation. At a temperature T ^{o}C:

$$\text{LFA(T)} = \text{LFA(25EC)} \; \frac{\text{VP(T)} \; @ (298)}{\text{VP(25)} \; (273+T)} \tag{A-1}$$

where VP(T) is the vapor pressure at TEC. The Temperature Correction Factor (TCF) is (VP(T)/VP(25)) $\times$ (298/(273+T)) in the above equation. See Appendix D, Section D.2, of the OCAG for the derivation of the TCF.

Appendix B, Section B.2, of the OCAG provides methods to estimate release rates for releases involving mixtures of toxic liquids (not addressed in the text of Chapter 4).

Appendix D, Sections D.1.2 and D.2.4 of the OCAG discuss the building mitigation factors cited in the text.

Flammable Substances. Equation 9 of Chapter 4, for the worst-case analysis of flammable substances, is the same as Equation C-2 in the OCAG, with the yield factor (0.1) incorporated into the constant.

Distances to the LFL for flammable substances given in Exhibit 4-10 are from Reference Tables 26, 27, 28, and 29 of the OCAG.

Equation 21 in the text is the same as Equation 11-1 in the OCAG.

ADDITIONAL METHODS OF ANALYSIS

Alternate Method for Estimation of Release Rate for Toxic Gases Liquefied by Refrigeration

You may consider a number of additional factors when you estimate the rate of release of a refrigerated liquid from a pool. If the material is confined in a dike of area A_d ft^2, then the rate of evaporation per unit area is given by

$$Q_o = 12.27 \; k_s \; (T_g - T)/((\alpha_s t)^{0.5} H_l) \tag{A-2}$$

where k_s = thermal conductivity of the material on which the pool lies (W/m/K)
T_g = temperature of the ground (K)
T = temperature of the liquid pool (the atmospheric boiling point of the released material) (K)
α_s = thermal diffusivity of the soil or concrete (m^2/s)
t = time after the spill (s)
H_L = latent heat of vaporization of spilled material (J/kg)

12.27 is a conversion factor from kg/s/m^2 to lb/min/ft^2, and

$$QR = A_d Q_o \; \text{lb/min} \tag{A-3}$$

The average rate of evaporation over a 10-minute (600 s) period is

$$QR = 24.54 \;_{Adds} (T_g - T)/((600 \alpha_s)^{0.5} H_l) \tag{A-4}$$

This equation is obtained by integrating Equation A-2 with respect to T over the range $0 \# T \# 10$ min.

After this time, the rate of evaporation is typically much less than one-tenth of the rate of release after one minute. This average 10-minute rate of release is taken as the release rate for use with dispersion models.

Example A-1. Refrigerated chlorine is spilled into a diked area with $A_d = 400$ ft^2. The temperature of the ground is 5EC = 278 K. The temperature of the liquid pool is assumed to be that of chlorine at its boiling point (239 K), so that $T_g - T = 39$ K. A typical value of the thermal conductivity of surfaces such as concrete and soil is $k_s = 2$ W/m/K (for insulating concrete, this value can be considerably smaller). A typical value of the thermal diffusivity of the underlying surface is $\alpha_s = 10^{-6}$ m^2/s. The latent heat of vaporization of chlorine is 2.88 x 10^5 J/kg. Using Equation A-4,

$$QR = (24.54)(400)(2)(39)/((600)^{½}(10^{-6})^{½} \; 2.88 \text{x} 10^5) = 109 \; \text{lb/min}$$

Bernoulli's Formula for Liquid Releases

The rate of release of a liquid through an orifice is given by Bernoulli's formula for predicting the rate of release R(lb/min) of liquid from a vessel:

$$R = 195 c D_L a (881 p_g/D_L + 0.189 gh)^{0.5} \tag{A-5}$$

where:

       c = a constant (typical value 0.8[*])

       D_L = the density of the liquid in the vessel (lb/ft^3)

       a = the area of the orifice (ft^2 - for example, the area of a hole of diameter 1" is 0.0055 ft^2)

       p_g = the gauge pressure in the vessel (psig)

       g = the acceleration due to gravity (32 ft/s^2)

       h = the static head (ft)

To derive Equation 11, for liquid releases of gases liquefied under pressure, it was assumed that the effect of the static head would be negligible compared to the effect of the pressure in the vessel, and the 189gh term was dropped from Equation A-5.

To derive Equation 16, for liquid releases from atmospheric tanks, the gauge pressure in the vessel would be zero, so the 881p_g/D_L term was dropped from Equation A-5.

Two-Phase Releases of Gases Liquefied Under Pressure

For long pipes ($L/d_h \gg 1$), where L is the length of the pipe between the reservoir of liquefied gas and the atmosphere, there can be flashing in the discharge pipe and a two-phase mixture emerges to the atmosphere. In this case, the rate of release in lb/min is given by:

$$R = 9{,}490(a)(F)(h_L)/[v_{lg}([T + 460]C_{pl})^{\frac{1}{2}}] \qquad\qquad\text{(A-6)}$$

where

      a = area of orifice (ft^2)

      F = a frictional loss factor that is dimensionless and takes on a value of 1 for $L/d_h \sim 0$, 0.85 for $L/d_h \sim 50$, 0.75 for $L/d_h \sim 100$, 0.65 $L/d_h \sim 200$ and 0.55 for $L/d_h \sim 400$

      h_L = the latent heat of vaporization (Btu/lb)

      v_{lg} = the difference in specific volume between the gas and liquid (lb/ft^3)

      T = the reservoir temperature (EF)

      C_{pl} = the liquid heat capacity (Btu/lb/EF)

Example A-2. Assume a rupture in a ½-in pipe leading from a chlorine vessel. For chlorine, h_L is 124 Btu/lb, v_{lg} = 0.68 lb/ft^3 and C_{pl} = 0.222 Btu/lb/EF. The area a is 0.00137 ft^2. Assume $L/d_h \sim 50$ (L ~ 2 ft), so that F ~ 0.85 and that the temperature is 77EF (25EC), Equation A-5 gives:

$$R = (9{,}490)(0.00137)(0.85)(124)/((0.68)[(537)(0.222)]^{\frac{1}{2}}) \sim 185 \text{ lb/min}$$

---

[*]This value of c has been chosen to be consistent with the OCAG. Note that c depends upon nozzle shape and Reynold number. Graphical presentations on how to determine c for various types of orifices can be found in fluid mechanics textbooks and handbooks (e.g., Perry, R.H., D.W. Green and J.O. Maloney, Ed., 1984: *Perry's Chemical Engineers Handbook*, McGraw-Hill Book Company). However, the value of c used above will generally be sufficiently accurate in light of the uncertainties that exist in atmospheric dispersion models.

DERIVATION OF EQUATIONS 1, 8, 13 AND 20 IN CHAPTER 4

To derive the equations in this chapter, the reference tables from the OCAG were fitted by straight lines on a log-log plot, having the general equation

$$D = a\,(R)^b \tag{1}$$

where D is the distance (mi) to the toxic endpoint and R is the rate of release (lb/min). a and b are parameters that depend upon the specific substance (in particular, upon the toxic endpoint), the weather condition (worst-case or alternative), whether the site is rural or urban, and whether the assumed duration of cloud passage is 10 min or 60 min. In Chapter 4, generic a and b are actually A1 and A2 (toxic gases, worst-case), B1 and B2 (toxic liquids, worst-case), C1 and C2 (toxic liquids, alternative scenarios), and D1 and D2 (toxic gases, alternative scenarios), respectively. You should not expect these equations to reproduce the OCAG reference tables exactly because these equations are only best fits to the data in the OCAG, not perfect fits.

The derivation of the equations in Chapter 4, including the log-log plots used to derive the parameters for estimating distances, is presented in detail in a background document, available from EPA.

Validity of Equations

Equations 1, 8, 13, and 20 in Chapter 4 are valid for 0.1 < D # 25 mi. This is because there is a lack of experimental data to justify their extrapolation below or above this range.

Chlorine, Sulfur Dioxide and Ammonia

For most chemicals, the values of A1, A2, B1, B2, C1, C2, D1 and D2 have been derived from the generic reference tables of distances in the OCAG, which were developed based on the modeling described in Appendix D of the OCAG. The exceptions are anhydrous ammonia, chlorine, sulfur dioxide and aqueous ammonia. The values of A1, A2, D1 and D2 for anhydrous ammonia are derived from the guidance given in the *Model Risk Management Program and Plan for Ammonia Refrigeration*. The values of the constants for chlorine, sulfur dioxide and aqueous ammonia are derived from the *Model Risk Management Program and Plan for Wastewater Treatment Facilities*.

The OCAG was developed to give conservative guidance that can be applied to all 77 toxic substances listed in 40 CFR § 68.130. However, EPA has also developed guidance specific to particular industries, such as ammonia refrigeration and wastewater treatment facilities. In developing this guidance, it was possible to devote resources to dispersion modeling that is tailored to the chemical in question and to remove some of the conservatism that was deliberately incorporated into the OCAG. That is why anhydrous and aqueous ammonia, and chlorine and sulfur dioxide, have been singled out for special treatment and have their own reference tables in OCAG.

For details on how the values of the constants were derived for aqueous ammonia, anhydrous ammonia, sulfur dioxide and chlorine, consult *Backup Information for the Hazard Assessments in the RMP Offsite Consequence Analysis Guidance, the Guidance for Wastewater Treatment Facilities and the Guidance for Ammonia Refrigeration - Anhydrous Ammonia, Aqueous Ammonia, Chlorine and Sulfur Dioxide*, available from EPA.

CONSERVATISMS AND MODELING CONSIDERATIONS

The consequences of an accidental release depend on the conditions of the release and the conditions at the site at the time of the release. This guidance provides the above-described equations for distances, based on tables in the OCAG, for estimation of worst-case and alternative scenario consequence distances. Distance estimates based on these tables are not intended to be accurate predictions of the distances that might be reached in the event of an accidental release. For this guidance, worst-case distances are based on modeling results assuming the worst-case conditions required by the rule. 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. 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 very different results; the same model also may give different results with different assumptions about release conditions.

As noted above, the equation 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. No experimental data or data from accidents are available at 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 long distances. Thus, at large distances (e.g., greater than about 6 to 10 miles), the modeling results should not be given much weight as 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 local agencies can use relative differences in distance results to aid in establishing priorities among facilities in a community for addressing chemical accident prevention and preparedness. However, EPA strongly urges communities and industry not to rely on large distances to the toxic endpoint in emergency planning and response activities. Emergency planning should <u>not</u> be based on worst-case results or on large distance results from the alternative scenario analysis.

OTHER APPROACHES

General Guidance on Modeling

If you decide to perform your own modeling, there are two major items that are not trivial. These are:

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

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

EPA has also published useful guidance. There is one document that looks carefully at the definition of source terms (USEPA, 1993). The EPA has also performed an evaluation of dense gas

dispersion models (USEPA, 1991). Another review of available models has been given by Hanna et al. (1991). Finally, Appendix A of OCAG contains a list of useful references.

REFERENCES FOR APPENDIX 4A

Center for Chemical Process Safety (CCPS, 1987). "Proceedings of the International Symposium on Vapor Cloud Modeling," Boston, MA; American Institute of Chemical Engineers, New York, NY.

Center for Chemical Process Safety (CCPS, 1991). "International Conference and Workshop on Modeling and Mitigating the Consequences of Accidental Releases of Hazardous Materials," New Orleans, LA; American Institute of Chemical Engineers, New York, NY.

Center for Chemical Process Safety (CCPS, 1995). "International Conference and Workshop on Modeling and Mitigating the Consequences of Accidental Releases of Hazardous Materials," New Orleans, LA; American Institute of Chemical Engineers, New York, NY.

Hanna, S.R., D.G. Strimatis and Joseph C. Chang (1991). "Uncertainties in Hazardous Model Gas Predictions," in CCPS (1991), pp. 345-368.

United States Environmental Protection Agency (USEPA, 1991). "Evaluation of Dense Gas Simulation Models," EPA-450/R-89-108, Research Triangle Park, NC.

United States Environmental Protection Agency (USEPA, 1993). "Contingency Analysis for Superfund Sites and Other Industrial Sources," EPA-454/R-93-001, Research Triangle Park, NC.