

VPN-001-2020 Enclosure 2

Trojan Calculation TI-164

Sargent & Lundy Calculation No. 2017-09306

Offsite Transportation Explosion Hazard Evaluation,
Revision 0

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Total Pages: Main Body (71) plus Appendices and Attachments (1,356) = 1,427 Pages

1.0 Purpose and Scope

The purpose of this evaluation is to analyze offsite transportation explosion hazards to the Trojan Independent Spent Fuel Storage Installation (ISFSI). The primary concern following a postulated explosion from a nearby railcar or vessel is the blast wave overpressure loading upon the ISFSI dry storage casks. This includes explosions at the railcar/vessel from solid explosives, vapor cloud explosions (VCE), and boiling liquid expanding vapor explosions (BLEVE). Additionally, a vapor release can result in a chemical vapor traveling to the ISFSI site with a concentration greater than or equal to the lower explosive limit (LEL) of the chemical.

The goal of this calculation is to show that none of the chemical hazards being transported via railway or waterway in the vicinity of the ISFSI site pose a threat by explosion. The sources include Burlington Northern Santa Fe (BNSF) railcars, Portland & Western Railroad (PNWR) railcars and vessels navigating the Columbia River.

Acceptance Criteria:

1. Standoff Distance for an Explosion:
 - a. The distance between the hazardous chemical source and the site must be greater than the standoff distance calculated using the method detailed in Regulatory Guide 1.91 [Ref. 2.2] and the SFPE Handbook [Ref. 2.26]. The maximum overpressure at a cask cannot exceed 2.2 psig [Ref. 2.19]. However, per Regulatory Guide 1.91, when overpressure at the target is less than or equal to 1.0 psig, the blast generated missile effects and ground motions are considered acceptable.
 - b. The gas plume must disperse enough such that the concentration of the chemical is less than the LEL at the concrete casks.
2. Probability – If the deterministic analyses for a chemical release show that the chemical can lead to a hazard (i.e., does not meet the above acceptance criteria) then the chemical must be analyzed probabilistically. To be acceptable, the frequency of a hazardous release for a chemical must be shown to be less than 10^{-6} hazards per year if conservative estimates are used [Ref. 2.2, p.6].

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 - 2.9.3 "Bisulfites, Aqueous Solution," <https://cameochemicals.noaa.gov/chemical/2622>, accessed October 2017.
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- 2.54 NUREG-1805, "Fire Dynamics Tools (FDTs): Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program," December 2004.

3.0 Definitions

3.1 Chemical

For the purposes of this document, chemical will mean any substance or material that could potentially be a hazard.

3.2 Lower Explosive Limit (LEL)

The LEL of an explosive chemical is the lowest concentration of that chemical capable of supporting an explosion, per the SFPE Handbook [Ref. 2.26, p.3-312]. Lower Flammability Limit (LFL) is related to the LEL. The LFL is the lowest concentration of a chemical that will support flame propagation. The LFL and LEL are often nearly the same. The SFPE Handbook recommends using whichever is more conservative. For this calculation, the LEL or LFL values in the referenced documents are used interchangeably.

3.3 Upper Explosive Limit (UEL)

The UEL of an explosive chemical is the highest concentration of that chemical capable of supporting an explosion, per the SFPE Handbook [Ref. 2.26, p.3-312]. Upper Flammability Limit (UFL) is related to the UEL. The UFL is the highest concentration of a chemical that will support flame propagation. The UFL and UEL are often nearly the same. The SFPE Handbook recommends using whichever is more conservative. For this calculation, the UEL or UFL values in the referenced documents are used interchangeably.

3.4 Vapor Cloud Explosion (VCE)

A VCE is an explosion as a result of a mass of gas in a vapor cloud being ignited, per the SFPE Handbook [Ref. 2.26, p.3-325].

3.5 Boiling Liquid Expanding Vapor Explosion (BLEVE)

A BLEVE is a violent rupture of a pressure vessel containing a chemical that is a gas at standard conditions but is stored as a pressurized saturated liquid, per the SFPE Handbook [Ref. 2.26, p.3-327].

4.0 Input Data

4.1 Facility Parameters

- The geographic coordinates of the Trojan site are 46°02'25" N latitude and 122°53'03" W longitude [Ref. 2.20].
- The specific location of the ISFSI pad and layout of the storage casks are taken from site drawings [Ref. 2.18] and Google Earth [Ref. 2.38].
- The height of the ISFSI storage casks is 211.5 in. (17.625 ft) [Ref. 2.25].
- The acceptable explosive overpressure limit at the ISFSI storage casks is 2.2 psig [Ref. 2.19].

4.2 Weather Conditions

- Design maximum temperature = 107°F [Ref. 2.22].
- Design minimum temperature = -3°F [Ref. 2.22].
- A compilation of the annual weather joint frequency distributions (1980, 1982-84, 1989) [Ref. 2.23] [Ref. 2.24] is provided in Appendix 1:
 - The worst Pasquill Stability Class that occurs at least 5% of the time is Class F.
 - Stability Classes F and G wind speeds do not exceed 5.01 m/s (11.21 mph); lower bound for Stability Classes A and B wind speed is 0.5 m/s (1.12 mph).

Table 4.2-1: Classification of Atmospheric Stability [Ref. 2.21]

Pasquill Stability Class	Temperature Gradient °C/100m
A	$\Delta T \leq -1.9$
B	$-1.9 < \Delta T \leq -1.7$
C	$-1.7 < \Delta T \leq -1.5$
D	$-1.5 < \Delta T \leq -0.5$
E	$-0.5 < \Delta T \leq 1.5$
F	$1.5 < \Delta T \leq 4.0$
G	$\Delta T > 4.0$

4.3 Chemical Data

4.3.1 Water:

- The density of water at 107°F and 1 atm = 61.91 lb_m/ft³ [Ref. 2.34, p.4-4].
- The thermal conductivity of water at 107°F (315 K) = 0.634 W/m·K [Ref. 2.30, p.949].
- The specific heat of water at 107°F (315 K) = 4.179 kJ/kg·K [Ref. 2.30, p.949].

4.3.2 Table 4.3-1 provides chemical physical properties and heats of combustion with references indicated.

Table 4.3-1: Chemical Properties and Heats of Combustion

Chemical Name	Molecular Weight ^(a)	Boiling Point ^(b)	Specific Gravity / Dens.	LEL (to UEL)	Physical Properties Ref.	Heat of Combustion ^(c) (kJ/kg)	Thermal Properties Ref.
Acetaldehyde	44.1	69°F (294 K)	0.79	4.0%	[Ref. 2.13]	25,100	[Ref. 2.27, Table A.38]
Acetic Acid	60.1	244°F (391 K)	1.05	4.0%-19.9%	[Ref. 2.13]	14,600	[Ref. 2.27, Table A.38]
Acetone	58.1	133°F (329 K)	0.79	2.5%-12.8%	[Ref. 2.13]	30,800	[Ref. 2.27, Table A.29]
Air	29.0	-	-	-	[Ref. 2.29, p.24-15]	-	-
Ammonia	17.0	-28°F (240 K)	36.005 lb _m /ft ³ (42.574 lb _m /ft ³ at P _{atm})	15%	[Ref. 2.13] Dens: [Ref. 2.12]	22,500	[Ref. 2.29, p.A-43]
Ammonium Nitrate	-	-	1.73	-	[Ref. 2.9.1]	-	-
Benzene	78.1	176°F (353 K)	0.88	1.2%-7.8%	[Ref. 2.13]	42,300	[Ref. 2.28, p.4-26]
Butane	58.1	31°F (273 K)	0.60	1.6%	[Ref. 2.13]	49,600	[Ref. 2.28, p.4-26]
Butanol (Butyl Alcohol)	74.1	243°F (390 K)	0.81	1.4%	[Ref. 2.13]	36,100	[Ref. 2.27, Table 18.2]
Butyl Acrylate (C ₇ H ₁₂ O ₂)	128.2	293°F (418 K)	0.89	1.5%	[Ref. 2.13]	-	-
Butylene (1-Butene)	56.1	20°F (267 K)	0.58	1.6%	[Ref. 2.9.4]	48,500	[Ref. 2.29, p.A-43]

Chemical Name	Molecular Weight ^(a)	Boiling Point ^(b)	Specific Gravity / Dens.	LEL (to UEL)	Physical Properties Ref.	Heat of Combustion ^(c) (kJ/kg)	Thermal Properties Ref.
Butyraldehyde	72.1	167°F (348 K)	0.82	1.4%	[Ref. 2.9.5]	33,800	[Ref. 2.27, Table A.38]
Carbon Disulfide	76.1	116°F (320 K)	1.26	1.3%	[Ref. 2.13]	6,300	[Ref. 2.27, Table A.30]
Dichloromethane (Methylene Chloride)	84.9	104°F (313 K)	1.33	13.0%	[Ref. 2.13]	6,000	[Ref. 2.27, Table A.39]
Diesel Fuel (Fuel Oil No. 1)	170.0	320°F (433 K)	0.82	0.7%	[Ref. 2.9.6] MW: [Ref. 2.29, p.22-6] LEL: [Ref. 2.15, p.325-67]	46,100	[Ref. 2.27, Table A.32]
1,1-Difluoroethane (C ₂ H ₄ F ₂)	66.1	52°F (284 K)	0.95	3.7%	[Ref. 2.9.7]	-	-
Ethane	-	-	-	3.0%	[Ref. 2.27, Table 17.1]	-	-
Ethanol (Ethyl Alcohol)	46.1	173°F (351 K)	0.79	3.3%-19%	[Ref. 2.13]	29,700	[Ref. 2.28, p.4-26]
Ethylene	-	-	-	2.7%	[Ref. 2.27, Table 17.1]	-	-
Ethylene Glycol Diethyl Ether (C ₆ H ₁₄ O ₂)	118.2	250°F (394 K)	0.84	1.2%	[Ref. 2.9.8]	-	-
Explosives	-	-	1.30-5.10	-	[Ref. 2.31]	-	-
Formic Acid	-	-	-	18%	[Ref. 2.13]	-	-

Chemical Name	Molecular Weight ^(a)	Boiling Point ^(b)	Specific Gravity / Dens.	LEL (to UEL)	Physical Properties Ref.	Heat of Combustion ^(c) (kJ/kg)	Thermal Properties Ref.
Gasoline	VD: 3-4 (Air = 1)	100-400°F (311-478 K)	0.72-0.77	1.4%-7.6%	[Ref. 2.9.12]	46,800	[Ref. 2.27, Table A.32]
Heptane	100.2	209°F (371 K)	0.68	1.1%	[Ref. 2.13]	44,600	[Ref. 2.27, Table A.38]
Hydrogen	2.0	-	-	4.0%	[Ref. 2.9.14]	142,000	[Ref. 2.28, p.4-26]
Isobutane	58.1	11°F (261 K)	33.020 lb _m /ft ³	1.6%	[Ref. 2.13] Dens: [Ref. 2.12]	49,400	[Ref. 2.29, p.A-43]
Isobutylene	56.1	20°F (266 K)	0.63	1.8%	[Ref. 2.9.16]	48,200	[Ref. 2.29, p.A-43]
Isoprene	68.1	93°F (307 K)	0.69	1.5%	[Ref. 2.9.17]	44,900	[Ref. 2.27, Table A.32]
Isopropanol (Isopropyl Alcohol)	60.1	181°F (356 K)	0.79	2.0%	[Ref. 2.13]	31,800	[Ref. 2.27, Table A.38]
Isopropyl Acetate	102.2	194°F (363 K)	0.87	1.8%	[Ref. 2.13]	26,600	[Ref. 2.27, Table A.38]
Liquefied Petroleum Gas (LPG)	VD: 1.8 (Air = 1)	-40 to -4°F (233-253 K)	0.51-0.58	1.9%	[Ref. 2.9.19]	46,000	[Ref. 2.27, Table 26.21]
Methane	16.0	-259 (112 K)	24.271 lb _m /ft ³	5%	[Ref. 2.9.20] Dens: [Ref. 2.12]	55,600	[Ref. 2.28, p.4-26]
Methanol (Methyl Alcohol)	32.1	147°F (337 K)	0.79	6.0%-36%	[Ref. 2.13]	22,700	[Ref. 2.28, p.4-26]
1-Methoxy-2-Propanol (Propylene Glycol Monomethyl Ether; C ₄ H ₁₀ O ₂)	90.1	248°F (393 K)	0.96	1.6%	[Ref. 2.13]	-	-

Chemical Name	Molecular Weight ^(a)	Boiling Point ^(b)	Specific Gravity / Dens.	LEL (to UEL)	Physical Properties Ref.	Heat of Combustion ^(c) (kJ/kg)	Thermal Properties Ref.
Methyl Chloride	50.5	-12°F (249 K)	0.92	8.1%	[Ref. 2.13] SG: [Ref. 2.9.21]	6,500	[Ref. 2.27, Table A.30]
Naphtha (Petroleum Distillates)	99.0	86-460°F (303-511 K)	0.63	1.1%-5.9%	[Ref. 2.13]	43,500	[Ref. 2.9.24]
Octane	114.2	258°F (399 K)	0.70	1.0%	[Ref. 2.13]	47,800	[Ref. 2.28, p.4-26]
Pentane	72.2	97°F (309 K)	0.63	1.5%	[Ref. 2.13]	49,100	[Ref. 2.28, p.4-26]
Petroleum Coke	-	-	0.8-1.0	15-1,000 g/m ³	SG: [Ref. 2.9.29] EL: [Ref. 2.9.30]	-	-
Phenol	94.1	359°F (455 K)	1.06	1.8%	[Ref. 2.13]	31,000	[Ref. 2.27, Table A.39]
Propane	44.1	-44°F (231 K)	28.999 lb _m /ft ³ (36.266 lb _m /ft ³ at P _{atm})	2.1%	[Ref. 2.13] Dens: [Ref. 2.12]	50,400	[Ref. 2.28, p.4-26]
Propanol (Propyl Alcohol)	60.1	207°F (370 K)	0.81	2.2%	[Ref. 2.13]	31,300	[Ref. 2.27, Table 18.2]
Propylene (Propene)	42.1	-54°F (225 K)	29.550 lb _m /ft ³	2.0%	[Ref. 2.9.32] Dens: [Ref. 2.12]	49,000	[Ref. 2.28, p.4-26]
Resin Solution ^(d)	104.2 ^(d)	295°F (419 K)	1.04-1.08	1.1%	[Ref. 2.9.34]	39,400 ^(d)	[Ref. 2.27, Table A.39]
Sodium	23.0	-	0.97	-	[Ref. 2.9.35]	-	-

Chemical Name	Molecular Weight ^(a)	Boiling Point ^(b)	Specific Gravity / Dens.	LEL (to UEL)	Physical Properties Ref.	Heat of Combustion ^(c) (kJ/kg)	Thermal Properties Ref.
Styrene	104.2	293°F (418 K)	0.91	0.9%	[Ref. 2.13]	39,400	[Ref. 2.27, Table A.39]
Sulfur	-	-	1.8	30-1,400 g/m ³	[Ref. 2.9.38]	-	-
Tetrahydrofuran	72.1	151°F (339 K)	0.89	2.0%	[Ref. 2.13]	32,200	[Ref. 2.27, Table A.39]
Toluene	92.1	232°F (384 K)	0.87	1.1%	[Ref. 2.13]	42,900	[Ref. 2.28, p.4-26]
Vinyl Acetate	86.1	162°F (345 K)	0.93	2.6%	[Ref. 2.13]	24,200	[Ref. 2.27, Table A.30]
Vinyl Chloride	62.5	7°F (259 K)	0.91	3.6%	[Ref. 2.13] SG: [Ref. 2.9.40]	20,200	[Ref. 2.27, Table A.30]
Xylene	106.2	281°F (411 K)	0.86	0.9%	[Ref. 2.13]	43,400	[Ref. 2.29, p.A-43]

Notes:

- For chemicals that provide relative vapor density (air =1) in lieu of molecular weight, the molecular weight is calculated as $MW = \rho_v \cdot MW_{air}$; where MW is molecular weight and ρ_v is relative vapor density.
- Temperature unit conversion: $T_{°F} = 32° + (9/5)T_{°C}$; $T_K = T_{°C} + 273.15° = (5/9) \cdot (T_{°F} + 459.67°)$ [Ref. 2.29].
- Heat of combustion provided as Btu/lb_m in Marks [Ref. 2.28] and MERM [Ref. 2.29] is converted to kJ/kg by multiplying by 2.326 [Ref. 2.29] and rounding to the nearest hundreds place.
- The molecular weight and heat of combustion for resin solution are taken to be those of styrene. This is consistent with the MSDS for resin solution [Ref. 2.9.34] which provides several properties as those of styrene (e.g., boiling point, LEL, vapor pressure, etc.).

4.3.3 Tables 4.3-2 and 4.3-3 provide thermophysical properties for chemicals with low boiling points that are stored as liquids and immediately flash to vapor in atmospheric conditions [Ref. 2.12].

Table 4.3-2: Chemical Thermophysical Properties [Ref. 2.12]

Chemical Name	Saturated Liquid Properties at 1 atm			Saturated Vapor Properties at 1 atm			Liquid Storage Tank Properties at 107°F		
	Internal Energy, u_f (Btu/lb _m)	Enthalpy, h_f (Btu/lb _m)	Entropy, s_f (Btu/lb _m -°R)	Internal Energy, u_g (Btu/lb _m)	Enthalpy, h_g (Btu/lb _m)	Entropy, s_g (Btu/lb _m -°R)	Internal Energy, u_r (Btu/lb _m)	Enthalpy, h_r (Btu/lb _m)	Entropy, s_r (Btu/lb _m -°R)
Ammonia	82.502	82.566	0.21111	622.74	671.74	1.5759	231.98	233.19	0.51195
Butane	85.482	85.554	0.23802	235.40	251.49	0.57612	129.21	129.52	0.32080
1,1-Difluoroethane	68.822	68.865	0.20260	197.88	210.80	0.51911	117.61	118.09	0.29898
Isobutane	74.566	74.639	0.21539	216.29	231.71	0.54921	128.84	129.29	0.32018
Isobutylene ^(a) (Isobutene)	3.6230	3.70	0.007654	154.10	170.49	0.35084	48.914	49.29	0.093781
Methane ^(b)	-0.10321	-	-5.9068e-14	195.77	-	1.0933	32.766	-	0.14955
Pentane	-0.071495	-2.4138e-11	-4.3004e-14	139.18	153.83	0.27639	5.6602	5.7472	0.010207
Propane	42.942	43.017	0.14474	208.20	226.25	0.58536	133.06	134.38	0.32879
Propylene (Propene)	38.709	38.781	0.13436	209.22	227.71	0.59990	131.71	133.27	0.32643

Notes:

- a) Thermophysical properties for isobutylene are not available in NIST [Ref. 2.12] and are taken from Table 2-228 of Perry [Ref. 2.14]. Energy is converted from kJ/mol to Btu/lb_m by dividing by molecular weight and multiplying by 429.92; entropy is converted from kJ/mol-K to Btu/lb_m-°R by dividing by molecular weight and multiplying by 238.85 [Ref. 2.29].
- b) Liquid storage tank properties for methane are taken at -220°F (Assumption 5.8).

Table 4.3-3: Chemical Phase Change Data [Ref. 2.12]

Chemical Name	Heat of Vaporization, h_{fg} (kJ/mol)	Heat Capacity of Liquid, $c_{p,liq}$ (J/mol-K)
Acetaldehyde	26.3	89.1
Butylene (1-Butene)	22.8	128.6
Dichloromethane	28.1	100.0
Isoprene	27.4	151.1
Methyl Chloride (Methane, chloro-)	21.0	81.2
Vinyl Chloride (Ethene, chloro-)	22.7	89.5

4.3.4 Table 4.3-4 provides chemical vapor pressure determined by Antoine Equation [Ref. 2.12].

Table 4.3-4: Antoine Equation for Vapor Pressure at 107°F [Ref. 2.12]

Chemical Name	Antoine Parameters at 107°F (315 K)			Vapor Pressure at 107°F (bar)
	A	B	C	
Acetic Acid	4.68206	1642.540	-39.764	0.1
Acetone	4.42448	1312.253	-32.445	0.6
Benzene	4.01814	1203.835	-53.226	0.3
Ethanol	5.37229	1670.409	-40.191	0.2
Methanol	5.20409	1581.341	-33.500	0.4

Antoine Equation: $\log(P) = A - [B / (T + C)]$; where P = vapor pressure (bar) and T = temperature (K) [Ref. 2.12]. Note: 1 bar \approx 1 atm [Ref. 2.29].

4.4 TNT Equivalence for Solid Explosives

The TNT equivalency yield fraction, α , for:

- Amonium nitrate is 0.42 [Ref. 2.17, Table 1-1]
- Explosives is 1.66 (bounding yield for explosives listed in Table 1-1 of U.S. Army FM 3-34.214 [Ref. 2.17])
- Lithium Batteries is 0.43 = 40/94 (one 94g lithium-sulfur dioxide D-cell [Ref. 2.35, p.9/5] is equal to 40g of TNT [Ref. 2.37])

4.5 Dust Explosion Maximum Pressure

The maximum explosion pressure, P_{max} , for dust of:

- Petroleum coke = 7.6 bar [Ref. 2.16, Table A.5.2.2(c)]
- Sulfur = 6.8 bar [Ref. 2.16, Table A.5.2.2(d)] [Ref. 2.27, p.2770]

4.6 Railway Transportation Data

4.6.1 The Burlington Northern Santa Fe (BNSF) and Portland & Western Railroad (PNWR) railway routes are obtained from the Oregon Department of Transportation (DOT) Rail Map [Ref. 2.41] and Google Earth [Ref. 2.38]. A screenshot of Google Earth is provided in Attachment B. The nearest approach of the BNSF line to the closest cask on the Trojan ISFSI site is 5,760 ft (1.09 mi). The nearest approach of the PNWR line to the ISFSI closest cask is 745 ft (0.14 mi).

4.6.2 The commodities shipped in 2016 on the BNSF railroad near the Trojan ISFSI have been provided by BNSF [Ref. 2.42]. The complete list of proprietary data is contained in Attachment H.

4.6.3 The 4-axle railcar gross weight restriction on the BNSF line is 286,000 lb_m [Ref. 2.43]. This includes weight of the cargo and car.

4.6.4 Ethanol is the only commodity to be analyzed on PNWR being transported near the Trojan ISFSI site. This is based on shipment information from the Global Partners Port Westward industrial park located in Clatskanie, OR [Ref. 2.44].

4.7 Waterborne Transportation Data

4.7.1 The course of the navigable channel in the Columbia River near the Trojan ISFSI site is obtained from NOAA Chart #18524 [Ref. 2.45] and Google Earth [Ref. 2.38]. A screenshot of Google Earth is provided in Attachment B. The nearest approach of the navigable channel to the closest cask on the Trojan ISFSI site is 957 ft (0.18 mi).

4.7.2 Data from the U.S. Army Corps of Engineers (USACE) [Ref. 2.46] is used to determine the commodities that are transported on the Columbia River. The USACE Navigation Data Center User's Guide [Ref. 2.47] provides additional details on the types of products that pertain to each commodity group. USACE data is reviewed for the ten most current years (2006-2015) [Ref. 2.46] to determine annual number of trips and mass per vessel (see Section 7.4 and Appendix 2).

4.7.3 The boundaries of the Prescott anchorage located near the Trojan ISFSI site are identified in CFR Title 33 §110.228(11) [Ref. 2.10] and shown on NOAA Chart #18524 [Ref. 2.45]. The anchorage was used 25 times in 2016, primarily for empty vessels [Ref. 2.24]. Usage is defined further in the Columbia River Anchorage Guidelines [Ref. 2.51].

4.8 Non-Explosive Chemicals

Table 4.8-1 identifies chemicals that are non-explosive and the references used.

Table 4.8-1: Non-Explosive Chemicals

Chemical Name	Ref.	Chemical Name	Ref.
Argon	[Ref. 2.9.2]	Pesticides	[Ref. 2.9.13] [Ref. 2.9.28]
Bisulfites Aqueous Solutions	[Ref. 2.9.3]	Phosphoric Acid	[Ref. 2.13]
Carbon Dioxide	[Ref. 2.13]	Potassic Fertilizer (Potash)	[Ref. 2.9.31]
Chlorine	[Ref. 2.13]	Potassium Hydroxide	[Ref. 2.13]
Ferric Chloride Solution	[Ref. 2.9.9]	Sodium Chlorate	[Ref. 2.9.36]
Ferrous Chloride Solution	[Ref. 2.9.10]	Sodium Hydroxide Solution	[Ref. 2.9.37]
Fluorosilicic Acid	[Ref. 2.9.11]	Sodium Hydroxide	[Ref. 2.13]
Hydrochloric Acid (Hydrogen Chloride)	[Ref. 2.13]	Sulfur Dioxide	[Ref. 2.13]
Hydrogen Peroxide	[Ref. 2.13]	Sulfur, Molten	[Ref. 2.9.22]
Hypochlorite Solutions	[Ref. 2.9.15]	Sulfuric Acid	[Ref. 2.13]
Nitrogen	[Ref. 2.9.25]		

4.9 Low Vapor Pressure Chemicals

Table 4.9-1 identifies liquid chemicals with a low vapor pressure (< 10 mmHg at 100°F) and the references used.

Table 4.9-1: Chemicals with Low Vapor Pressure (< 10 mmHg)

Chemical Name	Temp	Vapor Pressure	Units	Vapor Pressure at 100°F ^(a)		Ref.
				(atm)	(mmHg)	
Ethanolamine (Monoethanolamine)	100°F	0.022	lb _f /in ²	0.0015	1.1	[Ref. 2.9.23]
Fuel Oil	100°F	0.100	lb _f /in ²	0.0068	5.2	[Ref. 2.9.26]
Hexanol ^(b)	100°F	275	Pa	0.0027	2.1	[Ref. 2.14]
Kerosene	100°F	0.099	lb _f /in ²	0.0067	5.1	[Ref. 2.9.18]
Motor Oil	100°F	0.100	lb _f /in ²	0.0068	5.2	[Ref. 2.9.27]
Propylene Tetramer	120°F	0.022	lb _f /in ²	< 0.0015	< 1.1	[Ref. 2.9.33]
Toluene Diisocyanate	130°F	0.004	lb _f /in ²	< 0.0003	< 0.2	[Ref. 2.9.39]

Notes:

- Pressure unit conversion [Ref. 2.29]: Multiply lb_f/in² by 0.06805 to obtain atm; Multiply Pa by 9.8693×10^{-6} to obtain atm; Multiply atm by 760 to obtain mmHg
- For hexanol, vapor pressure (Pa) is derived using Perry as follows [Ref. 2.14, Table 2-8]:
 $\ln(P) = 135.421 - 12288/T - 15.732 \cdot \ln(T) + 1.2701E-17 \cdot T^6$; where $T = 311$ K (100°F)

4.10 Miscellaneous Material Densities

When determining the weighted-average density of all commodities shipped via vessel in Section 7.4, the following material densities are used [Ref. 2.28]:

Table 4.10-1: Miscellaneous Densities [Ref. 2.28]

Substance	Specific Gravity
Barytes	4.50
Clay, damp, plastic	1.76
Fats	0.97
Gypsum, alabaster	2.80
Iron slag	3.00
Lead	11.34
Oak, live	0.87
Paper	1.15
Petroleum	0.87
Plastics	2.50
Portland cement	3.20
Potassic Fert. (Potash)	2.00*
Steel, cold-drawn	7.83

*[Ref. 2.9.31]

5.0 Assumptions

- 5.1 Liquid leaks form a circular puddle centered at the release point and have a uniform depth of 1 cm. Minimizing the puddle depth maximizes the surface area, and therefore the evaporation rate. A 1 cm minimum thickness is consistent with NUREG-0570 [Ref. 2.5, p.5].
- 5.2 When determining plume rise, it is assumed that the chemicals reach atmospheric pressure and temperature immediately after the release. This is acceptable because a release from a source at a higher pressure would have rapid turbulent mixing, and quickly reach steady conditions; and a release from a source at atmospheric pressure will be a liquid which evaporates due to the wind, which would cause mixing.
- 5.3 Table 4.2-1 in Input 4.2 does not list a maximum temperature gradient for Stability Class G weather. It is assumed that the maximum temperature gradient is 8°C/100m. This assumption is based on the other temperature gradient values in Table 4.2-1.
- 5.4 Atmospheric pressure is assumed to be 14.7 psia. This is reasonable because the site is adjacent to the Columbia River off the Pacific Ocean (Input 4.1).
- 5.5 Based on the vapor pressure of fuel oil, kerosene, and motor oil (Input 4.9), it is assumed that gas oil, lube oil, petroleum crude oil, petroleum jelly, asphalt and other chemicals with petroleum or oil in their name have a vapor pressure less than 10 mmHg at 100°F.
- 5.6 For waterborne commerce, USACE provides the total number of vessel trips in a year and the yearly mass shipped for each commodity. However, a specific commodity's yearly number of trips or mass per trip is not known. Thus, yearly shipment quantities in terms of mass are assumed to be evenly distributed volumetrically throughout the total number of trips in a year. See Section 7.4 for more details.
- 5.7 Chemicals that are modeled as being liquids are assumed to be stored at atmospheric temperatures (see Assumption 5.8 for exception of methane). This will increase the initial mass that flashes to vapor which maximizes concentration and energy.
- 5.8 Methane is transported via cargo ships condensed to a liquid at close to atmospheric pressure by cooling it to below its boiling point, -259°F (Input 4.3) [Ref. 2.33]. Liquefied methane is conservatively assumed to be stored at -220°F in this analysis. Assuming liquid at a higher temperature increases the initial mass that flashes to vapor which maximizes concentration and energy.
- 5.9 The molecular weight of gasoline that is used for dispersion analyses, 86.91, is calculated assuming the relative vapor density is 3 ($86.91 = 3 \cdot 28.97$, the molecular weight of air per Input 4.3) and density is proportional to molecular weight per the ideal gas law (defined in Section 6.2.1). Using the lowest vapor density in the range specified in Input 4.3 is conservative because a smaller molecular weight will lead to a smaller conversion from volume based concentration (ppm) to mass based concentration (mg/m^3 or $\text{lb}_\text{m}/\text{ft}^3$). The vapor density of gasoline used for stationary explosion analyses is assumed to be 4. This

maximizes the mass of vapor in a tank. The vapor pressure of gasoline is assumed to be 1 atm (14.7 psia) at 107°F (i.e., the normal boiling temperature at atmospheric pressure is assumed to be 107°F). This is consistent with the MSDS [Ref. 2.9.12] which states that the Reid vapor pressure of gasoline at 100°F is between 6 and 15 psia. The same vapor pressure assumption is used for naphtha. This is reasonable since the vapor pressure of naphtha at 70°F, 0.732 lb_f/in² (38 mmHg) [Ref. 2.9.24], is much less than the vapor pressure of gasoline at 20°C (68°F), 220-450 mmHg [Ref. 2.9.12].

- 5.10 All chemicals are assumed to follow the ideal gas law (defined in Section 6.2.1).
- 5.11 When determining the explosive pressure in an enclosed vapor cloud explosion for a chemical that is liquid at atmospheric conditions and stored in a tank as a liquid, the mass of vapor is calculated assuming the entire volume of the tank is vapor at the UEL. This methodology is also applied for dust cloud explosions. This is conservative because it results in the largest possible amount of explosive mass. To simplify the analysis of the BNSF railcar vapor cloud explosions, UEL is ignored (i.e., a UEL of 100% is assumed); this is further conservative since a vapor cloud explosion cannot actually occur if the entire tank is filled with vapor (the fuel-air ratio would be too rich).

6.0 Methodology

The major tasks in this calculation are:

1. Chemical screening of non-hazardous sources.
2. Calculating the explosive overpressure due to a chemical explosion.
3. Determining the concentration in relation to the LEL from a chemical vapor release that travels to the ISFSI site.
4. Performing a probabilistic analysis (as necessary) for hazardous chemicals that exceed the limits in the deterministic analysis.

6.1 Chemical Screening of Non-Threat Sources

The first step of the analysis is to eliminate the non-hazardous chemicals being shipped via railcar and vessel. Chemicals can be screened out by meeting either of the following:

1. Material is non-explosive.
2. Vapor pressure of liquid chemical is less than 10 mmHg (0.013 atm) at 100°F – Per Regulatory Guide 1.78 [Ref. 2.1, p.8], this is an acceptable screening criteria in the analysis of toxicity which is often on the order of parts per million (0.0001%); therefore, it is very reasonable for explosion analyses since explosive limits are typically greater than a tenth of a percent (0.1%).

In addition, chemicals that are bounded by instances of the same chemical both in terms of distance and mass are screened out.

From Assumption 5.5, gas oil, lube oil, petroleum crude oil, petroleum jelly, asphalt and other chemicals with petroleum or oil in their name have a vapor pressure less than 10 mmHg and are therefore screened out.

Chemicals that cannot be screened out by the above methods are then analyzed using the methods described below.

6.2 Determination of the Explosive Overpressure due to a Chemical Explosion

The explosive overpressure at the nearest ISFSI cask due to a chemical explosion is calculated using the following methods.

6.2.1 TNT Equivalency

The first method for calculating the explosive overpressure uses Regulatory Guide 1.91 [Ref. 2.2]. This method uses TNT equivalence, where the mass of chemical that is exploded is converted into an equivalent mass of TNT. The standoff distance is calculated using Equation 6.2-1 below [Ref. 2.2, p.3]. Transportation routes and nearest approaches are identified in Input 4.6 and 4.7.

$$R_{min} = Z \cdot W^{1/3} \qquad \text{Eq. 6.2-1}$$

Where:

R_{min} = Distance from explosion (ft)
 Z = Scaled distance (ft/lb_m^{1/3}) [Ref. 2.26, Fig. 3-16.14] (Attachment A)
 W = Equivalent mass of TNT (lb_m)

For this calculation, the SFPE Fire Protection Handbook [Ref. 2.26, p.3-325], the book *Explosion Hazards and Evaluation* [Ref. 2.31, p.202] and NUREG-1805 [Ref. 2.54, p.15-10] provide methodology for the equivalent mass of TNT for vapor cloud explosions in Equation 6.2-2 below. From these references and Table B.3 of the FEMA Handbook of Chemical Hazard Analysis Procedures [Ref. 2.53, p.B-43], a yield of 0.1 is a conservative upper bound for an unconfined vapor cloud large explosion for the chemicals in this evaluation (note the SFPE Fire Protection Handbook states that some small explosions are estimated to have a yield of 0.01, however, large explosions are those of interest in this analysis). For the explosion of vapor confined in a tank, a yield of 1.0 is used per NUREG-1805 [Ref. 2.54, p.15-9]. This TNT equivalence is then used in Equation 6.2-1 above.

$$W_{TNT} = \frac{\alpha \cdot \Delta H_C \cdot m}{\Delta H_{TNT}} \quad \text{Eq. 6.2-2}$$

Where:

α = Yield fraction (-) (see above)
 ΔH_C = Heat of combustion of the chemical (kJ/kg) (Input 4.3)
 ΔH_{TNT} = Heat of explosion/detonation in a TNT explosion = 4500 kJ/kg per [Ref. 2.26, p.3-325] [Ref. 2.31, p.143] [Ref. 2.54, p.15-10]
 m = Mass of the chemical that is exploded (kg or lb_m)

For solid explosives in this evaluation, the equivalent mass of TNT is simply equal to the yield multiplied by the mass of the explosive. Yield fractions for the various solid explosives in this analysis are identified in Input 4.4.

For vapor cloud explosions of normal boiling point (NBP) chemicals, the mass of chemical exploded is the full volume of the container filled with vapor at the chemical's UEL, with exception of the analysis of BNSF railcar vapor cloud explosions which conservatively ignores UEL, i.e., a UEL of 100% is assumed (Assumption 5.11). Because density is higher at low temperatures, the site design minimum temperature (Input 4.2) is used in the ideal gas law to determine the explosive mass. Equations 24.45 and 24.46 in MERM [Ref. 2.29] provide the basis for the ideal gas relation shown below:

$$m = \frac{P \cdot 144 \cdot V}{(R_o / MW) \cdot T} \quad \text{Eq. 6.2-3}$$

Where:

P = Absolute pressure (psia) (Assumption 5.4)

V = Volume (ft^3)
 R_o = Universal gas constant = $1545 \text{ ft}\cdot\text{lb}_f/\text{lb}_{\text{mol}}\cdot^\circ\text{R}$ [Ref. 2.29]
 MW = Molecular weight ($\text{lb}_m/\text{lb}_{\text{mol}}$) (Input 4.3)
 T = Temperature ($^\circ\text{R}$) = $T_{\text{°F}} + 459.67^\circ$ [Ref. 2.29] (Input 4.2)

For vapor cloud explosions of low boiling point (LBP) chemicals that are stored pressurized as liquefied gases (e.g., ammonia, methane, propane, etc.), the mass of chemical exploded is equal to the mass that initially flashes to vapor upon release. In this case, factoring of the UEL is not applied since it is inherent in the use of the yield fraction for an unconfined vapor cloud explosion, $\alpha = 0.1$, as discussed above. The initial puff mass is found by multiplying the liquid (shipment) mass by the expansion mass quality, x (see Section 6.2.3 for the mass quality derivation). Alternatively, the initial puff mass can be found by the product of the liquid mass and the flashing fraction, F_i (see Section 6.3.2.2 for the flashing fraction calculation).

For solid explosives, the mass of the chemical is simply equal to the shipment mass.

6.2.1.1 Heat of Combustion Alternative Calculation

For the chemicals butyl acrylate, 1,1-difluoroethane, ethylene glycol diethyl ether, and 1-methoxy-2-propanol, documented heats of combustion could not be found. Therefore, the heat of combustion (kJ/kg) is calculated using the following relationship for a chemical of composition $\text{C}_c\text{H}_h\text{O}_o\text{N}_n$ (where $c \geq n + o$) [Ref. 2.36]:

$$\Delta H_c = \left[\frac{418 \cdot (c + 0.3h - 0.5o)}{MW} \cdot 1000 \right] \cdot (1 \pm \sigma) \quad \text{Eq. 6.2-4}$$

Where:

MW = Molecular weight of chemical (g/mol) (Input 4.3)

σ = Standard deviation = 3.1% per [Ref. 2.36]

6.2.2 Combustible Dust

Explosive overpressure is also calculated for solids that are identified as combustible in dust form. Evaluation of combustible dust clouds is inherently conservative since a small explosion must first occur to result in dust becoming airborne [Ref. 2.31, p.190]. This dust would then serve as the fuel source for a second explosion. The combustible dust mass and resulting explosion overpressure are related using Equation 70.5 from the SFPE Handbook Fifth Edition [Ref. 2.27, p.2774]:

$$M_{exp} = \frac{P_{es}}{DLF} \cdot \frac{C_w}{P_{max}} \cdot \frac{V_b}{\eta_D} \quad \text{Eq. 6.2-5}$$

Where:

M_{exp} = Dust mass (kg)

P_{es} = Overpressure due to blast wave (bar)

DLF = Dynamic load factor (-) = 1.5 (conservative) per [Ref. 2.27, p.2774]
 C_w = Minimum flammable concentration (kg/m^3) (Input 4.3)
 P_{max} = Maximum explosion pressure (bar) (Input 4.5)
 V_b = Blast volume (m^3) = $(2/3)\pi R^3$ = volume of a hemisphere – representing the blast zone from an explosion on a horizontal plane (e.g., at ground level or water surface level) – with radius, R (m), equal to the standoff distance from the detonation source
 η_D = Entrainment fraction (-) = 0.25 per [Ref. 2.27, p.2774]

For dust cloud explosions, the mass of chemical exploded is the full volume of the container filled with dust at the chemical's UEL (Assumption 5.11).

6.2.3 Boiling Liquid Expanding Vapor Explosion

The vessel rupture blast wave generated during a BLEVE is characterized by the energy released in the fluid expansion from the vessel rupture pressure to atmospheric pressure. This energy is given by Equation 3-14 of the SFPE Handbook [Ref. 2.26, p.3-327]:

$$E_e = m(u_r - u_a) \quad \text{Eq. 6.2-6}$$

Where:

E_e = Blast wave energy for fluid expansion (kJ or Btu)
 m = Mass of fluid in the storage vessel (kg or lb_m)
 u_r = Fluid internal energy at rupture conditions (kJ/kg or Btu/ lb_m)
 u_a = Fluid internal energy after expansion (kJ/kg or Btu/ lb_m)

The mass of fluid is conservatively computed based on the vessel volume and the density of saturated liquid at atmospheric pressure, even though the liquid storage temperature is greater than the normal boiling point temperature, and the liquid density decreases with increasing temperature. The initial internal energy, u_r , is taken as that of saturated liquid at the ambient temperature.

The expansion process is modeled as occurring isentropically, and thermodynamic data are used to determine the mass fraction of liquid which expands to vapor. The initial entropy of the liquid at the time of tank rupture is denoted by s_r . The entropy of the liquid-vapor mixture after expansion is s_2 . Since the expansion process is isentropic, by definition $s_r = s_2$.

The entropy of any single-component two-phase mixture is given by Equations 24.41 and 24.36 of MERM [Ref. 2.29] as:

$$s = s_f + x(s_g - s_f) \quad \text{Eq. 6.2-7}$$

where x is the mass quality, and the f and g subscripts refer respectively to saturated liquid and vapor. For expansion to atmospheric pressure, the entropy of saturated liquid and saturated vapor are known. The fraction of initial liquid mass which flashes to

vapor can be determined from the following relation, using the known initial entropy of the single-phase liquid.

$$s_2 = s_r = s_f + x(s_g - s_f)$$

Eq. 6.2-8

Solving for the mass quality gives:

$$x = \frac{s_r - s_f}{s_g - s_f}$$

Eq. 6.2-9

To maximize the value of x , the value of s_r is conservatively taken as that of saturated liquid at the ambient temperature, even though the chemical may be stored in insulated tanks.

Once the mass quality is determined, the internal energy of the isentropically expanded liquid-vapor mixture, u_a , can be determined according to the following relation:

$$u_a = u_f + x(u_g - u_f)$$

Eq. 6.2-10

With u_a computed, the value of E_e can be calculated and the blast wave overpressure determined through conversion to equivalent mass of TNT and the use of the scaled distance parameter as described in Section 6.2.1.

6.3 Traveling Vapor Cloud Explosion

For chemicals that pose an explosive hazard due to a traveling vapor cloud, the concentration of the vapor resulting from a chemical release is to be analyzed. Regulatory Guide 1.78 [Ref. 2.1] and NUREG-0570 [Ref. 2.5] describe the methods for evaluation. The standoff distance is defined as the distance where the concentration of the flammable vapor at the location of the cask is just less than the LEL. Note that an unconfined vapor cloud explosion would not generate sufficient overpressure to damage the cask. If the concentration of the flammable vapor is above the LEL at the cask location, a damaging detonation could occur at the ISFSI.

An important component of calculating the vapor cloud concentration is accounting for atmospheric dispersion downwind of the chemical leak. Dispersion causes the vapor to become less concentrated with distance. When calculating atmospheric dispersion, conservative meteorological conditions are used. The worst case wind speed must be found iteratively. A low wind speed may be conservative in some cases while a high wind speed may be more conservative in others because of the effects of meander (see below for more details on meander). As specified in Regulatory Guide 1.78 [Ref. 2.1, p.4], the worst case weather conditions that are exceeded less than 5% of the year will be used.

There are two methodologies that can be followed in order to determine the concentration following a release. First, the entire mass of the chemical can be analyzed as being

released as a vapor all at once. This is a puff release. Dilution of the initial puff may occur if gases are stored under pressure prior to release due to air entrainment. Second, if the chemical is stored as a liquid, it can spill from its container and evaporate over time. If the chemical has been pressurized, some of the mass may instantly flash to vapor in an initial puff. Combined, this is a puff-plume release. A puff release is more conservative because the peak concentration of chemical is higher. The chemical concentration is calculated using Mathcad [Ref. 2.40] based on the methodology discussed in the following sections. Additional discussion is included in the Mathcad models, which are documented in Appendices 4 and 6.

6.3.1 Puff Release and Dispersion

The procedure and equations describing a puff release and the subsequent dispersion of the vapor cloud come from Regulatory Guide 1.78 [Ref. 2.1] and NUREG-0570 [Ref. 2.5].

As a vapor cloud travels with the wind, there is additional dispersion. The calculation for this dispersion uses constants depending on the Pasquill Atmospheric Stability Class. Using the methods and equations from Regulatory Guide 1.145 [2.3] and EPA-454/B-95-003b [Ref. 2.4], the following equation for lateral dispersion is obtained:

$$\sigma_{hi} = [465.11628(x) \cdot \tan(TH)] \cdot 3.281 \quad \text{Eq. 6.3-1}$$

$$TH = 0.017453293 \cdot [c - d \cdot \ln(x)] \quad \text{Eq. 6.3-2}$$

And for vertical dispersion:

$$\sigma_{vi} = [a \cdot x^b] \cdot 3.281 \quad \text{For } \sigma_{vi} < 5000 \text{ m} \quad \text{Eq. 6.3-3}$$

$$\sigma_{vi} = 5000 \cdot 3.281 \quad \text{For } \sigma_{vi} \geq 5000 \text{ m} \quad \text{Eq. 6.3-4}$$

Where:

- x = Distance from release to evaluation point (km)
- σ_{hi} = Lateral dispersion standard deviation (ft)
- σ_{vi} = Vertical dispersion standard deviation (ft)
- a, b, c, d = Stability class coefficients (-) [Ref. 2.4]

The stability class coefficients used in the equations above from EPA-454/B-95-003b [Ref. 2.4] are only applicable for Stability Classes A-F. For Stability Class G weather, σ_{hi} is the value for Stability Class F multiplied by 2/3, and σ_{vi} is the value for Stability Class F multiplied by 3/5 [Ref. 2.3].

For this analysis, the dispersion is calculated using the following equations [Ref. 2.5, p.18]:

$$\sigma_h = \sqrt{\sigma_i^2 + \sigma_{hi}^2} \text{ (ft)} \quad \text{Eq. 6.3-5}$$

$$\sigma_v = \sqrt{\sigma_i^2 + \sigma_{vi}^2} \text{ (ft)} \quad \text{Eq. 6.3-6}$$

$$\sigma_i = \left[\frac{Q}{\sqrt{2\pi^3} \rho_v} \right]^{1/3} \text{ (ft)} \quad \text{Eq. 6.3-7}$$

Where:

Q = Total amount of mass released (lb_m)

ρ_v = Gas vapor density (lb_m/ft³)

σ_i = Initial dispersion due to the expansion of pressurized gas

Equation 6.3-7 only applies to puff releases, for plume releases, Equation 6.3-23 is used. The dispersion is then put into coordinates where x is along the wind direction, y is horizontal and perpendicular to the wind direction, and z is vertical, as shown below.

$$\sigma_y = \sigma_x = \sigma_h \quad \text{Eq. 6.3-8}$$

$$\sigma_z = \sigma_v \quad \text{Eq. 6.3-9}$$

The Gaussian diffusion model for puff of vapor results in the following equation for the chemical concentration in lb_m/ft³ at the point of interest [Ref. 2.5, p.18] [Ref. 2.32, p.115]:

$$X_{puff}(x, y, z, h) = \frac{Q}{(2\pi)^{1.5} \sigma_x \sigma_y \sigma_z} \exp \left\{ -\frac{1}{2} \left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2} \right) \right\} \left\{ \exp \left(\frac{-1(z-h)^2}{2\sigma_z^2} \right) + \exp \left(\frac{-1(z+h)^2}{2\sigma_z^2} \right) \right\} \quad \text{Eq. 6.3-10}$$

Where:

$x = x_o - U \cdot t$ (ft)

x, y, z = Distance from the puff center (ft)

U = Wind speed (ft/s)

t = Time (s)

x_o = Initial distance of release from point of interest (ft)

h = Height elevation of source (ft)

Note Equation 6.3-10 is taken from Equation 3.154 of Slade [Ref. 2.32], since there is an error in the exponent of π in NUREG-0570, Eq. 2.2-1. Since the vapor cloud is taken as traveling in a straight line from the source, the center-line concentration of the cloud is obtained by setting $y = 0$, per the recommendation of NUREG-0570 [Ref. 2.5, p.19]. This time dependent centerline concentration is then used to determine the time dependent chemical concentration.

6.3.2 Plume Release and Dispersion

The equations describing a plume release come from NUREG-0570 [Ref. 2.5]. This describes how a liquid puddle evaporates and how the vapor dissipates as it travels with the wind.

6.3.2.1 Spill Area

A released liquid quickly spreads by gravity from its initial shape into a thin pool on the ground. The surface area of the pool as a function of time is defined by the following expression from NUREG-0570 [Ref. 2.5, p.4]:

$$A(t) = \pi \left[r_o^2 + 2t \left[\frac{g \cdot V_o}{\pi} \cdot \frac{(\rho_l - \rho_a)}{\rho_l} \right]^{1/2} \right] \quad \text{Eq. 6.3-11}$$

Where:

$$r_o = \text{Initial radius of the spill} = \left(\frac{m_o}{\pi \rho_l} \right)^{1/3} \text{ (ft)}$$

m_o = Initial mass of chemical that is spilled (lb_m)

g = Gravitational acceleration (ft/s²)

V_o = Volume of the spill, πr_o^3 (ft³)

ρ_l = Density of the liquid (lb_m/ft³)

ρ_a = Density of the air (lb_m/ft³)

t = Time (s)

The surface area is limited to the smaller value corresponding to the volume at a thickness of 1 cm (Assumption 5.1) or the berm area, if applicable. The corresponding maximum diameter of the spill, provided there is not a berm, will therefore be:

$$A_{\max} = \pi \frac{D_s^2}{4} = \frac{V}{th_{\min}} \quad \text{Eq. 6.3-12}$$

Where:

A_{\max} = Area of the spill (ft²)

D_s = Diameter of the spill (ft) = $\sqrt{4A/\pi}$

V = Volume of the spill (ft³)

th_{\min} = Thickness of the puddle = 1 cm (converted to ft)

6.3.2.2 Source Strength of Low Boiling Point (LBP) Liquids

If the chemical that is spilled is stored or transported as a sub-cooled or pressurized liquid, some of the chemical will immediately flash to gas and some will spill onto

the ground and boil off. This results in a combined puff-plume release. The equations used to determine the mass release rate are from NUREG-0570 [Ref. 2.5] and are shown below.

The liquid mass that initially flashes to vapor, Q , is given by the product of the flashing fraction, F_i , and the initial mass M [Ref. 2.5, p.5]:

$$F_i = \frac{c_p (T_a - T_b)}{h_{fg}} = \frac{h_{fa} - h_{fb}}{h_{fg}} \quad \text{Eq. 6.3-13}$$

Where:

c_p = Chemical specific heat (Btu/lb_m-°R)
 T_a = Ambient temperature (°R)
 T_b = Chemical boiling temperature at one atmosphere (°R)
 h_{fa} = Chemical liquid enthalpy at storage conditions (Btu/lb_m)
 h_{fb} = Chemical liquid enthalpy at 1 atm and boiling temperature (Btu/lb_m)
 h_{fg} = Chemical latent heat of vaporization (Btu/lb_m)

$$Q = F_i M \quad \text{Eq. 6.3-14}$$

Where:

Q = Mass initially flashed to vapor (lb_m)
 M = Total mass of stored liquid (lb_m)

The initial mass release is used in Equation 6.3-10. The continuous source strength is determined by calculating the boil-off of the liquid spill due to various heat transfer mechanisms. Per NUREG-0570 [Ref. 2.5], the three methods of heat transfer that should be considered in an analysis are conduction, convection, and radiation.

The conductive heat flux between the earth and the chemical puddle is determined using the following relation [Ref. 2.5, p.8]:

$$q_d = k_e \cdot (T_e - T_b) \cdot \left[\frac{\pi \cdot k_e \cdot t}{\rho_e \cdot C_{pe}} \right]^{-1/2} \quad \text{Eq. 6.3-15}$$

Where:

q_d = Rate of conduction heat transfer (cal/m²-s)
 k_e = Thermal conductivity of the earth (cal/m-s-K)
 T_e = Temperature of the earth (K)
 T_b = Boiling temperature of the chemical puddle (K)
 t = Time after spill (s)
 ρ_e = Density of the earth (gm/m³)
 C_{pe} = Specific heat of the earth (cal/gm-K)

Using values presented in NUREG-0570 [Ref. 2.5], the above equation reduces to:

$$q_d = 197 \frac{(T_e - T_b)}{\sqrt{t}} \quad \text{Eq. 6.3-16}$$

This heat flux is then multiplied by the surface area of the puddle and the time allowed for heat transfer to take place. This results in the amount of heat transferred to the puddle for the time period considered (in calories).

The convective rate of heat transfer q_c is derived from empirical studies, which are summarized in NUREG-0570 [Ref. 2.5]. For a wind speed of 1 m/s at 21°C (70°F), the convective heat transfer coefficient is 1.6 cal/m²-s-K. From Equation 2.1-6 on page 8 of NUREG-0570, the convective heat transfer scales with wind speed to the 0.6th power. The convective heat transfer is scaled by the wind speed for this analysis. The heat transfer due to convection is determined by multiplying this coefficient by the surface area of the chemical spill, the temperature differential between ambient air and the spill, and the time step used.

For the rate of heat transfer due to radiation q_r , the maximum heat flux value of 275 cal/m²-s is used, per NUREG-0570 [Ref. 2.5]. This corresponds to the maximum measured radiative heat flux at noon on a sunny day at 30° North latitude. This coefficient is multiplied by the same factors as the conductive heat flux to yield the overall heat transfer due to solar radiation, in calories.

With conversion of heat transfer rates to British units (Btu/ft²-s), the total vaporization rate becomes [Ref. 2.5]:

$$\dot{Q} = \frac{A(t) \cdot (q_d + q_c + q_r)}{H_v} \quad \text{Eq. 6.3-17}$$

Where:

\dot{Q} = Continuous source strength (lb_m/s)
 $A(t)$ = Spill area as a function of time (ft²)
 H_v = Heat of vaporization (Btu/lb_m)

6.3.2.3 Source Strength of Normal Boiling Point (NBP) Liquids

The continuous source strength for pools with boiling points greater than the ambient temperature is determined by calculating the evaporation rate of the liquid spill by forced convection, per NUREG-0570 [Ref. 2.5, p.12].

As the spill volume is depleted due to evaporation, the area will begin to decrease from its maximum computed value. Note that the evaporation rate is highest for higher temperatures, therefore, the site design maximum temperature is used for this analysis (Input 4.2). The area is updated based on the remaining pool volume while

maintaining the 1 cm thickness. From NUREG-0570 [Ref. 2.5, p.12], with turbulent flow conditions, the mass transfer coefficient is given by:

$$h_d = 0.037 \frac{D}{D_s} Re^{0.8} Sc^{1/3} \quad \text{Eq. 6.3-18}$$

Where:

h_d = Mass transfer coefficient (ft/s)
 D = Diffusion coefficient for liquid chemical to air (ft²/s)
 D_s = Diameter of the spill area (ft)
 Re = Reynolds number (-)
 Sc = Schmidt number (-)

Per NUREG-0570 [Ref. 2.5, p.10], the diffusion coefficient is taken as a worst case value of 0.2 cm²/s. The Schmidt number and the Reynolds number used above are defined as:

$$Sc = \frac{\mu}{D \cdot \rho_a} \cdot g_c \quad \text{Eq. 6.3-19}$$

$$Re = \frac{D_s \cdot u \cdot \rho_a}{\mu} \cdot \frac{1}{g_c} \quad \text{Eq. 6.3-20}$$

Where:

μ = Absolute viscosity of air (lb_f-s/ft²)
 u = Velocity of the wind (ft/s)
 g_c = Gravitational constant (lb_m-ft/lb_f-s²)

The rate of evaporation of the liquid chemical is then determined using the following from NUREG-0570 [Ref. 2.5, p.12]:

$$\dot{Q} = h_d \cdot M \cdot A(t) \cdot \frac{(P_s - P_a)}{R_u (T_a)} \quad \text{Eq. 6.3-21}$$

Where:

\dot{Q} = Mass evaporation rate (lb_m/s)
 M = Molecular Weight of the chemical (lb_m/lb_{mol})
 P_s = Saturation vapor pressure at ambient temperature (psf)
 P_a = Existing partial pressure of the chemical in the air (psf)
 R_u = Universal Gas Constant (ft-lb_f/lb_{mol}-°R)
 T_a = Ambient Temperature (°R)

6.3.2.4 Plume Dispersion

The dispersion equation for a continuous plume release with a finite initial volume is given by Equation 2.2-9 of NUREG-0570 [Ref. 2.5, p.19], as the following:

$$\chi(x, y, z, h) = \frac{Q}{2\pi U \sigma_y \sigma_z} \exp\left\{-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2}\right)\right\} \left\{ \exp\left(-\frac{1}{2}\frac{(z-h)^2}{\sigma_z^2}\right) + \exp\left(-\frac{1}{2}\frac{(z+h)^2}{\sigma_z^2}\right) \right\}$$

Eq. 6.3-22

An initial dispersion is also taken into account because the evaporation release rate for the plume is assumed to come from a point source. Similar to Equation 6.3-7, the initial dispersion for a plume can be derived by setting the distance of the release to zero and solving Equation 6.3-22 for the density of the chemical.

$$\sigma_i = \left[\frac{\dot{Q}}{\rho_v \pi U} \right]^{1/2}$$

Eq. 6.3-23

As cited in NUREG/CR-2260 [Ref. 2.7], the effluent concentrations measured at low wind speeds are usually substantially lower than those predicted using the Pasquill dispersion coefficients. The reduced concentrations are due primarily to enhanced horizontal spreading of the plume as it meanders over a large area. This meandering produces σ_y values that are much larger than those obtained using the Pasquill constants. To account for this effect, use is made of a meander factor, M_f , which modifies the value of σ_y to include the lateral plume spread due to meander, Σ_y . The value of Σ_y is calculated in accordance with Regulatory Guide 1.145 [Ref. 2.3] and NUREG/CR-2260 [Ref. 2.7, p.II-9], as:

$$\Sigma_y = M_f \sigma_y \quad \text{For distances} \leq 800 \text{ m} \quad \text{Eq. 6.3-24}$$

$$\Sigma_y = (M_f - 1) \sigma_{y800} + \sigma_y \quad \text{For distances} > 800 \text{ m} \quad \text{Eq. 6.3-25}$$

The meander factor is a function of wind speed and atmospheric stability class. The value of M_f is a constant for wind speeds less than 2.0 m/s, and decreases to a minimum value of 1.0 at a wind speed of 6 m/s. The meander factor is determined from Figure 3 of Regulatory Guide 1.145 [Ref. 2.3].

Regulatory Guide 1.145 [Ref. 2.3, p.3] provides equations for ground-level relative concentration at the plume centerline with credit for plume meander as:

$$\chi = \frac{1}{U_{10} \pi \Sigma_y \sigma_z}$$

Eq. 6.3-26

Where:

U_{10} = Wind speed at 10m above plant grade

This equation for a ground-level concentration with meander is created by setting z , h , and y equal to zero in Eq. 6.3-22 and replacing σ_y with Σ_y . For an above ground release, Eq. 6.3-22 is only modified by replacing σ_y with Σ_y , giving the equation for plume concentration with meander, Eq. 6.3-27.

$$\frac{X}{Q} = \frac{1}{2U\pi\Sigma_y\sigma_z} \exp\left\{\frac{-1\left(\frac{y^2}{\Sigma_y^2}\right)}{2}\right\} \left\{\exp\left(\frac{-1\left(\frac{z-h}{\sigma_z}\right)^2}{2}\right) + \exp\left(\frac{-1\left(\frac{z+h}{\sigma_z}\right)^2}{2}\right)\right\} \quad \text{Eq. 6.3-27}$$

6.3.3 Puff-Plume Combination

In this calculation, where a mass of liquid evaporates off over time, the puff and plume analysis methodology is combined into an integrated puff method. In this method, the mass release rate over a given time step is released as a single puff. All of the concentrations for each puff are then added together to come up with the concentration at any given point. Because of this, Equation 6.3-10 is used with the dispersion coefficients accounting for meander, as used in Equation 6.3-27.

Any benefit from plume rise for gases that are lighter than air is ignored in this evaluation except for in the analysis of vessel shipments of methane, in which case, the value of h in Eq. 6.3-10 is replaced by z , the height of the ISFSI storage casks (Input 4.1), per the guidance in NUREG-0570 [Ref. 2.5, p.19]. This effectively places the plume centerline at the same elevation as the cask height to include the additional benefit for vertical dispersion.

6.4 Probabilistic Analysis

For transported chemicals that do not meet the acceptance criteria from the above deterministic analyses, a probabilistic analysis is used. Probabilistic analysis is necessary for several vessel explosions hazards in this evaluation. The purpose of a probabilistic analysis is to show that the frequency of a hazard is less than 10^{-6} hazards per year, based on Regulatory Guide 1.91 [Ref. 2.2, p.6]. In addition, the Standard Review Plan, NUREG-0800 Section 2.2.3 [Ref. 2.6], states that a hazard occurring with a probability of 10^{-7} per year, or greater, is a design basis event when accurate data is used. If data are not available to make an accurate estimate, a hazard is a design basis event if the probability of occurrence is greater than 10^{-6} per year provided qualitative arguments can be made to show the realistic probability is lower. For this analysis, a rate of a hazard for each vessel trip is calculated. This rate is then used to determine a number of allowable shipments of each chemical. The number of allowable shipments is compared to the actual number of shipments in order to determine if the hazard is of acceptably low probability.

6.4.1 Allowable Number of Vessel Trips

The process for determining the allowable number of vessel trips involves running many deterministic cases and summing the frequency of a hazard for each case. Each case involves picking a set of parameters, for example, Pasquill Stability Class E with a wind speed of 0.76 mph and a spill of 50,000 liquid gallons of chemical. Each of these parameters has a specific probability of occurrence. Using these parameters, a standoff distance is determined. If the standoff distance is less than the nearest distance of the transportation route to the site, then that case does not pose a hazard. If the standoff distance is more than the nearest distance from the transportation route to the site, the case does pose a hazard. For each case, the rate of a hazard is calculated using Equation 6.4-1.

$$R_{haz} = P_{spill} \cdot R_{accident} \cdot P_{weather} \cdot D_{trip} \quad \text{Eq. 6.4-1}$$

Where:

- R_{haz} = Rate of hazards per vessel trip near the site (hazardous spills/trip)
- P_{spill} = Probability of the spill size (spills/accident)
- $R_{accident}$ = Rate of accidents (accidents/vessel mile)
- $P_{weather}$ = Adverse wind direction probability (hazardous weather conditions at the site)
- D_{trip} = Hazardous trip length, the total number of miles that a vessel travels past the site each trip where an accident could result in a hazardous condition (vessel miles/trip)

The probability of the spill size is taken from U.S. Coast Guard information provided in the MISLE database [Ref. 2.49]. The value used is the probability of a spill of a given size given that a spill has occurred. This is more conservative than the probability of a spill of a given size given an accident because not all accidents will result in a spill (i.e., vessel grounding). See Section 7.3 for more detail on the values used for this probability.

The rate of accidents is taken from NUREG/CR-6624 [Ref. 2.8, p.9]. The rate of an accident per barge mile is 1.8×10^{-6} accidents per mile. For this analysis, barge accident rates are used for vessel accident rates. The WASH-1238 value is used because they are identified in NUREG/CR-6624 as the primary source to which other accident rates are compared.

The probability of adverse wind directions is dependent on both the weather parameters and the standoff distance calculated. The standoff distance is used to determine which wind directions will blow the spill toward the site.

The distance that a vessel travels past the site is measured based on the standoff distance. The NOAA nautical chart [Ref. 2.45] and Google Earth [Ref. 2.38] are used to determine the route a vessel will take as it travels along the Columbia River (Input 4.7.1). Per the NOAA chart, the vessel follows the Kalama and Cottonwood

Island Ranges which are marked by buoys. For the probability analysis, the vessels are modeled as remaining in the route defined on the NOAA chart.

This process is repeated for all possible combinations of parameters. Some combinations are not included explicitly because they are bounded by other cases. For example, as the Stability Class letter goes toward A, the release will disperse more and be less of a hazard. Therefore, if Class F is acceptable at a given spill size, then Class E will also be acceptable and does not need to be analyzed.

The rate of a hazard for each case is summed to determine the total rate of a hazard.

The total number of allowable trips is calculated using Equation 6.4-2:

$$T_{\text{allowable}} = \frac{10^{-6} (\text{hazards/year})}{\sum R_{\text{haz}}} \quad \text{Eq. 6.4-2}$$

Where:

$T_{\text{allowable}}$ = Allowable number of trips (trips/year)

10^{-6} = Total allowable number of hazards per year per Reg. Guide 1.91

6.4.2 Prescott Anchorage

The Prescott anchorage boundaries are identified in CFR Title 33 §110.228(11) [Ref. 2.10] with location shown on NOAA Chart #18524 [Ref. 2.45]. Per CFR Title 33 §110.228(11), no vessel carrying a Cargo of Particular Hazard identified in CFR Title 33 §126.10 [Ref. 2.11] (which includes Division 1.1 and 1.2 explosives) may occupy the anchorage without permission from the Captain of the Port.

Additionally, the following characteristics of the Prescott Anchorage serve to minimize any increase in accident probability:

1. Probability of collision accidents is not increased by ships using the anchorage due to the position of the anchorage outside of the channel. Additionally, per the Columbia River Anchorage Guidelines [Ref. 2.51], the Prescott anchorage is provided with a stern buoy to prevent the anchored vessel from swinging into the channel.
2. Probability of groundings is similarly not increased by the anchorage since the anchorage position is deep. The Lower Columbia Region Harbor Safety Committee characterizes the risk of grounding in this anchorage as "low" [Ref. 2.51]. The depth of the position is listed as 52-ft to over 65-ft which can safely accommodate fully laden vessels.
3. Probability of allisions is not increased by the anchorage since there are no fixed objects within the anchorage position.

In general, no new types of accidents are created by the Prescott anchorage since the use of other anchorage positions is already included in river accident statistics.

Per the Anchorage Guidelines [Ref. 2.51], a fully laden vessel may use the Prescott anchorage for no longer than 72 hours without permission of the Captain of the Port. Other vessels would normally stay at the anchorage for no more than seven days. No vessel may occupy the anchorage for more than 30 consecutive days without a permit from the Captain of the Port. The Prescott anchorage was used 25 times in 2016, primarily for empty vessels awaiting a berth at one of the loading docks along the river (Input 4.7.3).

To demonstrate that the probability of a hazardous explosion at the Prescott anchorage is negligible, consider the following: The failure rate for a single-walled chemical tank is 1×10^{-4} releases per year where 10% of those result in the entire contents being spilled instantaneously, per the FEMA Handbook of Chemical Hazard Analysis Procedures [Ref. 2.53, p.11-36]. Therefore, the complete spill frequency for a single-walled chemical tank is 1×10^{-5} . Using this spill rate is reasonable because it is likely that tanks on vessels, particularly tanks of highly combustible materials, are more robust than a single-walled tank. Per Input 4.7.3, the anchorage was used 25 times in 2016, primarily for empty vessels. Consider 10% of the vessels that use the anchorage are loaded. Of those loaded vessels, 31.4% are considered to be carrying explosive cargo – this percentage is found by dividing the sum of all explosive hazard annual trips (12,218 trips, see Section 7.4) by the total number of trips in a year (38,905 trips, taken from 2012 which had the lowest total number of trips in the ten years of USACE data in Input 4.7.2). Assuming that the average anchorage time is eight hours and that all hazardous spills lead to an explosion, the anchorage annual explosion frequency is calculated to be:

$$1 \times 10^{-5} \frac{\text{spill}}{\text{yr}} \cdot 25 \frac{\text{vsl}}{\text{yr}} \cdot 10\% \frac{\text{vsl}_{\text{loaded}}}{\text{vsl}} \cdot 31.4\% \frac{\text{vsl}_{\text{haz}}}{\text{vsl}_{\text{loaded}}} \cdot 8 \frac{\text{hr}}{\text{vsl}_{\text{haz}}} \cdot \frac{1}{8766} \frac{\text{yr}}{\text{hr}} = 7.17 \times 10^{-9}$$

This anchorage hazard probability is negligible in the total probability of site damage from offsite explosion hazards.

6.4.3 Actual Number of Vessel Trips

The actual number of vessel trips of each chemical is unknown; however, data from the U.S. Army Corps of Engineers (USACE) [Ref. 2.46] has been collected that is used to provide an estimate for the number of trips (Input 4.7.2). Data from the USACE is reviewed for the ten most current years (2006-2015). The USACE data includes information on the total number of vessel trips in a year and the yearly mass shipped for each commodity. See Section 7.4 for the calculation of the number of shipments for each chemical.

7.0 Numeric Analysis

7.1 Rail Chemicals

Burlington Northern Santa Fe (BNSF) identified the following list of commodities that were shipped on their railroad near the Trojan ISFSI site in 2016 (Input 4.6.2) – only the commodities with shipments greater than zero are analyzed in this evaluation. Several of the commodities are non-explosive and screen away immediately. See Input 4.8 for non-explosive commodities that are not intuitive by name such as fire extinguishers and vehicle parts (defueled). Other commodities like fuel oil and petroleum crude oil have low vapor pressures (< 10 mmHg) and screen away (see Input 4.9 and Assumption 5.5). Some commodities are bounded by other chemical analyses. The type of explosion analysis is indicated for the commodities that do not screen away. Explosive chemical vapors are analyzed for both stationary and traveling vapor cloud explosions (VCE). If the chemical is normally stored as a pressurized liquid – has a low boiling point (< 107°F) per Input 4.3 – then it is also analyzed for a boiling liquid expanding vapor explosion (BLEVE). Solid explosives are analyzed as stationary explosions only.

Table 7.1-1: Commodities Transported by Rail near the Trojan ISFSI Site

Commodity	Disposition	Commodity	Disposition
1,1-Difluoroethane	Analyze (VCE, BLEVE)	Hazardous Waste, Solid, N.O.S.	Bounded ^(a)
1-Methoxy-2-Propanol	Analyze (VCE)	Heptanes	Analyze (VCE)
Acetaldehyde	Analyze (VCE, BLEVE)	Hexanols	Low Vapor Pressure
Acetic Acid, Glacial	Analyze (VCE)	Hydrocarbons, Liquid, N.O.S.	Analyze as Vinyl Chloride (VCE, BLEVE)
Acetone	Analyze (VCE)	Hydrochloric Acid	Non-Explosive
Alcoholic Beverages	Non-Explosive	Hydrogen	Analyze due to Sodium Shipment (VCE)
Alcohols, N.O.S.	Analyzed as Methanol / Ethanol	Hydrogen Peroxide, Aqueous Solutions	Non-Explosive
Ammonia, Anhydrous	Analyze (VCE, BLEVE)	Hydrogen Peroxide, Stabilized	Non-Explosive
Ammonium Nitrate	Analyze (Stat. Expl. only)	Hypochlorite Solutions	Non-Explosive
Ammonium Nitrate Based Fertilizer	Analyze (Stat. Expl. only)	Isobutane	Analyze (VCE, BLEVE)
Argon, Refrigerated Liquid	Non-Explosive	Isobutylene	Analyze (VCE, BLEVE)
Benzene	Analyze (VCE)	Isoprene, Stabilized	Analyze (VCE, BLEVE)
Bisulfites, Aqueous Solutions, N.O.S.	Non-Explosive	Isopropanol	Analyze (VCE)
Butane	Analyze (VCE, BLEVE)	Isopropyl Acetate	Analyze (VCE)
Butanols	Analyze (VCE)	Lithium Battery	Analyze (Stat. Expl. only)
Butyl Acrylates, Stabilized	Analyze (VCE)	Methanol	Analyze (VCE)
Butylene	Analyze (VCE, BLEVE)	Methyl Chloride	Analyze (VCE, BLEVE)
Butyraldehyde	Analyze (VCE)	Nitrogen, Compressed	Non-Explosive
Carbon Dioxide, Refrigerated Liquid	Non-Explosive	N-Propanol	Analyze (VCE)
Carbon Disulfide	Analyze (VCE)	Octanes	Analyze (VCE)
Chlorine	Non-Explosive	Other Regulated Substances, Liquid, N.O.S.	Bounded ^(a)
Combustible Liquid, N.O.S.	Bounded ^(a)	Pentanes	Analyze (VCE, BLEVE)

Commodity	Disposition	Commodity	Disposition
Corrosive Liquid, Acidic, Inorganic, N.O.S.	Bounded ^(a)	Pesticide, Liquid, Toxic, Flammable, N.O.S.	Bounded ^(a)
Corrosive Liquid, Acidic, Organic, N.O.S.	Bounded ^(a)	Petroleum Crude Oil	Low Vapor Pressure
Corrosive Liquid, Basic, Inorganic, N.O.S.	Bounded ^(a)	Petroleum Distillates, N.O.S.	Analyze (VCE)
Corrosive Liquid, Basic, Organic, N.O.S.	Bounded ^(a)	Petroleum Gases, Liquefied or Liquefied Petroleum Gas	Analyze ^(b) (VCE, BLEVE)
Corrosive Liquids, Flammable, N.O.S.	Bounded ^(a)	Phenol, Molten	Analyze (VCE)
Corrosive Liquids, N.O.S.	Bounded ^(a)	Phosphoric Acid Solution	Non-Explosive
Corrosive Liquids, Toxic, N.O.S.	Bounded ^(a)	Potassium Hydroxide, Solution	Non-Explosive
Dichloromethane	Analyze (VCE, BLEVE)	Propane	Analyze (VCE, BLEVE)
Diesel Fuel	Analyze (VCE)	Propylene	Analyze (VCE, BLEVE)
Elevated Temperature Liquid, Flammable, N.O.S.	Bounded ^(a)	Propylene Tetramer	Low Vapor Pressure
Elevated Temperature Liquid, N.O.S.	Non-Explosive	Radioactive Material, Transported Under Special Arrangement	Non-Explosive
Engines, Internal Combustion	Non-Explosive	Radioactive Material, Type B(U) Package	Non-Explosive
Environmentally Hazardous Substances, Liquid, N.O.S.	Bounded ^(a)	Resin Solution	Analyze (VCE)
Environmentally Hazardous Substances, Solid, N.O.S.	Bounded ^(a)	Rocket Motors	Non-Explosive
Ethanol	Analyze (VCE)	Sodium	Analyze (VCE; contact w/ water forms Hydrogen)
Ethanol and Gasoline Mixture	Analyzed as Ethanol / Gasoline	Sodium Borohydride and Sodium Hydroxide, Solution	Non-Explosive
Ethanolamine	Low Vapor Pressure	Sodium Chlorate	Non-Explosive
Ethylene Glycol Diethyl Ether	Analyze (VCE)	Sodium Hydroxide Solution	Non-Explosive
FAK-Hazardous Materials	Bounded ^(a)	Styrene Monomer, Stabilized	Analyze (VCE)
Ferric Chloride, Solution	Non-Explosive	Sulfur Dioxide	Non-Explosive
Ferrous Chloride, Solution	Non-Explosive	Sulfur, Molten	Non-Explosive
Fire Extinguishers	Non-Explosive	Sulfuric Acid	Non-Explosive
Flammable Liquids, N.O.S.	Bounded ^(a)	Sulfuric Acid, Spent	Non-Explosive
Flammable Liquids, Toxic, N.O.S.	Bounded ^(a)	Tetrahydrofuran	Analyze (VCE)
Fluorosilicic Acid	Non-Explosive	Toluene	Analyze (VCE)
Fuel Oil	Low Vapor Pressure	Toluene Diisocyanate	Low Vapor Pressure
Fuel, Aviation, Turbine Engine	Analyzed as Gasoline	Vinyl Acetate, Stabilized	Analyze (VCE)
Gas Oil	Low Vapor Pressure	Xylenes	Analyze (VCE)
Gasoline	Analyze (VCE)		

Notes:

- Unless specified otherwise, because generic N.O.S. (not otherwise specified) and FAK (freight all kinds) materials are not explicitly stated, they are considered to be bounded by more hazardous/explosive materials that are analyzed.
- Liquefied petroleum gas is analyzed as propane for BLEVE & travelling VCE.

The only analyzed chemical transported on the Portland & Western Railroad (PNWR) near the Trojan ISFSI site is ethanol shipments for the Global Partners Port Westward industrial park located in Clatskanie, OR (Input 4.6.4). The ethanol shipments are analyzed for both stationary and travelling vapor cloud explosions.

Railcar commodity shipment weights are not provided. Therefore, the BNSF (4-axle) railcar gross weight restriction of 286,000 lb_m is used (Input 4.6.3). This is conservative as maximum cargo capacity is much less than the gross railcar weight.

7.2 Vessel Chemicals

Data from the U.S. Army Corps of Engineers (USACE) [Ref. 2.46] is used to determine the commodities that are transported on the Columbia River (Input 4.7.2). Most of these commodities are non-explosive and screen away immediately. See Input 4.8 for non-explosive commodities that are not intuitive by name such as fruit and steel. Other commodities like kerosene and crude oil have low vapor pressures (< 10 mmHg) and screen away (see Input 4.9 and Assumption 5.5). Table 7.2-1 shows the complete list of commodities and the first disposition of each of them.

Table 7.2-1: Commodities Transported by Vessel near the Trojan ISFSI Site

Commodity ^(a)	Disposition	Commodity ^(a)	Disposition
Acyclic Hydrocarbons	Analyze	Marine Shells	Non-Explosive
Aircraft & Parts	Non-Explosive	Meat, Fresh, Frozen	Non-Explosive
Alcoholic Beverages	Non-Explosive	Meat, Prepared	Non-Explosive
Alcohols	Analyze	Medicines	Non-Explosive
Aluminum	Non-Explosive	Metallic Salts	Non-Explosive
Aluminum Ore	Non-Explosive	Misc. Mineral Prod.	Non-Explosive
Ammonia	Analyze	Molasses	Non-Explosive
Animal Feed, Prep.	Non-Explosive	Naphtha & Solvents	Analyze
Animals & Prod. NEC	Non-Explosive	Natural Fibers NEC	Non-Explosive
Asphalt, Tar & Pitch	Low Vapor Press.	Newsprint	Non-Explosive
Bananas & Plantains	Non-Explosive	Nitrogen Func. Comp.	Analyze
Barley & Rye	Non-Explosive	Nitrogenous Fert.	Analyze
Benzene & Toluene	Analyze	Non-Ferrous Ores NEC	Non-Explosive
Building Stone	Non-Explosive	Non-Ferrous Scrap	Non-Explosive
Carboxylic Acids	Analyze	Non-Metal. Min. NEC	Non-Explosive
Cement & Concrete	Non-Explosive	Oats	Non-Explosive
Chem. Products NEC	Analyze	Oilseeds NEC	Non-Explosive
Chemical Additives ^(b)	Low Vapor Press.	Ordnance & Access.	Analyze
Clay & Refrac. Mat.	Non-Explosive	Organic Comp. NEC	Analyze
Coal & Lignite	Non-Explosive	Organo – Inorg. Comp.	Analyze
Coal Coke	Non-Explosive	Other Hydrocarbons	Analyze
Cocoa Beans	Non-Explosive	Paper & Paperboard	Non-Explosive
Coffee	Non-Explosive	Paper Products NEC	Non-Explosive
Coloring Mat. NEC	Non-Explosive	Peanuts	Non-Explosive
Copper	Non-Explosive	Perfumes & Cleansers	Non-Explosive
Copper Ore	Non-Explosive	Pesticides	Non-Explosive
Corn	Non-Explosive	Petro. Jelly & Waxes	Low Vapor Press.
Cotton	Non-Explosive	Petro. Products NEC	Analyze
Crude Petroleum	Low Vapor Press.	Petroleum Coke	Analyze

Commodity ^(a)	Disposition	Commodity ^(a)	Disposition
Dairy Products	Non-Explosive	Pig Iron	Non-Explosive
Distillate Fuel Oil	Low Vapor Press.	Pigments & Paints	Non-Explosive
Electrical Machinery	Non-Explosive	Plastics	Non-Explosive
Explosives	Analyze	Potassic Fert. (Potash)	Non-Explosive
Fab. Metal Products	Non-Explosive	Primary I&S NEC	Non-Explosive
Farm Products NEC	Non-Explosive	Primary Wood Prod.	Non-Explosive
Ferro Alloys	Non-Explosive	Pulp & Waste Paper	Non-Explosive
Fert. & Mixes NEC	Analyze	Radioactive Material	Non-Explosive
Fish (Not Shellfish)	Non-Explosive	Residual Fuel Oil	Low Vapor Press.
Fish, Prepared	Non-Explosive	Rice	Non-Explosive
Flaxseed	Non-Explosive	Rubber & Gums	Non-Explosive
Food Products NEC	Non-Explosive	Rubber & Plastic Pr.	Non-Explosive
Forest Products NEC	Non-Explosive	Sand & Gravel	Non-Explosive
Fruit & Nuts NEC	Non-Explosive	Shellfish	Non-Explosive
Fruit Juices	Non-Explosive	Ships & Boats	Non-Explosive
Fuel Wood	Non-Explosive	Slag	Non-Explosive
Gasoline	Analyze	Smelted Prod. NEC	Non-Explosive
Glass & Glass Prod.	Non-Explosive	Sodium Hydroxide	Non-Explosive
Grain Mill Products	Non-Explosive	Soil & Fill Dirt	Non-Explosive
Groceries	Non-Explosive	Sorghum Grains	Non-Explosive
Gypsum	Non-Explosive	Soybeans	Non-Explosive
Hay & Fodder	Non-Explosive	Starches, Gluten, Glue	Non-Explosive
I&S Bars & Shapes	Non-Explosive	Sugar	Non-Explosive
I&S Pipe & Tube	Non-Explosive	Sulfur, Dry	Analyze
I&S Plates & Sheets	Non-Explosive	Sulfuric Acid	Non-Explosive
I&S Primary Forms	Non-Explosive	Tallow, Animal Oils	Non-Explosive
Inorg. Elem., Oxides, & Halogen Salts	Non-Explosive	Textile Products	Non-Explosive
Inorganic Chem. NEC	Analyze	Tobacco & Products	Non-Explosive
Iron & Steel Scrap	Non-Explosive	Unknown or NEC	Ignored ^(c)
Iron Ore	Non-Explosive	Vegetable Oils	Non-Explosive
Kerosene	Low Vapor Press.	Vegetables & Prod.	Non-Explosive
Lime	Non-Explosive	Vehicles & Parts	Non-Explosive
Limestone	Non-Explosive	Waste & Scrap NEC	Non-Explosive
Liquid Natural Gas	Analyze	Water & Ice	Non-Explosive
Lube Oil & Greases	Low Vapor Press.	Wheat	Non-Explosive
Lumber	Non-Explosive	Wheat Flour	Non-Explosive
Machinery (Not Elec)	Non-Explosive	Wood & Resin Chem.	Non-Explosive
Manganese Ore	Non-Explosive	Wood Chips	Non-Explosive
Manufac. Prod. NEC	Non-Explosive	Wood in the Rough	Non-Explosive
Manufac. Wood Prod.	Non-Explosive		

Notes:

- NEC is a shipping abbreviation for "not elsewhere classified."
- "Chemical Additives" is identified in the USACE User's Guide [Ref. 2.47] as oils, lubricants, antifreeze, or transmission fluid. All have low vapor pressures (< 10 mmHg) per Input 4.9 and Assumption 5.5.
- "Unknown or NEC" is too broad to analyze and likely non-hazardous.

The commodities to be analyzed are shown in Table 7.2-2. In addition, Table 7.2-2 shows what chemical will be analyzed for each commodity and what type of explosion must be analyzed. The chemicals used are taken from the USACE Navigation Data Center User's Guide [Ref. 2.47].

Table 7.2-2: Commodities to be Analyzed

Commodity	Chemical Used in the Analysis*	Types of Hazards
Acyclic Hydrocarbons	Analyzed as propane (propane has a lower LEL than ethylene and similar LEL to propene).*	VCE, BLEVE (Propane)
Alcohols	Analyzed as methanol and ethanol. Methanol has the lowest boiling temperature between methanol, ethanol, propanol, and butanol, thus a higher evaporation rate; ethanol has a lower LEL (Input 4.3). Pressurization not required for liquefaction; therefore, BLEVE not postulated.	VCE (Methanol / Ethanol)
Ammonia	Analyzed.	VCE, BLEVE
Benzene & Toluene	Analyzed as benzene – lower boiling temperature and similar LEL (Input 4.3). Pressurization not required for liquefaction; therefore, BLEVE not postulated.	VCE (Benzene)
Carboxylic Acids	Analyzed as acetic acid – a liquid, whereas benzoic acid is solid; has a much lower LEL than formic acid (Input 4.3). Pressurization not required for liquefaction; therefore, BLEVE not postulated.	VCE (Acetic Acid)
Chem. Products NEC	All chemical products identified in the USACE User's Guide [Ref. 2.47] are waxes, alkylbenzenes, solids, or chemical products and preparations. All are bounded by ammonia.	VCE, BLEVE (Ammonia)
Explosives	Analyze (stationary explosion only).	Stat. Expl. Only
Fert. & Mixes NEC	Analyzed as ammonium nitrate (all identified chemicals are solids, ammonium nitrate bounds stationary explosion).	Stat. Expl. Only (Ammonium Nitrate)
Gasoline	Analyzed. Pressurization not required for liquefaction; therefore, BLEVE not postulated.	VCE
Inorganic Chem. NEC	Analyzed as ammonium nitrate (ammonium nitrate bounds for stationary explosion).	Stat. Expl. Only (Ammonium Nitrate)
Liquid Natural Gas	Corresponds to liquefied natural gas (LNG) per the USACE User's Guide [Ref. 2.47]. Methane is used.	VCE, BLEVE (Methane)
Naphtha & Solvents	Analyze as naphtha. Pressurization not required for liquefaction; therefore, BLEVE not postulated.	VCE (Naphtha)
Nitrogen Func. Comp.	Analyzed as ammonia for VCE and ammonium nitrate for stationary explosion.	VCE, BLEVE (Ammonia), Stat. Expl. Only (Ammonium Nitrate)
Nitrogenous Fert.	Analyzed as ammonium nitrate (all identified chemicals in [Ref. 2.47] are solids, ammonium nitrate bounds stationary explosion).	Stat. Expl. Only (Ammonium Nitrate)
Ordinance & Access.	Analyzed (stationary explosion only).	Stat. Expl. Only
Organic Comp. NEC	Analyzed as acetone – Has a high vapor pressure [Ref. 2.13] and a low LEL (Input 4.3). Pressurization not required for liquefaction; therefore, BLEVE not postulated.	VCE (Acetone)
Organo – Inorg. Comp.	Analyzed as propane.*	VCE, BLEVE (Propane)
Other Hydrocarbons	Analyzed as vinyl chloride. Per the USACE User's Guide [Ref. 2.47], other hydrocarbons include: cyclohexane, xylenes, styrene, ethylbenzene, cumene, and trichloroethylene. Vinyl chloride is the only one that is a gas at atmospheric conditions.	VCE, BLEVE (Vinyl Chloride)
Petro. Products NEC	Analyzed as propane.*	VCE, BLEVE (Propane)
Petroleum Coke	Analyzed as combustible dust (stationary explosion only).	Stat. Expl. Only (Dust)

Commodity	Chemical Used in the Analysis*	Types of Hazards
Sulfur, Dry	Analyzed as combustible dust (stationary explosion only).	Stat. Expl. Only (Dust)

*Propane is selected as the most explosive chemical vapor shipped. Propane has a lower LEL than methane, ethane and ethylene (Input 4.3). In addition, propane is heavier than air (unlike methane), so the benefits of plume rise cannot be credited.

Table 7.2-3 summarizes the chemicals and types of explosions that are analyzed for the commodities listed in Table 7.2-2 to disposition all hazards transported by vessel near the site.

Table 7.2-3: Chemicals to be Analyzed and their Associated Commodities

Chemical	Commodities Analyzed for Stationary Explosions Only	Commodities Analyzed for Stationary and Traveling Vapor Cloud Explosions (VCE)	Commodities Analyzed for Boiling Liquid Expanding Vapor Explosions (BLEVE)
Acetic Acid	-	Carboxylic Acid	-
Acetone	-	Organic Comp. NEC	-
Ammonia	-	Ammonia; Chem. Products NEC; Nitrogen Func. Comp.	Ammonia; Chem. Products NEC; Nitrogen Func. Comp.
Ammonium Nitrate	Fert. & Mixes NEC; Inorganic Chem. NEC; Nitrogen Func. Comp.; Nitrogenous Fert.	-	-
Benzene	-	Benzene & Toluene	-
Explosives	Explosives; Ordinance & Access.	-	-
Gasoline	-	Gasoline	-
Methane	-	Liquid Natural Gas	Liquid Natural Gas
Methanol / Ethanol	-	Alcohols	-
Naphtha	-	Naphtha & Solvents	-
Petroleum Coke	Petroleum Coke (Dust)	-	-
Propane	-	Acyclic Hydrocarbons; Organo - Inorg. Comp.; Petro. Products NEC	Acyclic Hydrocarbons; Organo - Inorg. Comp.; Petro. Products NEC
Sulfur	Sulfur, Dry (Dust)	-	-
Vinyl Chloride	-	Other Hydrocarbons	Other Hydrocarbons

7.3 Spill Size Probability

Data from the U.S. Coast Guard and the Office of Hazardous Materials Safety are used to determine the probability of sizes of spills.

The Office of Hazardous Materials Safety [Ref. 2.50] has an online searchable database of reported vessel accidents in and near the waterways of the United States. In the database, the only criteria that are placed on the search are: the incident occurred between 2007 and 2016, the incident occurred on a waterway, and the incident occurred during transit (as opposed to loading or unloading). The results of this search are shown in Attachment F. A total of 436 incidents are reported. Several of the incidents do not have an associated quantity spilled; however, the largest spill release size in the database is 5,500 gallons. The

MISLE database (see below) has many more incidents and many more large incidents. Therefore the MISLE database is used for the rate of spill sizes. The Office of Hazardous Materials Safety data is consistent with the MISLE data, as both show that over 90% of the releases are less than 100 gallons.

The U.S. Coast Guard Office of Marine Safety and Environmental Protection (USCG-MSEP) maintains a database of marine accidents in its Marine Information for Safety and Law Enforcement (MISLE) information system. The subset of the MISLE, Marine Casualty and Pollution Database [Ref. 2.49], contains data describing all investigations involving commercial vessels operating in U.S. territorial waters, or U.S.-registered commercial vessels operating elsewhere in the world that meet certain criteria. Accident investigations documented in MISLE are initiated for events resulting in any one of the following [Ref. 2.52, p.10]:

- (a) One or more deaths;
- (b) One or more injuries resulting in substantial impairment of any body part or function;
- (c) A fire causing property damage exceeding \$25,000;
- (d) An oil spill exceeding 200 barrels;
- (e) Other injuries, casualties, accidents, complaints of unsafe working conditions, fires, pollution, and incidents that are deemed necessary to promote the safety of life or property or protect the marine environment.

A commercial vessel's owner, agent, master, operator, or person in charge, is responsible for notifying the Coast Guard when the vessel is involved in a reportable accident or incident. Computerized data, entered by Coast Guard staff, are reviewed by front-line supervisors and then transmitted to the USCG-MSEP for inclusion in the MISLE database.

The data is provided as a set of text files. To analyze and use these files, a database is setup using Microsoft Access [Ref. 2.39] which allows the MISLE data to be queried by the type of vessel, waterway, tonnage and other fields. Two of the text files (MisleVslPoll.txt and MisleVslEvents.txt) are combined in Access to determine the characteristics of the spill. The Access file query links the incident numbers in these two text files (the Access file is MISLEVessel.mdb in the electronic attachments). This query is reduced in the following ways:

1. Date Range: The most current ten years of data is used: July 2005 to July 2015. The end of the date range takes into account that the database only uses closed case files.
2. One Spill per Vessel: For vessels carrying multiple chemicals, only the largest spill volume is used. This is for two reasons. First, a larger spill is bounding. Second, because this is used in a probability analysis, the data of interest is the number of vessel trips that could be hazardous: a single vessel can only lead to one hazardous condition at the site.

The resultant table is shown in Attachment E. With the narrowed database, there are 14,954 reported incidents. Of these, 14,187 incidents had a reported spill size associated with them. The 14,187 reported spills are used to determine a probability of a given spill size given a spill. Note the 207 million gallon oil spill from the Deepwater Horizon event on April 20, 2010 is not considered in this analysis because the mobile

offshore drilling unit was stationed in the Gulf of Mexico at the time of the accident, not being transported on any waterways, and the primary source of the spill was the well, not cargo on board. Table 7.3-1 shows the probability broken down by spill size. In addition, Table 7.3-1 shows the rate of spills per vessel mile by multiplying the probability of a given size spill by the rate of vessel accidents from NUREG/CR-6624 [Ref. 2.8, p.9], 1.8×10^{-6} accidents per mile. This multiplication uses the conservative methodology that any accident that qualifies for NUREG/CR-6624 would result in a spill that is reported to the MISLE database. NUREG/CR-6624 has an additional multiplier of 0.025 (2.5%) that is the conditional spill probability given an incident. Based on Table 7.3-1, a spill of 1,000 gallons or larger occurs 1.13% of the time. It is therefore reasonable to use the probabilities in Table 7.3-1 as the rate of spill size per accident of a vessel.

Table 7.3-1: Breakdown of Spill Sizes

Spill Size	Occurrences	Probability	Spills per Vessel Mile*
0 to 100 Gallons	13,432	0.9467	1.70E-06
>100 to 1,000 Gallons	595	0.0419	7.55E-08
>1,000 to 2,000 Gallons	54	0.0038	6.85E-09
>2,000 to 10,000 Gallons	77	0.0054	9.77E-09
>10,000 to 50,000 Gallons	21	0.0015	2.66E-09
>50,000 to 287,000 Gallons	7	0.0005	8.88E-10
>287,000 Gallons	1	0.0001	1.27E-10
Total	14,187	1.0000	1.80E-06

*Note: NUREG/CR-6624 states that barge incidents occur at a rate of 1.8×10^{-6} incidents per barge mile. The probability for each spill size is used to determine the rate of spills per vessel mile. For example, the probability of a spill of 0 to 100 gallons is 1.70×10^{-6} spills per vessel mile ($= 1.8 \times 10^{-6} \cdot 0.9467$). Also, note that the Spills per Vessel Mile column is based on the calculated probability values, as opposed to the rounded values reported in the Probability column.

Furthermore, of the 14,954 reported incidents of chemical spills for vessels in the MISLE database between July 2005 and July 2015, there are 15 explosions of any type (0.1%) [Ref. 2.49]. Based on this data, it is conservatively analyzed that 0.5% of incidents involving vessels containing explosive chemicals will lead to an explosion.

7.4 Number of Trips

USACE provides the total number of vessel trips in a year and the yearly mass shipped for each commodity (Input 4.7.2). However, a specific commodity's yearly number of trips or mass per trip is unknown. Thus, yearly shipment quantities in terms of mass are assumed to be evenly distributed volumetrically throughout the total number of trips in a year. That is, the ratio of a specific commodity's number of trips per year to the total number of trips in a year is assumed to be directly proportional to the ratio of a specific commodity's annual shipment volume to the total annual shipment volume (Assumption 5.6). This is restated in the following equation:

$$\frac{n_c}{n_t} = \frac{V_c}{V_t} \Rightarrow \frac{n_c}{n_t} = \frac{m_c / \rho_c}{m_t / \rho_{t,avg}} \Rightarrow n_c = \frac{n_t m_c \rho_{t,avg}}{m_t \rho_c} \quad \text{Eq. 7.4-1}$$

Where:

- n_c = number of vessel trips per year for the specific commodity (-)
 n_t = total number of all vessel trips in a year (-) [Ref. 2.46]
 V_c = m_c / ρ_c = volume of the specific commodity shipped in a year (ft³)
 V_t = $m_t / \rho_{t,avg}$ = total volume of all commodities shipped in a year (ft³)
 m_c = mass of the specific commodity shipped in a year (lb_m) [Ref. 2.46]
 m_t = total mass of all commodities shipped in a year (lb_m) [Ref. 2.46]
 ρ_c = density of the specific commodity (lb_m/ft³) (Input 4.3)
 $\rho_{t,avg}$ = weighted-average density of all commodities shipped in a year (lb_m/ft³) (see below)

The ten most recent years (2006-2015) of data from the USACE [Ref. 2.46] (Input 4.7.2) are reviewed to determine a conservative estimate for the number of trips for each commodity listed in Table 7.2-3. Data is pulled for the "COLUMBIA RIVER SYSTEM," which includes all main channels and navigable tributaries of the Columbia, Willamette and Snake Rivers. This is conservative as not all traffic on the river system passes by the Trojan ISFSI site. Data extracted from the USACE reports for 2006-2015 is summarized in Appendix 2.

For probability analyses, the parameters in Eq. 7.4-1 are conservatively biased using appropriate "worst year" data to maximize the calculated number of trips in a year. For the deterministic analyses, the parameters in Eq. 7.4-1 are biased to minimize the number of trips, thus, maximizing the mass per vessel – calculated by dividing the maximum mass of a commodity shipped in a year by the minimum annual number of vessel trips of the commodity ($= m_{c,max}/n_{c,min}$).

To maximize the calculated number of trips, the weighted-average density of all commodities shipped in a year, $\rho_{t,avg}$, is biased high. The following product densities (Input 4.10) are used for the various commodity groupings identified in USACE [Ref. 2.46] as being shipped on the Columbia River. Refer to USACE [Ref. 2.46] for the complete list of commodities within each grouping.

Table 7.4-1: Commodity Densities

Grp.	Name	Substance	Specific Gravity
20	Petroleum and Petroleum Products	Petroleum	0.87
31	Fertilizers	Potassic Fert. (Potash)	2.00
32	Other Chemicals and Related Products	Plastics	2.50
41	Forest Products, Wood and Chips	Oak, live	0.87
42	Pulp and Waste Paper	Paper	1.15
43	Soil, Sand, Gravel, Rock and Stone	Gypsum, alabaster	2.80
44	Iron Ore and Scrap	Steel, cold-drawn	7.83
46	Non-Ferrous Ores and Scrap	Lead	11.34
47	Sulphur, Clay and Salt	Clay, damp, plastic	1.76
48	Slag	Iron slag	3.00
49	Other Non-Metal. Min.	Barytes	4.50
51	Paper Products	Paper	1.15

Grp.	Name	Substance	Specific Gravity
52	Lime, Cement and Glass	Portland cement	3.20
53	Primary Iron and Steel Products	Steel, cold-drawn	7.83
54	Primary Non-Ferrous Metal Products	Lead	11.34
55	Primary Wood Products	Oak, live	0.87
60	Total Food and Farm Products	Fats	0.97
70	Manufactured Equip., Mach. and Products	Lead	11.34
80	Waste and Scrap NEC	Lead	11.34
90	Unknown or NEC	Lead	11.34

Using the densities listed above, the maximum average density of annual shipments, $(\rho_{t,avg})_{max}$, is found in Appendix 2 to be 137 lb_m/ft³ in 2008.

The calculated annual number of vessel trips and mass per vessel for each explosive hazard is shown below in Table 7.4-2. Also shown is the maximum annual mass shipped for each chemical, $m_{c,max}$. Note that when biasing low the total mass of all commodities shipped in a year, $m_{t,min}$ is specified as the lesser between the m_t associated with the year from which $m_{c,max}$ is taken (varies for each chemical) and $m_t = 53,009,000$ tons in 2006, the year from which $n_{t,max}$ is taken. Conversely, $m_{t,max}$ biased high is specified as the greater between the m_t associated with the year from which $m_{c,min}$ is taken (varies for each chemical) and $m_t = 57,267,000$ tons in 2012, the year from which $n_{t,min}$ is taken. Furthermore, when calculating $n_{c,min}$ in determining mass per vessel, the density terms in Eq. 7.4-1 are conservatively ignored. These calculations are performed in Excel and are electronically attached as VesselAnalyses.xlsx.

Table 7.4-2: USACE Data (2006-2015) – Annual Vessel Trips and Mass per Vessel

Chemical	Maximum Total Mass of Chemical Shipped per Year, $m_{c,max}$ (tons)	Annual Number of Trips, $n_{c,max}$ (-) [Eq. 7.4-1]	Mass per Vessel (tons/trip) [$= m_{c,max}/n_{c,min}$]
Acetic Acid (Carboxylic Acid)	12,000	48	4,000
Acetone	8,000	43	8,000
Ammonia	118,000	849	3,688
Ammonium Nitrate	530,000	1,285	3,897
Benzene	100,000	476	2,778
Explosives	3,000	10	3,000
Gasoline	4,181,000	1,671*	6,744*
Methane	9,000	96	9,000
Methanol/Ethanol (Alcohols)	302,000	1,599	11,615
Naphtha	21,000	140	10,500
Petroleum Coke	993,000	5,933	2,573
Propane	2,000	21	2,000
Sulfur	2,000	5	1,000
Vinyl Chloride	9,000	42	9,000

*Note: To account for gasoline shipping in larger bulk quantities than other commodities, Eq. 7.4-1 is not used to calculate number of trips. Per EPA Publication No. 903R83004 [Ref. 2.48, p.2], gasoline barges range in capacity from 420,000 gallons to 2,100,000 gallons and the average capacity is 840,000 gallons (2,503 tons using the specific gravity for gasoline of 0.72 per Input 4.3). Dividing the annual mass shipped,

4,181,000 tons, by this average capacity equates to 1,671 trips per year. For the deterministic analysis, the maximum value of 2,100,000 gallons (6,744 tons, using a density of $0.77 \cdot 62.4 \text{ lb}_m/\text{ft}^3$ per Input 4.3) per vessel is used.

The Coast Guard MISLE database [Ref. 2.49] is used to determine the size of spills. The largest spill reported in the MISLE data is 1,826,626 gallons (as stated in Section 7.3, the Deepwater Horizon oil spill on April 20, 2010 is not considered in this evaluation). A spill of 2,000,000 gallons is used as the maximum spill size in this analysis. This mass (2,000,000 gallons equates to approximately 3,000 to 9,000 tons for specific gravities ranging from 0.35 to 1.05) is on the same order of magnitude as the vessel sizes from the USACE data in Table 7.4-2.

8.0 Results

8.1 Railway Transportation

8.1.1 Solid Explosive and Stationary Vapor Cloud Explosions on Railcar

Blast wave pressures from solid explosives and vapor cloud explosions on BNSF and PNWR railcars are calculated in Appendix 3 using the TNT equivalence method documented in NUREG-1805 and SFPE Fire Protection Handbook. The results are summarized below in Table 8.1-1. Each of the hazards result in a blast wave pressure at the Trojan ISFSI site of less than 1.0 psig.

Table 8.1-1: Results of Stationary Explosion on Railcar

Chemical	Railway Details	Blast Wave Pressure (psig)
1,1-Difluoroethane	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
1-Methoxy-2-Propanol	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Acetaldehyde	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Acetic Acid, Glacial	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Acetone	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Ammonia, Anhydrous	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Ammonium Nitrate	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Ammonium Nitrate Based Fertilizer	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Benzene	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Butane	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Butanols	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Butyl Acrylates, Stabilized	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Butylene	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Butyraldehyde	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Carbon Disulfide	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3

Chemical	Railway Details	Blast Wave Pressure (psig)
Dichloromethane	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Diesel Fuel	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Ethanol	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Ethanol	286,000 lb on PNWR 745 ft from Site	0.5
Ethylene Glycol Diethyl Ether	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Gasoline	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Heptanes	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Hydrocarbons, Liquid, N.O.S. (Vinyl Chloride)	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Isobutane	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Isobutylene	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Isoprene, Stabilized	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Isopropanol	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Isopropyl Acetate	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Lithium Battery	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Methanol	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Methyl Chloride	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
N-Propanol	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Octanes	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Pentanes	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Petroleum Distillates, N.O.S.	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Liquefied Petroleum Gas	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3

Chemical	Railway Details	Blast Wave Pressure (psig)
Phenol, Molten	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Propane	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Propylene	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Resin Solution	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Sodium (contact with water produces Hydrogen)	286,000 lb on BNSF 5,760 ft from Site	$\ll 0.1$
Styrene Monomer, Stabilized	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Tetrahydrofuran	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Toluene	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Vinyl Acetate, Stabilized	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3
Xylenes	286,000 lb on BNSF 5,760 ft from Site	≤ 0.3

8.1.2 Boiling Liquid Expanding Vapor Explosions on Railcar

Blast wave pressures from a BLEVE on a BNSF railcar are calculated in Appendix 3 using guidance from the SFPE Fire Protection Handbook. The ethanol shipment on PNWR is not a BLEVE hazard (i.e., does not have a low boiling point). Results are summarized below in Table 8.1-2. Each of the BLEVE hazards result in a blast wave pressure at the Trojan ISFSI site of less than 0.1 psig.

Table 8.1-2: Results of BLEVE on Railcar

Chemical	Boiling Point	Vapor Density at NTP (lb _m /ft ³)	Blast Wave Pressure (psig)	Note
1,1-Difluoroethane	52°F	0.171	< 0.1	
Acetaldehyde	69°F	0.115	< 0.1	(a)
Ammonia, Anhydrous	-28°F	0.044	< 0.1	
Butane	31°F	0.151	< 0.1	
Butylene	20°F	0.146	< 0.1	(a)
Dichloromethane	104°F	0.220	< 0.1	(b)
Hydrocarbons, Liquid, N.O.S. (Vinyl Chloride)	7°F	0.162	< 0.1	(a)
Isobutane	11°F	0.151	< 0.1	
Isobutylene	20°F	0.146	< 0.1	
Isoprene, Stabilized	93°F	0.177	< 0.1	(b)

Chemical	Boiling Point	Vapor Density at NTP (lb _m /ft ³)	Blast Wave Pressure (psig)	Note
Methyl Chloride	-12°F	0.131	< 0.1	(a)
Pentanes	97°F	0.187	< 0.1	
Propane	-44°F	0.115	< 0.1	
Propylene	-54°F	0.109	< 0.1	

Notes:

- Acetaldehyde, butylene, vinyl chloride (hydrocarbons, liquid, N.O.S.), and methyl chloride have both a boiling point and vapor density greater than or equal to that of propane; therefore, a BLEVE from these commodities is bounded by a BLEVE from propane.
- Dichloromethane and isoprene have both a boiling point and vapor density greater than that of butane; therefore, a BLEVE from these commodities is bounded by a BLEVE from butane.

8.1.3 Traveling Vapor Cloud Explosions from Railcar

The BNSF and PNWR vapor cloud explosions hazards are analyzed in Appendix 4 to determine that the concentration from a chemical release is less than the LEL at the Trojan ISFSI site using the dispersion analysis methods described in Regulatory Guide 1.78 and NUREG-0570. The results are summarized below in Table 8.1-3.

Table 8.1-3: Results of Travelling VCE from Railcar

Chemical	Boiling Point	LEL	Railway Details	Worst Peak Conc. at Site
1,1-Difluoroethane	52°F	3.7%	286,000 lb on BNSF 1.09 mi from Site	2.8%
1-Methoxy-2-Propanol	248°F	1.6%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Acetaldehyde	69°F	4.0%	286,000 lb on BNSF 1.09 mi from Site	1.0%
Acetic Acid, Glacial	244°F	4.0%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Acetone	133°F	2.5%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Ammonia, Anhydrous	-28°F	15.0%	286,000 lb on BNSF 1.09 mi from Site	6.7%
Benzene	176°F	1.2%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Butane	31°F	1.6%	286,000 lb on BNSF 1.09 mi from Site	<u>2.5%</u>
Butanols	243°F	1.4%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Butyl Acrylates, Stabilized	293°F	1.5%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Butylene	20°F	1.6%	286,000 lb on BNSF 1.09 mi from Site	<u>2.6%</u>

Chemical	Boiling Point	LEL	Railway Details	Worst Peak Conc. at Site
Butyraldehyde	167°F	1.4%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Carbon Disulfide	116°F	1.3%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Dichloromethane	104°F	13.0%	286,000 lb on BNSF 1.09 mi from Site	0.3%
Diesel Fuel	320°F	0.7%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Ethanol	173°F	3.3%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Ethanol	173°F	3.3%	286,000 lb on PNWR 0.14 mi from Site	2.9%
Ethylene Glycol Diethyl Ether	250°F	1.2%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Gasoline	107°F	1.4%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Heptanes	209°F	1.1%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Hydrocarbons, Liquid, N.O.S. (Vinyl Chloride)	7°F	3.6%	286,000 lb on BNSF 1.09 mi from Site	2.0%
Isobutane	11°F	1.6%	286,000 lb on BNSF 1.09 mi from Site	<u>3.2%</u>
Isobutylene	20°F	1.8%	286,000 lb on BNSF 1.09 mi from Site	<u>2.7%</u>
Isoprene, Stabilized	93°F	1.5%	286,000 lb on BNSF 1.09 mi from Site	0.6%
Isopropanol	181°F	2.0%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Isopropyl Acetate	194°F	1.8%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Methanol	147°F	6.0%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Methyl Chloride	-12°F	8.1%	286,000 lb on BNSF 1.09 mi from Site	2.7%
N-Propanol	207°F	2.2%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Octanes	258°F	1.0%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Pentanes	97°F	1.5%	286,000 lb on BNSF 1.09 mi from Site	0.6%
Petroleum Distillates, N.O.S.	107°F	1.1%	286,000 lb on BNSF 1.09 mi from Site	0.6%*

Chemical	Boiling Point	LEL	Railway Details	Worst Peak Conc. at Site
Phenol, Molten	359°F	1.8%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Propane	-44°F	2.1%	286,000 lb on BNSF 1.09 mi from Site	5.4%
Propylene	-54°F	2.0%	286,000 lb on BNSF 1.09 mi from Site	5.6%
Resin Solution	295°F	1.1%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Sodium (contact with water produces Hydrogen)	N/A	4.0%	286,000 lb on BNSF 1.09 mi from Site	0.03%
Styrene Monomer, Stabilized	293°F	0.9%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Tetrahydrofuran	151°F	2.0%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Toluene	232°F	1.1%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Vinyl Acetate, Stabilized	162°F	2.6%	286,000 lb on BNSF 1.09 mi from Site	0.6%*
Xylenes	281°F	0.9%	286,000 lb on BNSF 1.09 mi from Site	0.6%*

*Note: A fictional chemical release is analyzed to bound all chemicals on BNSF with a boiling point $\geq 107^\circ\text{F}$ by using a vapor pressure equal to 1 atm (14.7 psia) at 107°F , the minimum molecular weight in that of methanol, 32.1 (Input 4.3), and the minimum density in that of naphtha, SG = 0.63 (Input 4.3).

As shown in Table 8.1-3, each of the chemical releases result in a concentration less than the chemical LEL at the Trojan ISFSI site except for the BNSF shipments of butane, butylene, isobutene, isobutylene, propane and propylene.

BNSF railcar releases of butane, butylene, isobutene and isobutylene will not result in a concentration greater than the chemical LEL at the Trojan ISFSI site for Stability Classes A through E at any wind speed. For Stability Class F, these releases will result in a concentration greater than the chemical LEL at the Trojan site for wind speeds greater than 3.01 m/s. From Input 4.2, these conditions exist 0.24% of the time (irrespective of direction). Additionally, postulating that all wind speeds of Stability Class G (0.88% frequency) exceed the LEL, the combined frequency is 1.12% of the time. Thus, the BNSF shipments of butane, butylene, isobutene and isobutylene are acceptable per the guidance in Regulatory Guide 1.78 (see Section 6.3) because the weather conditions which lead to a hazard occur less than 5% of the time.

BNSF railcar releases of propane and propylene will not result in a concentration greater than the chemical LEL at the Trojan ISFSI site for Stability Classes A through E at any wind speed. For Stability Class F, these releases will result in a concentration greater than the chemical LEL at the Trojan site for wind speeds greater than 2.01 m/s. From

Input 4.2, these conditions exist 0.84% of the time (irrespective of direction). Additionally, postulating that all wind speeds of Stability Class G (0.88% frequency) exceed the LEL, the combined frequency is 1.72% of the time. Thus, the BNSF shipments of propane and propylene are acceptable per the guidance in Regulatory Guide 1.78 (see Section 6.3) because the weather conditions which lead to a hazard occur less than 5% of the time.

8.2 Waterborne Transportation

8.2.1 Solid Explosive and Stationary Vapor Cloud Explosions on Vessel

Blast wave pressures from solid explosives and vapor cloud explosions on vessels traversing the Columbia River, 957 ft from the Trojan ISFSI site at its nearest approach, are calculated in Appendix 5 using the TNT equivalence and combustible dust methods documented in NUREG-1805 and SFPE Fire Protection Handbook. The results are summarized below in Table 8.2-1. Also reproduced from Table 7.4-2 is each chemical's number of trips and mass shipped per vessel. Aside from the dust explosions of petroleum coke and sulfur, each chemical hazard can result in a blast wave pressure greater than 2.2 psig or greater than 1.0 psig. Therefore, a probabilistic analysis is required to demonstrate that the frequency of a hazardous explosion is less than 10^{-6} hazards per year as defined by Regulatory Guide 1.91 and NUREG-0800. The calculated chemical hazard frequency is also tabulated below. See the discussion below Table 8.2-1 for details of the probability calculations. With exception of the solid explosives, these stationary explosion hazards additionally require probabilistic analysis for traveling VCE (see Section 8.2.3); therefore, the stationary hazard frequency must be combined with the traveling VCE hazard frequency to determine the overall allowable number of trips. This calculation is performed in Section 8.2.4.

Table 8.2-1: Results of Stationary Explosion on Vessel

Chemical	Annual Number of Trips	Mass per Vessel (tons/trip)	Blast Wave Pressure (psig)	Hazard Frequency (explosions/trip)
Acetic Acid (Carboxylic Acid)	48	4,000	> 1	1.33E-10
Acetone	43	8,000	> 2.2	1.33E-10
Ammonia	849	3,688	>> 2.2	3.85E-10
Ammonium Nitrate	1,285	3,897	>> 2.2	6.14E-10 (1,628 allowable trips)
Benzene	476	2,778	> 1	1.33E-10
Ethanol (Alcohols)	1,599	11,615	> 2.2	1.33E-10
Explosives	10	3,000	>> 2.2	8.93E-10 (1,120 allowable trips)
Gasoline	1,671	6,744	> 2.2	1.33E-10
Methane	96	9,000	>> 2.2	6.14E-10
Methanol (Alcohols)	1,599	11,615	> 2.2	1.33E-10
Naphtha	140	10,500	> 2.2	1.33E-10

Chemical	Annual Number of Trips	Mass per Vessel (tons/trip)	Blast Wave Pressure (psig)	Hazard Frequency (explosions/trip)
Petroleum Coke	5,933	2,573	< 1.0	-
Propane	21	2,000	>> 2.2	6.14E-10
Sulfur	5	1,000	< 0.1	-
Vinyl Chloride	42	9,000	>> 2.2	6.14E-10

A 1.0 psig overpressure is used in the probabilistic analysis (per Regulatory Guide 1.91, when overpressure at the target is less than or equal to 1.0 psig, the blast generated missile effects and ground motions are considered acceptable). The probability calculations are performed in Appendix 5. The following is the analysis summary for ammonium nitrate: The standoff distance for 1.0 psig overpressure from an explosion of 3,897 tons of ammonium nitrate is 1.27 miles. Using the probabilities established in NUREG/ CR-6624 [Ref. 2.8] and determined from the MISLE database [Ref. 2.49], the hazard frequency for ammonium nitrate is calculated as follows:

Incidents per Mile	1.8×10^{-6}	[Ref. 2.8] See Section 7.3
Spills per Incident	0.025	[Ref. 2.8] See Section 7.3
Explosions per Spill	0.005	[Ref. 2.49] See Section 7.3
Miles per Shipment	< 2.73 mi	Waterway length within 1.27 mi of site (Input 4.7.1)
Explosions per Trip	6.14×10^{-10}	Product

Dividing this frequency by 10^{-6} hazards per year, the number of allowable trips for ammonium nitrate is 1,628 trips per year. As shown in Table 8.2-1, the annual number of trips for ammonium nitrate is less than 1,628; therefore, meeting the probabilistic acceptance criteria.

8.2.2 Boiling Liquid Expanding Vapor Explosions on Vessel

Blast wave pressures from a BLEVE on vessels traversing the Columbia River are calculated in Appendix 5 using guidance from the SFPE Fire Protection Handbook. Results are summarized below in Table 8.2-2. Also reproduced from Table 7.4-2 is each chemical's mass shipped per vessel.

Table 8.2-2: Results of BLEVE on Vessel

Chemical	Mass per Vessel (tons/trip)	Blast Wave Pressure (psig)
Ammonia	3,688	≈ 3.5
Methane	9,000	> 2.2
Propane	2,000	> 2.2
Vinyl Chloride	9,000	≈ 5.0

As shown in Table 8.2-2, each of the BLEVE hazards result in a blast wave pressure at the Trojan ISFSI that exceeds 2.2 psig. Similar to the vessel stationary explosions in Section 8.2.1, a BLEVE probabilistic analysis is performed in Appendix 5 for 1.0 psig overpressure. For each BLEVE hazard, the standoff distance for 1.0 psig overpressure is

calculated to be less than 0.5 miles. The waterway length within 0.5 miles of the ISFSI site is 0.87 miles. Using this length in the same probability calculation shown in Section 8.2.1, the hazard frequency for each BLEVE hazard is 1.96×10^{-10} . These stationary explosion hazards also require probabilistic analysis for traveling VCE (see Section 8.2.3); therefore, the stationary hazard frequency must be combined with the traveling VCE hazard frequency to determine the overall allowable number of trips. This calculation is performed in Section 8.2.4.

8.2.3 Traveling Vapor Cloud Explosions from Vessel

Traveling vapor cloud explosion hazards shipped on the Columbia River are analyzed in Appendix 6 using the dispersion analysis methods described in Regulatory Guide 1.78 and NUREG-0570. Each chemical release can result in a concentration greater than the chemical LEL at the ISFSI site. Therefore, a probabilistic analysis is required to demonstrate that the frequency of a hazardous release is less than 10^{-6} hazards per year.

The traveling vapor cloud hazard frequency is determined for each chemical using spill size probability from NUREG/CR-6624 and MISLE data, joint wind speed-wind direction-stability class data and waterway route lengths. In some cases, it is necessary to refine the analysis more than others to show that the probabilistic acceptance criterion is met (e.g., each wind direction is analyzed individually as opposed to using the worst direction in the group). Each traveling VCE hazard required a probability analysis for both a stationary explosion and traveling VCE; the combined probability of a hazard is calculated in Section 8.2.4. The detailed results of each traveling vapor cloud explosion hazard are provided in the following sections.

8.2.3.1 Acetic Acid (Carboxylic Acid) by Vessel – Traveling VCE:

Carboxylic acid is analyzed as acetic acid based on the commodity information from the USACE User's Guide [Ref. 2.47]. The largest spill of any chemical in the MISLE database is 1,826,626 gallons (see Attachment E). As shown in Appendix 6, a 2,000,000 gallon spill of acetic acid can lead to an explosive concentration for Stability Class F. The vapor pressure of acetic acid is 0.1 atm at 107°F (Input 4.3.4). This is less than the vapor pressure of gasoline, which is assumed to be 1 atm at 107°F for this analysis. The LEL of acetic acid is 4.0% which is higher than the LEL of gasoline, 1.4% (Input 4.3.2). The acetic acid analysis is therefore bounded by the analysis of gasoline. The traveling VCE hazard frequency for acetic acid shipments is set to 4.35×10^{-10} , the same as gasoline (see Section 8.2.3.5). Acetic acid also required probabilistic analysis for a stationary explosion (see Section 8.2.1); therefore the traveling VCE hazard frequency must be combined with the stationary hazard frequency to determine the allowable number of trips. This calculation is performed in Section 8.2.4.

8.2.3.2 Acetone by Vessel – Traveling VCE:

Organic components NEC are analyzed as acetone based on the commodity information from the USACE User's Guide [Ref. 2.47]. The largest spill of any

chemical in the MISLE database is 1,826,626 gallons (see Attachment E). As shown in Appendix 6, a 2,000,000 gallon spill of acetone can lead to an explosive concentration for Stability Class F. The vapor pressure of acetone is 0.6 atm at 107°F (Input 4.3.4). This is less than the vapor pressure of gasoline, which is assumed to be 1 atm at 107°F for this analysis. The LEL of acetone is 2.5% which is higher than the LEL of gasoline, 1.4% (Input 4.3.2). The acetone analysis is therefore bounded by the analysis of gasoline. The traveling VCE hazard frequency for acetone shipments is set to 4.35×10^{-10} , the same as gasoline (see Section 8.2.3.5). Acetone also required probabilistic analysis for a stationary explosion (see Section 8.2.1); therefore the traveling VCE hazard frequency must be combined with the stationary hazard frequency to determine the allowable number of trips. This calculation is performed in Section 8.2.4.

8.2.3.3 Ammonia by Vessel – Traveling VCE:

Several of the chemicals identified as being transported by vessel near the site are analyzed as ammonia for a vapor cloud explosion. These are: ammonia, fertilizers & mixes NEC, inorganic chemicals NEC, nitrogen func. composites, and nitrogenous fertilizer (see Section 7.2).

Ammonia is released as a puff/plume. Because the ammonia is transported as a liquid under pressure, part of the ammonia will be released as an initial puff. The analyses for all of the ammonia models are shown in Appendix 6.

The frequency of a hazard per trip is calculated below. It is conservatively evaluated that the standoff distance for all spills greater than 287,000 gallons is 5 miles and can occur at all stability classes. For hazardous releases in Stability Classes D-G with a standoff distance of 0.5 miles, hazard frequency is calculated for each wind direction individually.

Table 8.2-3: Traveling VCE Hazard Frequency for Ammonia by Vessel

Spill Volume (gal)	Weather Stability Class	Standoff Dist. (mi)	Trip Length (mi)	Directions	Worst Wind Direction	Worst Wind Dir. Freq.	Spill Rate	Total Hazard
100	G	<0.18	0	-	-	0	1.70E-06	0
1,000	G	0.5	0.1	NNE	-	0.01%	7.55E-08	6.95E-13
1,000	G	0.5	0.19	NE	-	0.00%	7.55E-08	6.55E-13
1,000	G	0.5	0.11	ENE	-	0.00%	7.55E-08	0.00E+00
1,000	G	0.5	0.1	E	-	0.00%	7.55E-08	1.77E-13
1,000	G	0.5	0.12	ESE	-	0.00%	7.55E-08	2.12E-13
1,000	G	0.5	0.22	SE	-	0.06%	7.55E-08	9.14E-12
1,000	G	0.5	0.03	SSE	-	0.16%	7.55E-08	3.54E-12
2,000	G	0.5	0.1	NNE	-	0.01%	6.85E-09	6.30E-14
2,000	G	0.5	0.19	NE	-	0.00%	6.85E-09	5.94E-14
2,000	G	0.5	0.11	ENE	-	0.00%	6.85E-09	0.00E+00
2,000	G	0.5	0.1	E	-	0.00%	6.85E-09	1.60E-14
2,000	G	0.5	0.12	ESE	-	0.00%	6.85E-09	1.92E-14
2,000	G	0.5	0.22	SE	-	0.06%	6.85E-09	8.29E-13
2,000	G	0.5	0.03	SSE	-	0.16%	6.85E-09	3.21E-13

2,000	F	<0.18	0	-	-	0	6.85E-09	0
2,000	D	<0.18	0	-	-	0	6.85E-09	0
10,000	G	0.5	0.87	NNE-SSE	SSE	0.16%	9.77E-09	1.33E-11
10,000	F	0.5	0.1	NNE	-	0.06%	9.77E-09	5.38E-13
10,000	F	0.5	0.19	NE	-	0.01%	9.77E-09	2.55E-13
10,000	F	0.5	0.11	ENE	-	0.00%	9.77E-09	2.46E-14
10,000	F	0.5	0.1	E	-	0.00%	9.77E-09	4.51E-14
10,000	F	0.5	0.12	ESE	-	0.02%	9.77E-09	1.88E-13
10,000	F	0.5	0.22	SE	-	0.30%	9.77E-09	6.37E-12
10,000	F	0.5	0.03	SSE	-	0.81%	9.77E-09	2.38E-12
10,000	E	0.5	0.1	NNE	-	0.80%	9.77E-09	7.83E-12
10,000	E	0.5	0.19	NE	-	0.26%	9.77E-09	4.82E-12
10,000	E	0.5	0.11	ENE	-	0.09%	9.77E-09	9.85E-13
10,000	E	0.5	0.1	E	-	0.08%	9.77E-09	7.64E-13
10,000	E	0.5	0.12	ESE	-	0.11%	9.77E-09	1.31E-12
10,000	E	0.5	0.22	SE	-	1.16%	9.77E-09	2.50E-11
10,000	E	0.5	0.03	SSE	-	3.45%	9.77E-09	1.01E-11
10,000	D	<0.18	0	-	-	0	9.77E-09	0
50,000	G	1.4	2.73	N-SSE	SSE	0.16%	2.66E-09	1.14E-11
50,000	F	0.9	1.71	NNE-SSE	SSE	0.81%	2.66E-09	3.70E-11
50,000	E	0.5	0.1	NNE	-	0.80%	2.66E-09	2.14E-12
50,000	E	0.5	0.19	NE	-	0.26%	2.66E-09	1.31E-12
50,000	E	0.5	0.11	ENE	-	0.09%	2.66E-09	2.69E-13
50,000	E	0.5	0.1	E	-	0.08%	2.66E-09	2.08E-13
50,000	E	0.5	0.12	ESE	-	0.11%	2.66E-09	3.58E-13
50,000	E	0.5	0.22	SE	-	1.16%	2.66E-09	6.81E-12
50,000	E	0.5	0.03	SSE	-	3.45%	2.66E-09	2.76E-12
50,000	D	0.5	0.1	NNE	-	2.36%	2.66E-09	6.28E-12
50,000	D	0.5	0.19	NE	-	0.48%	2.66E-09	2.45E-12
50,000	D	0.5	0.11	ENE	-	0.20%	2.66E-09	5.92E-13
50,000	D	0.5	0.1	E	-	0.15%	2.66E-09	3.92E-13
50,000	D	0.5	0.12	ESE	-	0.32%	2.66E-09	1.04E-12
50,000	D	0.5	0.22	SE	-	2.41%	2.66E-09	1.41E-11
50,000	D	0.5	0.03	SSE	-	10.57%	2.66E-09	8.45E-12
50,000	C	0.5	0.87	NNE-SSE	SSE	0.76%	2.66E-09	1.76E-11
50,000	B	<0.18	0	-	-	0	2.66E-09	0
287,000	G	2	3.97	N-SSE	SSE	0.16%	8.88E-10	5.51E-12
287,000	F	1.4	2.73	N-SSE	SSE	0.81%	8.88E-10	1.97E-11
287,000	E	0.9	1.71	NNE-SSE	SSE	3.45%	8.88E-10	5.25E-11
287,000	D	0.9	1.71	NNE-SSE	SSE	10.57%	8.88E-10	1.61E-10
287,000	C	0.5	0.87	NNE-SSE	SSE	0.76%	8.88E-10	5.87E-12
287,000	B	0.5	0.87	NNE-SSE	SSE	0.62%	8.88E-10	4.81E-12
287,000	A	<0.18	0	-	-	0	8.88E-10	0
>287,000	All	5	10.58	NW-SSE	SSE	17.31%	1.27E-10	2.32E-10
Total								6.84E-10

The traveling VCE hazard frequency for vessel shipments of ammonia is 6.84×10^{-10} . Ammonia also required probabilistic analysis for a stationary explosion (see Sections 8.2.1 and 8.2.2); therefore the traveling VCE hazard frequency must be combined with the stationary hazard frequency to determine the allowable number of trips. This calculation is performed in Section 8.2.4.

8.2.3.4 Benzene by Vessel – Traveling VCE:

Because benzene is a liquid at standard conditions, it is released as an evaporating plume and the peak concentrations are substantially lower than those of chemicals that are gaseous at standard conditions. The analyses for all of the benzene models are shown in Appendix 6.

The frequency of a hazard per trip is calculated below. It is conservatively evaluated that the standoff distance for all spills greater than 287,000 gallons is 5 miles and can occur at all stability classes.

Table 8.2-4: Traveling VCE Hazard Frequency for Benzene by Vessel

Spill Volume (gal)	Weather Stability Class	Standoff Dist. (mi)	Trip Length (mi)	Directions	Worst Wind Direction	Worst Wind Dir. Freq.	Spill Rate	Total Hazard
2,000	G	<0.18	0	-	-	0	6.85E-09	0
10,000	G	0.5	0.87	NNE-SSE	SSE	0.16%	9.77E-09	1.33E-11
10,000	F	<0.18	0	-	-	0	9.77E-09	0
50,000	G	0.9	1.71	NNE-SSE	SSE	0.16%	2.66E-09	7.13E-12
50,000	F	0.5	0.87	NNE-SSE	SSE	0.81%	2.66E-09	1.88E-11
50,000	E	0.5	0.87	NNE-SSE	SSE	3.45%	2.66E-09	8.01E-11
50,000	D	<0.18	0	-	-	0	2.66E-09	0
287,000	G	1.4	2.73	N-SSE	SSE	0.16%	8.88E-10	3.79E-12
287,000	F	0.9	1.71	NNE-SSE	SSE	0.81%	8.88E-10	1.23E-11
287,000	E	0.5	0.87	NNE-SSE	SSE	3.45%	8.88E-10	2.67E-11
287,000	D	0.5	0.87	NNE-SSE	SSE	10.57%	8.88E-10	8.17E-11
287,000	C	0.5	0.87	NNE-SSE	SSE	0.76%	8.88E-10	5.87E-12
287,000	B	<0.18	0	-	-	0	8.88E-10	0
>287,000	All	5	10.58	NW-SSE	SSE	17.31%	1.27E-10	2.32E-10
Total								4.82E-10

The traveling VCE hazard frequency for benzene is 4.82×10^{-10} . Benzene also required probabilistic analysis for a stationary explosion (see Section 8.2.1); therefore the traveling VCE hazard frequency must be combined with the stationary hazard frequency to determine the allowable number of trips. This calculation is performed in Section 8.2.4.

8.2.3.5 Gasoline by Vessel – Traveling VCE:

Because gasoline is a liquid at standard conditions, it is released as an evaporating plume and the peak concentrations are substantially lower than those of chemicals that are gaseous at standard conditions. The analyses for all of the gasoline models are shown in Appendix 6.

The frequency of a hazard per trip is calculated below. It is conservatively evaluated that the standoff distance for all spills greater than 287,000 gallons is 5 miles and can occur at all stability classes. For releases with a standoff distance between 0.18 and 0.9 miles, hazard frequency is calculated for each wind direction individually.

Table 8.2-5: Traveling VCE Hazard Frequency for Gasoline by Vessel

Spill Volume (gal)	Weather Stability Class	Standoff Dist. (mi)	Trip Length (mi)	Directions	Worst Wind Direction	Worst Wind Dir. Freq.	Spill Rate	Total Hazard
2,000	G	<0.18	0	-	-	0	6.85E-09	0
10,000	G	0.5	0.1	NNE	-	0.01%	9.77E-09	8.99E-14
10,000	G	0.5	0.19	NE	-	0.00%	9.77E-09	8.47E-14
10,000	G	0.5	0.11	ENE	-	0.00%	9.77E-09	0.00E+00
10,000	G	0.5	0.1	E	-	0.00%	9.77E-09	2.28E-14
10,000	G	0.5	0.12	ESE	-	0.00%	9.77E-09	2.74E-14
10,000	G	0.5	0.22	SE	-	0.06%	9.77E-09	1.18E-12
10,000	G	0.5	0.03	SSE	-	0.16%	9.77E-09	4.58E-13
10,000	F	0.5	0.1	NNE	-	0.06%	9.77E-09	5.38E-13
10,000	F	0.5	0.19	NE	-	0.01%	9.77E-09	2.55E-13
10,000	F	0.5	0.11	ENE	-	0.00%	9.77E-09	2.46E-14
10,000	F	0.5	0.1	E	-	0.00%	9.77E-09	4.51E-14
10,000	F	0.5	0.12	ESE	-	0.02%	9.77E-09	1.88E-13
10,000	F	0.5	0.22	SE	-	0.30%	9.77E-09	6.37E-12
10,000	F	0.5	0.03	SSE	-	0.81%	9.77E-09	2.38E-12
10,000	E	<0.18	0	-	-	0	9.77E-09	0
50,000	G	1.4	2.73	N-SSE	SSE	0.16%	2.66E-09	1.14E-11
50,000	F	0.9	0.53	NNE	-	0.06%	2.66E-09	7.77E-13
50,000	F	0.9	0.19	NE	-	0.01%	2.66E-09	6.96E-14
50,000	F	0.9	0.11	ENE	-	0.00%	2.66E-09	6.70E-15
50,000	F	0.9	0.1	E	-	0.00%	2.66E-09	1.23E-14
50,000	F	0.9	0.12	ESE	-	0.02%	2.66E-09	5.13E-14
50,000	F	0.9	0.22	SE	-	0.30%	2.66E-09	1.74E-12
50,000	F	0.9	0.44	SSE	-	0.81%	2.66E-09	9.51E-12
50,000	E	0.5	0.1	NNE	-	0.80%	2.66E-09	2.14E-12
50,000	E	0.5	0.19	NE	-	0.26%	2.66E-09	1.31E-12
50,000	E	0.5	0.11	ENE	-	0.09%	2.66E-09	2.69E-13
50,000	E	0.5	0.1	E	-	0.08%	2.66E-09	2.08E-13
50,000	E	0.5	0.12	ESE	-	0.11%	2.66E-09	3.58E-13
50,000	E	0.5	0.22	SE	-	1.16%	2.66E-09	6.81E-12
50,000	E	0.5	0.03	SSE	-	3.45%	2.66E-09	2.76E-12
50,000	D	0.5	0.1	NNE	-	2.36%	2.66E-09	6.28E-12
50,000	D	0.5	0.19	NE	-	0.48%	2.66E-09	2.45E-12
50,000	D	0.5	0.11	ENE	-	0.20%	2.66E-09	5.92E-13
50,000	D	0.5	0.1	E	-	0.15%	2.66E-09	3.92E-13
50,000	D	0.5	0.12	ESE	-	0.32%	2.66E-09	1.04E-12
50,000	D	0.5	0.22	SE	-	2.41%	2.66E-09	1.41E-11
50,000	D	0.5	0.03	SSE	-	10.57%	2.66E-09	8.45E-12
50,000	C	0.5	0.1	NNE	-	0.01%	2.66E-09	3.07E-14
50,000	C	0.5	0.19	NE	-	0.03%	2.66E-09	1.28E-13
50,000	C	0.5	0.11	ENE	-	0.00%	2.66E-09	1.34E-14
50,000	C	0.5	0.1	E	-	0.01%	2.66E-09	1.87E-14
50,000	C	0.5	0.12	ESE	-	0.02%	2.66E-09	6.62E-14
50,000	C	0.5	0.22	SE	-	0.04%	2.66E-09	2.29E-13
50,000	C	0.5	0.03	SSE	-	0.03%	2.66E-09	2.75E-14
50,000	B	<0.18	0	-	-	0	2.66E-09	0
287,000	G	3.4	7.02	NNW-SSE	SSE	0.16%	8.88E-10	9.75E-12
287,000	F	1.7	3.37	N-SSE	SSE	0.81%	8.88E-10	2.43E-11

Spill Volume (gal)	Weather Stability Class	Standoff Dist. (mi)	Trip Length (mi)	Directions	Worst Wind Direction	Worst Wind Dir. Freq.	Spill Rate	Total Hazard
287,000	E	0.9	0.53	NNE	-	0.80%	8.88E-10	3.77E-12
287,000	E	0.9	0.19	NE	-	0.26%	8.88E-10	4.38E-13
287,000	E	0.9	0.11	ENE	-	0.09%	8.88E-10	8.96E-14
287,000	E	0.9	0.1	E	-	0.08%	8.88E-10	6.95E-14
287,000	E	0.9	0.12	ESE	-	0.11%	8.88E-10	1.19E-13
287,000	E	0.9	0.22	SE	-	1.16%	8.88E-10	2.27E-12
287,000	E	0.9	0.44	SSE	-	3.45%	8.88E-10	1.35E-11
287,000	D	0.9	0.53	NNE	-	2.36%	8.88E-10	1.11E-11
287,000	D	0.9	0.19	NE	-	0.48%	8.88E-10	8.18E-13
287,000	D	0.9	0.11	ENE	-	0.20%	8.88E-10	1.97E-13
287,000	D	0.9	0.1	E	-	0.15%	8.88E-10	1.31E-13
287,000	D	0.9	0.12	ESE	-	0.32%	8.88E-10	3.46E-13
287,000	D	0.9	0.22	SE	-	2.41%	8.88E-10	4.71E-12
287,000	D	0.9	0.44	SSE	-	10.57%	8.88E-10	4.13E-11
287,000	C	0.5	0.1	NNE	-	0.27%	8.88E-10	2.37E-13
287,000	C	0.5	0.19	NE	-	0.07%	8.88E-10	1.13E-13
287,000	C	0.5	0.11	ENE	-	0.04%	8.88E-10	3.58E-14
287,000	C	0.5	0.1	E	-	0.01%	8.88E-10	1.02E-14
287,000	C	0.5	0.12	ESE	-	0.05%	8.88E-10	5.36E-14
287,000	C	0.5	0.22	SE	-	0.45%	8.88E-10	8.84E-13
287,000	C	0.5	0.03	SSE	-	0.76%	8.88E-10	2.02E-13
287,000	B	0.5	0.1	NNE	-	0.24%	8.88E-10	2.14E-13
287,000	B	0.5	0.19	NE	-	0.06%	8.88E-10	1.01E-13
287,000	B	0.5	0.11	ENE	-	0.01%	8.88E-10	8.98E-15
287,000	B	0.5	0.1	E	-	0.03%	8.88E-10	2.65E-14
287,000	B	0.5	0.12	ESE	-	0.04%	8.88E-10	4.65E-14
287,000	B	0.5	0.22	SE	-	0.31%	8.88E-10	6.05E-13
287,000	B	0.5	0.03	SSE	-	0.62%	8.88E-10	1.66E-13
287,000	A	0.5	0.1	NNE	-	0.66%	8.88E-10	5.89E-13
287,000	A	0.5	0.19	NE	-	0.18%	8.88E-10	3.03E-13
287,000	A	0.5	0.11	ENE	-	0.08%	8.88E-10	7.64E-14
287,000	A	0.5	0.1	E	-	0.03%	8.88E-10	2.85E-14
287,000	A	0.5	0.12	ESE	-	0.16%	8.88E-10	1.66E-13
287,000	A	0.5	0.22	SE	-	1.42%	8.88E-10	2.77E-12
287,000	A	0.5	0.03	SSE	-	0.93%	8.88E-10	2.48E-13
>287,000	All	5	10.58	NW-SSE	SSE	17.31%	1.27E-10	2.32E-10
Total								4.35E-10

The traveling VCE hazard frequency for gasoline is 4.35×10^{-10} . Gasoline also required probabilistic analysis for a stationary explosion (see Section 8.2.1); therefore the traveling VCE hazard frequency must be combined with the stationary hazard frequency to determine the allowable number of trips. This calculation is performed in Section 8.2.4.

8.2.3.6 Methane by Vessel – Traveling VCE:

The commodity “hydrocarbon & petrol gases, liquefied and gaseous” is analyzed as methane based on the commodity information from the USACE User’s Guide [Ref. 2.47].

The frequency of a hazard per trip is calculated below. See Appendix 6 for the complete analysis. It is conservatively evaluated that the standoff distance for all spills greater than 287,000 gallons is 5 miles and can occur at all stability classes. For the 100 gallon hazardous release, hazard frequency is calculated for each wind direction individually.

Table 8.2-6: Traveling VCE Hazard Frequency for Methane by Vessel

Spill Volume (gal)	Weather Stability Class	Standoff Dist. (mi)	Trip Length (mi)	Directions	Worst Wind Direction	Worst Wind Dir. Freq.	Spill Rate	Total Hazard
100	G	0.5	0.1	NNE	-	0.01%	1.70E-06	1.57E-11
100	G	0.5	0.19	NE	-	0.00%	1.70E-06	1.48E-11
100	G	0.5	0.11	ENE	-	0.00%	1.70E-06	0.00E+00
100	G	0.5	0.1	E	-	0.00%	1.70E-06	3.99E-12
100	G	0.5	0.12	ESE	-	0.00%	1.70E-06	4.78E-12
100	G	0.5	0.22	SE	-	0.06%	1.70E-06	2.06E-10
100	G	0.5	0.03	SSE	-	0.16%	1.70E-06	8.00E-11
100	F	<0.18	0	-	-	0	1.70E-06	0
1,000	G	0.9	1.71	NNE-SSE	SSE	0.16%	7.55E-08	2.02E-10
1,000	F	0.5	0.87	NNE-SSE	SSE	0.81%	7.55E-08	5.33E-10
1,000	E	0.5	0.87	NNE-SSE	SSE	3.45%	7.55E-08	2.27E-09
1,000	D	<0.18	0	-	-	0	7.55E-08	0
2,000	G	0.9	1.71	NNE-SSE	SSE	0.16%	6.85E-09	1.83E-11
2,000	F	0.5	0.87	NNE-SSE	SSE	0.81%	6.85E-09	4.84E-11
2,000	E	0.5	0.87	NNE-SSE	SSE	3.45%	6.85E-09	2.06E-10
2,000	D	0.5	0.87	NNE-SSE	SSE	10.57%	6.85E-09	6.30E-10
2,000	C	<0.18	0	-	-	0	6.85E-09	0
10,000	G	1.7	3.37	N-SSE	SSE	0.16%	9.77E-09	5.15E-11
10,000	F	1.4	2.73	N-SSE	SSE	0.81%	9.77E-09	2.16E-10
10,000	E	0.9	1.71	NNE-SSE	SSE	3.45%	9.77E-09	5.77E-10
10,000	D	0.5	0.87	NNE-SSE	SSE	10.57%	9.77E-09	8.99E-10
10,000	C	0.5	0.87	NNE-SSE	SSE	0.76%	9.77E-09	6.46E-11
10,000	B	<0.18	0	-	-	0	9.77E-09	0
50,000	G	3.4	7.02	NNW-SSE	SSE	0.16%	2.66E-09	2.93E-11
50,000	F	2	3.97	N-SSE	SSE	0.81%	2.66E-09	8.58E-11
50,000	E	1.4	2.73	N-SSE	SSE	3.45%	2.66E-09	2.51E-10
50,000	D	0.9	1.71	NNE-SSE	SSE	10.57%	2.66E-09	4.82E-10
50,000	C	0.5	0.87	NNE-SSE	SSE	0.76%	2.66E-09	1.76E-11
50,000	B	0.5	0.87	NNE-SSE	SSE	0.62%	2.66E-09	1.44E-11
50,000	A	0.5	0.87	NNE-SSE	SE	1.42%	2.66E-09	3.28E-11
287,000	G	5	10.58	NW-SSE	SSE	0.16%	8.88E-10	1.47E-11
287,000	F	4.1	8.64	NNW-SSE	SSE	0.81%	8.88E-10	6.23E-11
287,000	E	3.4	7.02	NNW-SSE	SSE	3.45%	8.88E-10	2.15E-10
287,000	D	1.7	3.37	N-SSE	SSE	10.57%	8.88E-10	3.16E-10
287,000	C	0.9	1.71	NNE-SSE	SSE	0.76%	8.88E-10	1.15E-11

Spill Volume (gal)	Weather Stability Class	Standoff Dist. (mi)	Trip Length (mi)	Directions	Worst Wind Direction	Worst Wind Dir. Freq.	Spill Rate	Total Hazard
287,000	B	0.9	1.71	NNE-SSE	SSE	0.62%	8.88E-10	9.45E-12
287,000	A	0.5	0.87	NNE-SSE	SE	1.42%	8.88E-10	1.09E-11
>287,000	All	5	10.58	NW-SSE	SSE	17.31%	1.27E-10	2.32E-10
Total								7.83E-09

The traveling VCE hazard frequency for vessel shipments of methane is 7.83×10^{-9} . Methane also required probabilistic analysis for a stationary explosion (see Sections 8.2.1 and 8.2.2); therefore the traveling VCE hazard frequency must be combined with the stationary hazard frequency to determine the allowable number of trips. This calculation is performed in Section 8.2.4.

8.2.3.7 Methanol/Ethanol (Alcohols) by Vessel – Traveling VCE:

Methanol and ethanol are analyzed for alcohols based on the commodity information from the USACE User's Guide [Ref. 2.47]. Methanol is selected as a worst case alcohol because it has the lowest boiling point. Ethanol is selected because it has a smaller LEL. The largest spill of any chemical in the MISLE database is 1,826,626 gallons (see Attachment E). As shown in Appendix 6, a 2,000,000 gallon spill of either chemical can lead to an explosive concentration for Stability Class F. The vapor pressure of each chemical at 107°F (Input 4.3.4) is less than the vapor pressure of gasoline, which is assumed to be 1 atm at 107°F for this analysis. Also, the LEL of each chemical is higher than the LEL of gasoline, 1.4% (Input 4.3.2). The methanol/ethanol analysis is therefore bounded by the analysis of gasoline. The traveling VCE hazard frequency for methanol/ethanol shipments is set to 4.35×10^{-10} , the same as gasoline (see Section 8.2.3.5). Methanol/ethanol also required probabilistic analysis for a stationary explosion (see Section 8.2.1); therefore the traveling VCE hazard frequency must be combined with the stationary hazard frequency to determine the allowable number of trips. This calculation is performed in Section 8.2.4.

8.2.3.8 Naphtha by Vessel – Traveling VCE:

Because naphtha is a liquid at standard conditions, it is released as an evaporating plume and the peak concentrations are substantially lower than those of chemicals that are gaseous at standard conditions. The analyses for all of the naphtha models are shown in Appendix 6.

The frequency of a hazard per trip is calculated below. It is conservatively evaluated that the standoff distance for all spills greater than 287,000 gallons is 5 miles and can occur at all stability classes.

Table 8.2-7: Traveling VCE Hazard Frequency for Naphtha by Vessel

Spill Volume (gal)	Weather Stability Class	Standoff Dist. (mi)	Trip Length (mi)	Directions	Worst Wind Direction	Worst Wind Dir. Freq.	Spill Rate	Total Hazard
1,000	G	<0.18	0	-	-	0	7.55E-08	0
2,000	G	0.5	0.87	NNE-SSE	SSE	0.16%	6.85E-09	9.32E-12
2,000	F	<0.18	0	-	-	0	6.85E-09	0
10,000	G	0.5	0.87	NNE-SSE	SSE	0.16%	9.77E-09	1.33E-11
10,000	F	0.5	0.87	NNE-SSE	SSE	0.81%	9.77E-09	6.90E-11
10,000	E	<0.18	0	-	-	0	9.77E-09	0
50,000	G	1.4	2.73	N-SSE	SSE	0.16%	2.66E-09	1.14E-11
50,000	F	0.9	1.71	NNE-SSE	SSE	0.81%	2.66E-09	3.70E-11
50,000	E	0.5	0.87	NNE-SSE	SSE	3.45%	2.66E-09	8.01E-11
50,000	D	0.5	0.87	NNE-SSE	SSE	10.57%	2.66E-09	2.45E-10
50,000	C	0.5	0.87	NNE-SSE	SSE	0.76%	2.66E-09	1.76E-11
50,000	B	0.5	0.87	NNE-SSE	SSE	0.62%	2.66E-09	1.44E-11
50,000	A	<0.18	0	-	-	0	2.66E-09	0
287,000	G	3.4	7.02	NNW-SSE	SSE	0.16%	8.88E-10	9.75E-12
287,000	F	1.7	3.37	N-SSE	SSE	0.81%	8.88E-10	2.43E-11
287,000	E	1.4	2.73	N-SSE	SSE	3.45%	8.88E-10	8.38E-11
287,000	D	0.9	1.71	NNE-SSE	SSE	10.57%	8.88E-10	1.61E-10
287,000	C	0.9	1.71	NNE-SSE	SSE	0.76%	8.88E-10	1.15E-11
287,000	B	0.5	0.87	NNE-SSE	SSE	0.62%	8.88E-10	4.81E-12
287,000	A	0.5	0.87	NNE-SSE	SE	1.42%	8.88E-10	1.09E-11
>287,000	All	5	10.58	NW-SSE	SSE	17.31%	1.27E-10	2.32E-10
Total								1.04E-09

The traveling VCE hazard frequency for naphtha is 1.04×10^{-9} . Naphtha also required probabilistic analysis for a stationary explosion (see Section 8.2.1); therefore the traveling VCE hazard frequency must be combined with the stationary hazard frequency to determine the allowable number of trips. This calculation is performed in Section 8.2.4.

8.2.3.9 Propane by Vessel – Traveling VCE:

Several of the chemicals identified as being transported by vessel near the site are analyzed as propane. These are: acyclic hydrocarbons (propane is acyclic), organo/inorgano compounds and petroleum products NEC.

The frequency of a hazard per trip is calculated below. See Appendix 6 for the complete analysis. It is conservatively evaluated that the standoff distance for all spills greater than 287,000 gallons is 5 miles and can occur at all stability classes.

Table 8.2-8: Traveling VCE Hazard Frequency for Propane by Vessel

Spill Volume (gal)	Weather Stability Class	Standoff Dist. (mi)	Trip Length (mi)	Directions	Worst Wind Direction	Worst Wind Dir. Freq.	Spill Rate	Total Hazard
100	G	<0.18	0	-	-	0	1.70E-06	0
1,000	G	0.5	0.87	NNE-SSE	SSE	0.16%	7.55E-08	1.03E-10

Spill Volume (gal)	Weather Stability Class	Standoff Dist. (mi)	Trip Length (mi)	Directions	Worst Wind Direction	Worst Wind Dir. Freq.	Spill Rate	Total Hazard
1,000	F	0.5	0.87	NNE-SSE	SSE	0.81%	7.55E-08	5.33E-10
1,000	E	0.5	0.87	NNE-SSE	SSE	3.45%	7.55E-08	2.27E-09
1,000	D	<0.18	0	-	-	0	7.55E-08	0
2,000	G	0.5	0.87	NNE-SSE	SSE	0.16%	6.85E-09	9.32E-12
2,000	F	0.5	0.87	NNE-SSE	SSE	0.81%	6.85E-09	4.84E-11
2,000	E	0.5	0.87	NNE-SSE	SSE	3.45%	6.85E-09	2.06E-10
2,000	D	<0.18	0	-	-	0	6.85E-09	0
10,000	G	1.4	2.73	N-SSE	SSE	0.16%	9.77E-09	4.17E-11
10,000	F	0.9	1.71	NNE-SSE	SSE	0.81%	9.77E-09	1.36E-10
10,000	E	0.5	0.87	NNE-SSE	SSE	3.45%	9.77E-09	2.94E-10
10,000	D	0.5	0.87	NNE-SSE	SSE	10.57%	9.77E-09	8.99E-10
10,000	C	0.5	0.87	NNE-SSE	SSE	0.76%	9.77E-09	6.46E-11
10,000	B	<0.18	0	-	-	0	9.77E-09	0
50,000	G	3.4	7.02	NNW-SSE	SSE	0.16%	2.66E-09	2.93E-11
50,000	F	1.4	2.73	N-SSE	SSE	0.81%	2.66E-09	5.90E-11
50,000	E	0.9	1.71	NNE-SSE	SSE	3.45%	2.66E-09	1.57E-10
50,000	D	0.9	1.71	NNE-SSE	SSE	10.57%	2.66E-09	4.82E-10
50,000	C	0.5	0.87	NNE-SSE	SSE	0.76%	2.66E-09	1.76E-11
50,000	B	0.5	0.87	NNE-SSE	SSE	0.62%	2.66E-09	1.44E-11
50,000	A	<0.18	0	-	-	0	2.66E-09	0
287,000	G	5	10.58	NW-SSE	SSE	0.16%	8.88E-10	1.47E-11
287,000	F	3.4	7.02	NNW-SSE	SSE	0.81%	8.88E-10	5.06E-11
287,000	E	2	3.97	N-SSE	SSE	3.45%	8.88E-10	1.22E-10
287,000	D	1.4	2.73	N-SSE	SSE	10.57%	8.88E-10	2.56E-10
287,000	C	0.9	1.71	NNE-SSE	SSE	0.76%	8.88E-10	1.15E-11
287,000	B	0.5	0.87	NNE-SSE	SSE	0.62%	8.88E-10	4.81E-12
287,000	A	0.5	0.87	NNE-SSE	SE	1.42%	8.88E-10	1.09E-11
>287,000	All	5	10.58	NW-SSE	SSE	17.31%	1.27E-10	2.32E-10
Total								6.06E-09

The traveling VCE hazard frequency for vessel shipments of propane is 6.06×10^{-9} . Propane also required probabilistic analysis for a stationary explosion (see Sections 8.2.1 and 8.2.2); therefore the traveling VCE hazard frequency must be combined with the stationary hazard frequency to determine the allowable number of trips. This calculation is performed in Section 8.2.4.

8.2.3.10 Vinyl Chloride by Vessel – Traveling VCE:

The commodity “other hydrocarbons” is analyzed as vinyl chloride based on the commodity information from the USACE User’s Guide [Ref. 2.47].

The frequency of a hazard per trip is calculated below. See Appendix 6 for the complete analysis. It is conservatively evaluated that the standoff distance for all spills greater than 287,000 gallons is 5 miles and can occur at all stability classes.

Table 8.2-9: Traveling VCE Hazard Frequency for Vinyl Chloride by Vessel

Spill Volume (gal)	Weather Stability Class	Standoff Dist. (mi)	Trip Length (mi)	Directions	Worst Wind Direction	Worst Wind Dir. Freq.	Spill Rate	Total Hazard
100	G	0.5	0.87	NNE-SSE	SSE	0.16%	1.70E-06	2.32E-09
100	F	<0.18	0	-	-	0	1.70E-06	0
1,000	G	0.9	1.71	NNE-SSE	SSE	0.16%	7.55E-08	2.02E-10
1,000	F	0.5	0.87	NNE-SSE	SSE	0.81%	7.55E-08	5.33E-10
1,000	E	0.5	0.87	NNE-SSE	SSE	3.45%	7.55E-08	2.27E-09
1,000	D	<0.18	0	-	-	0	7.55E-08	0
2,000	G	0.9	1.71	NNE-SSE	SSE	0.16%	6.85E-09	1.83E-11
2,000	F	0.5	0.87	NNE-SSE	SSE	0.81%	6.85E-09	4.84E-11
2,000	E	0.5	0.87	NNE-SSE	SSE	3.45%	6.85E-09	2.06E-10
2,000	D	0.5	0.87	NNE-SSE	SSE	10.57%	6.85E-09	6.30E-10
2,000	C	<0.18	0	-	-	0	6.85E-09	0
10,000	G	1.7	3.37	N-SSE	SSE	0.16%	9.77E-09	5.15E-11
10,000	F	0.9	1.71	NNE-SSE	SSE	0.81%	9.77E-09	1.36E-10
10,000	E	0.9	1.71	NNE-SSE	SSE	3.45%	9.77E-09	5.77E-10
10,000	D	0.5	0.87	NNE-SSE	SSE	10.57%	9.77E-09	8.99E-10
10,000	C	0.5	0.87	NNE-SSE	SSE	0.76%	9.77E-09	6.46E-11
10,000	B	<0.18	0	-	-	0	9.77E-09	0
50,000	G	3.4	7.02	NNW-SSE	SSE	0.16%	2.66E-09	2.93E-11
50,000	F	1.7	3.37	N-SSE	SSE	0.81%	2.66E-09	7.29E-11
50,000	E	1.4	2.73	N-SSE	SSE	3.45%	2.66E-09	2.51E-10
50,000	D	0.9	1.71	NNE-SSE	SSE	10.57%	2.66E-09	4.82E-10
50,000	C	0.5	0.87	NNE-SSE	SSE	0.76%	2.66E-09	1.76E-11
50,000	B	0.5	0.87	NNE-SSE	SSE	0.62%	2.66E-09	1.44E-11
50,000	A	<0.18	0	-	-	0	2.66E-09	0
287,000	G	5	10.58	NW-SSE	SSE	0.16%	8.88E-10	1.47E-11
287,000	F	4.1	8.64	NNW-SSE	SSE	0.81%	8.88E-10	6.23E-11
287,000	E	3.4	7.02	NNW-SSE	SSE	3.45%	8.88E-10	2.15E-10
287,000	D	1.7	3.37	N-SSE	SSE	10.57%	8.88E-10	3.16E-10
287,000	C	0.9	1.71	NNE-SSE	SSE	0.76%	8.88E-10	1.15E-11
287,000	B	0.5	0.87	NNE-SSE	SSE	0.62%	8.88E-10	4.81E-12
287,000	A	0.5	0.87	NNE-SSE	SE	1.42%	8.88E-10	1.09E-11
>287,000	All	5	10.58	NW-SSE	SSE	17.31%	1.27E-10	2.32E-10
Total								9.69E-09

The traveling VCE hazard frequency for vessel shipments of vinyl chloride is 9.69×10^{-9} . Vinyl chloride also required probabilistic analysis for a stationary explosion (see Sections 8.2.1 and 8.2.2); therefore the traveling VCE hazard frequency must be combined with the stationary hazard frequency to determine the allowable number of trips. This calculation is performed in Section 8.2.4.

8.2.4 Combined Probability

For vessel shipments of the chemicals listed below in Table 8.2-10, a probability analysis is required for both a stationary explosion (Sections 8.2.1 and 8.2.2) and traveling VCE (Section 8.2.3). To determine that the overall hazard probability of each chemical is acceptable, the hazard frequency of both types of explosions must be

combined. For the stationary explosion hazard frequency, the bounding frequency between the stationary vapor cloud explosion hazard (Section 8.2.1) and BLEVE hazard (Section 8.2.2) is used -- in all cases, the stationary vapor cloud explosion hazard frequency is bounding. The combined hazard frequency is calculated below in Table 8.2-10. Also reproduced from Table 7.4-2 is each chemical's number of trips. The overall allowable number of trips for each chemical is found by dividing the combined frequency by 10^{-6} hazards per year.

Table 8.2-10: Vessel Shipments with Combined Hazard Frequency

Chemical	Annual Number of Trips	Stationary Hazard Frequency (Secs. 8.2.1 & 8.2.2)	Traveling VCE Hazard Frequency (Sec. 8.2.3)	Combined Hazard Frequency	Overall Allowable Number of Trips
Acetic Acid (Carboxylic Acid)	48	1.33E-10	4.35E-10*	5.68E-10	1,761
Acetone	43	1.33E-10	4.35E-10*	5.68E-10	1,761
Ammonia	849	3.85E-10	6.84E-10	1.07E-09	936
Benzene	476	1.33E-10	4.82E-10	6.15E-10	1,627
Gasoline	1,671	1.33E-10	4.35E-10	5.68E-10	1,761
Methane	96	6.14E-10	7.83E-09	8.44E-09	118
Methanol/Ethanol (Alcohols)	1,599	1.33E-10	4.35E-10*	5.68E-10	1,761
Naphtha	140	1.33E-10	1.04E-09	1.17E-09	856
Propane	21	6.14E-10	6.06E-09	1.65E-09	150
Vinyl Chloride	42	6.14E-10	9.69E-09	1.03E-08	97

*Results are obtained from bounding analysis of gasoline.

As shown in Table 8.2-10, the number of trips is less than the allowable for each chemical, thus, meeting the probabilistic acceptance criteria.

9.0 Conclusion

As shown in Section 8.0, Results, the acceptance criteria for each of the potentially hazardous chemicals are met. None of the chemicals pose a hazard due to explosive overpressure on the Trojan ISFSI. A summary of the hazard analysis results is provided below. Table 9.0-1, below, details those chemicals that are acceptable based on a deterministic analysis and those chemicals that are acceptable based on a probabilistic analysis. Accident probability is not increased by ships using the Prescott anchorage as determined in Section 6.4.2.

For each chemical requiring probabilistic analysis, this evaluation determines that the frequency is less than 10^{-6} hazards per year, per the acceptance criteria. Several conservatisms are used in the probability analyses. Significant conservatisms in the vessel traveling VCE analyses are listed below:

1. The spill size for each case is the maximum in the range of spill sizes. For instance, a spill of 51,000 gallons is modeled as a spill of 287,000 gallons of chemical.
2. Data for the entire Columbia River System is used and the estimation of the number of shipments for each chemical is biased high in Section 7.4.
3. Storage conditions for chemicals are selected in order to maximize the release rate, which would maximize the concentration at the Trojan site. In some cases, chemicals that are typically stored or transported as liquids are modeled as gases (e.g., propane, methane, etc.).
4. For a specific weather stability class, only certain wind speeds may result in a hazard; however, a probability of 1.0 for adverse wind speed is used in the probability calculation.

Table 9.0-1: Offsite Transportation Explosion Hazard Evaluation Results

Source	Nearest Approach	Type of Explosions	Deterministic Analysis Results	Probability Analysis Results
BNSF Railcar	1.09 mi	Solid Explosives and Stationary VCE (Section 8.1.1)	All Hazards < 1.0 psig (Table 8.1-1)	N/A
		BLEVE (Section 8.1.2)	All Hazards < 0.1 psig (Table 8.1-2)	N/A
		Traveling VCE (Section 8.1.3)	Butane, Butylene, Isobutene, Isobutylene, Propane & Propylene > LEL for Weather < 5% of the Time (Section 8.1.3) Remainder < LEL (Table 8.1-3)	N/A
PNWR Railcar	0.14 mi	Solid Explosives and Stationary VCE (Section 8.1.1)	Ethanol < 1.0 psig	N/A
		BLEVE (Section 8.1.2)	N/A	N/A
		Traveling VCE (Section 8.1.3)	Ethanol < LEL	N/A
Columbia River Vessel	0.18 mi	Solid Explosives and Stationary VCE (Section 8.2.1 & 8.2.4)	Petroleum Coke < 1.0 psig Sulfur < 0.1 psig Remainder > 2.2 psig or > 1 psig (Table 8.2-1)	Ammonium Nitrate < 1,628 Allowable Trips Explosives < 1,120 Allowable Trips (Table 8.2-1) Remainder → Combined Probability (see below)
		BLEVE (Section 8.2.2 & 8.2.4)	All Hazards > 2.2 psig (Table 8.2-2)	All Hazards (Excl. Solids & Dust) Stationary & Traveling VCE Combined Probability < Allowable Trips (Table 8.2-10)
		Traveling VCE (Section 8.2.3 & 8.2.4)	All Hazards > LEL (Section 8.2.3)	