FACILITY SITING STUDY & QUANTITATIVE RISK ASSESSMENT

VANCOUVER ENERGY TERMINAL PORT OF VANCOUVER, WASHINGTON

Final Report
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EXECUTIVE SUMMARY

Baker Engineering and Risk Consultants, Inc. (BakerRisk®) was hired to perform a Facility Siting Study (FSS) and Quantitative Risk Assessment (QRA) of the proposed Vancouver Energy Terminal located in Port of Vancouver, Washington (Terminal). The Terminal is a project of Tesoro Savage Petroleum Terminal LLC (Tesoro Savage or applicant), a Delaware limited liability company doing business as Vancouver Energy (Vancouver Energy). This study is based on a detailed review of the processes and data provided by Tesoro Savage. BakerRisk has previously commented on this project in a letter dated January 22, 2016, in which BakerRisk provided a qualitative assessment of the project and comments on the methodologies used in the Draft Environmental Impact Statement. In this report, BakerRisk completed the more detailed Quantitative Risk Assessment described in that earlier letter. The purpose of the study is to identify and evaluate the consequences and associated risks of fire, toxic, and explosion hazards to onsite personnel (building occupants and personnel in outdoor areas) and offsite populations.

When considering risks, this study looks at both the consequence of particular events and the likelihood of such events actually occurring. Although there are multiple methods of calculating risks, the methodology used in this study was based on the American Institute of Chemical Engineers (Center for Chemical Process Safety, CCPS), which is endorsed by the Hazardous Materials Cooperative Research Program (HMCRP) sponsored by the Pipeline and Hazardous Materials Safety Administration (PHMSA).

This study covered the 360,000 barrel-per-day (bpd) crude-oil-rail car unloading and marine loading facility. A representative set of accident scenarios was selected for identified significant fire, explosion, and toxic hazards. A range of release magnitudes (0.5-inch, 2-inch, and full bore up to 6-inch equivalent diameter hole sizes) was evaluated for each hazard source. Dispersion of the material from releases was modeled using BakerRisk's $SafeSite_{3G}^{©}$ software, which takes into account thermodynamic properties, flashing, rainout, pooling, evaporation, and gas dispersion. Pool fire and jet fire impacts were assessed as a function of thermal radiation intensity and personnel survivability. Flash fire impacts were assessed for areas potentially impacted by flammable gas. Toxic impacts were assessed for areas potentially impacted by hydrogen sulfide (H_2S).

Vapor cloud explosions (VCEs) were modeled for scenarios where the cloud of flammable vapors was predicted to intersect areas of congestion, such as process equipment or vegetation, before igniting. VCE consequences were modeled using the Baker-Strehlow-Tang (BST) methodology to determine blast loads on buildings. The resulting building damage levels (BDLs) and occupant vulnerability (OVs) values were predicted for buildings. Because no structural drawings were available for buildings in this analysis, a relatively weak building model (modular building) was assumed. Occupancy data provided by the applicant was used to convert vulnerability values to predicted consequences in terms of fatalities.

Frequencies were assigned to accident scenarios assessed, accounting for source-specific equipment counts, typical industry failure rates, source-specific ignition probabilities and timing, and regional statistical meteorological data. Scenario frequencies and consequences were used to assess risk posed to onsite personnel and the public. Risks are presented in terms of onsite, offsite, and total societal risk tables.

Figure ES-1 shows the FN curve results for onsite risk from all releases evaluated along with typical industry risk tolerance criteria. FN curves are typically used in industry as a way to measure risks against common criteria. The U.S. government does not have applicable standard risk tolerance criteria, so risk has been charted against the UK standard risk tolerance criteria[1]. Two industry risk tolerance criteria are shown. The first (red line) is the "upper criteria" and corresponds to the risk level that should not be exceeded. Risk above the red line is considered significant, and mitigation should be actively sought and implemented. The second (green line) is the "lower criteria" and corresponds to the risk level below which risk is considered tolerable without further mitigation. These risks are considered negligible, meaning they do not have a measurable addition to the risk profile. Risks above the green line but below the red line are considered tolerable, such that mitigation should be sought but only implemented if practicable. Facilities with risks in this range are within typical industry risk tolerance criteria.

As shown in Figure ES-1, the FN curves for the Terminal indicate that, for the credible accident scenarios modeled, the total risk is within typical industry risk tolerance criteria (below the red line). Flash fire risk mitigation options should be considered; however, few, if any, risk mitigation options identified are expected to be practicable.

Figure ES-2 shows the FN curve results for offsite risk from all releases evaluated along with typical industry risk tolerance criteria. The FN curves show that the total offsite risk is well below the green line (i.e., typically considered tolerable without further mitigation).

Table ES-1 shows the amount of risk incurred by occupants of each onsite building and outdoor area assessed. The total onsite risk was calculated to be 7E-4 fatalities per year which falls within the tolerable region based on typical industry criteria. Approximately 67% of the onsite risk is incurred by personnel in the *Train Unloading Area* and 27% in the *Boiler Building.* Flash fire is the primary hazard in the *Train Unloading Area*, and explosion is the primary hazard in the *Boiler Building*.

Table ES-2 shows the amount of risk incurred by offsite persons in each building and outdoor area assessed. The total offsite risk was calculated to be 5E-9 fatalities per year (i.e., more than 10,000 times less than the onsite risk). The total risk to offsite outdoor populations is very small and should be viewed as tolerable. The building with the most risk incurred by offsite personnel is the *Farwest Steel Building* (94% of total offsite risk), and essentially all of that risk is from flash fire hazards.

Table ES-3 shows the contribution of risk from each source assessed. Approximately 54% of the total risk is caused by releases from the loading hoses in the North and South train unloading areas (01-SouthRail, 04-NorthRail and 06-HeatedRail) and 26% is from the boilers (35-Boiler3, 34-Boiler2, and 33-Boiler1). Approximately 66% of the total calculated risk is due to flash fire hazards, 33% of total risk is due to explosion hazards, and the remaining 1% is due to jet/pool fire hazards. Toxic hazards were determined to be negligible.

[1] *HSE R2P2, Reducing Risks, Protecting People, HSE's Decision-Making Process;* paragraph 136.

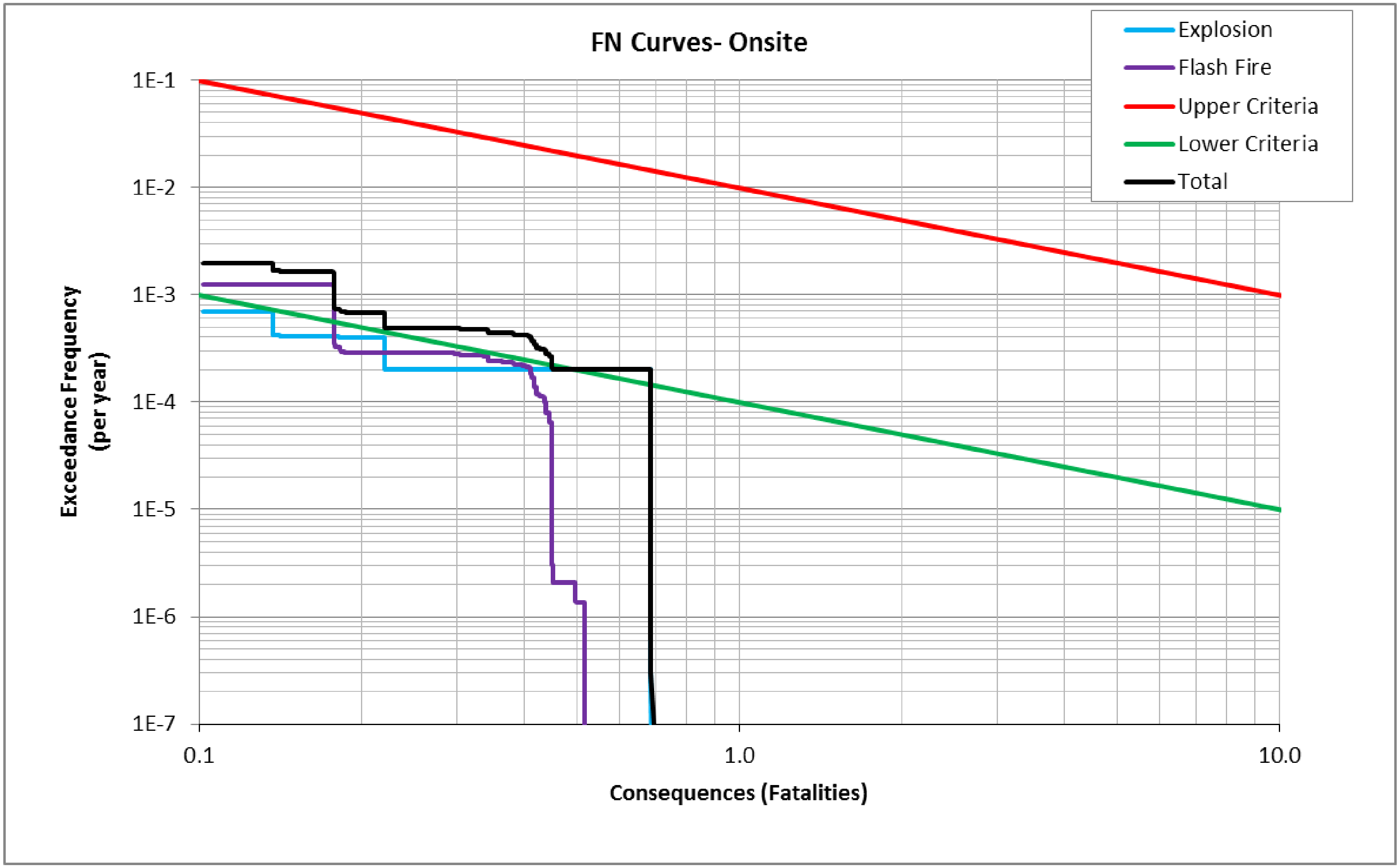

Figure ES-1. FN Curves – Onsite

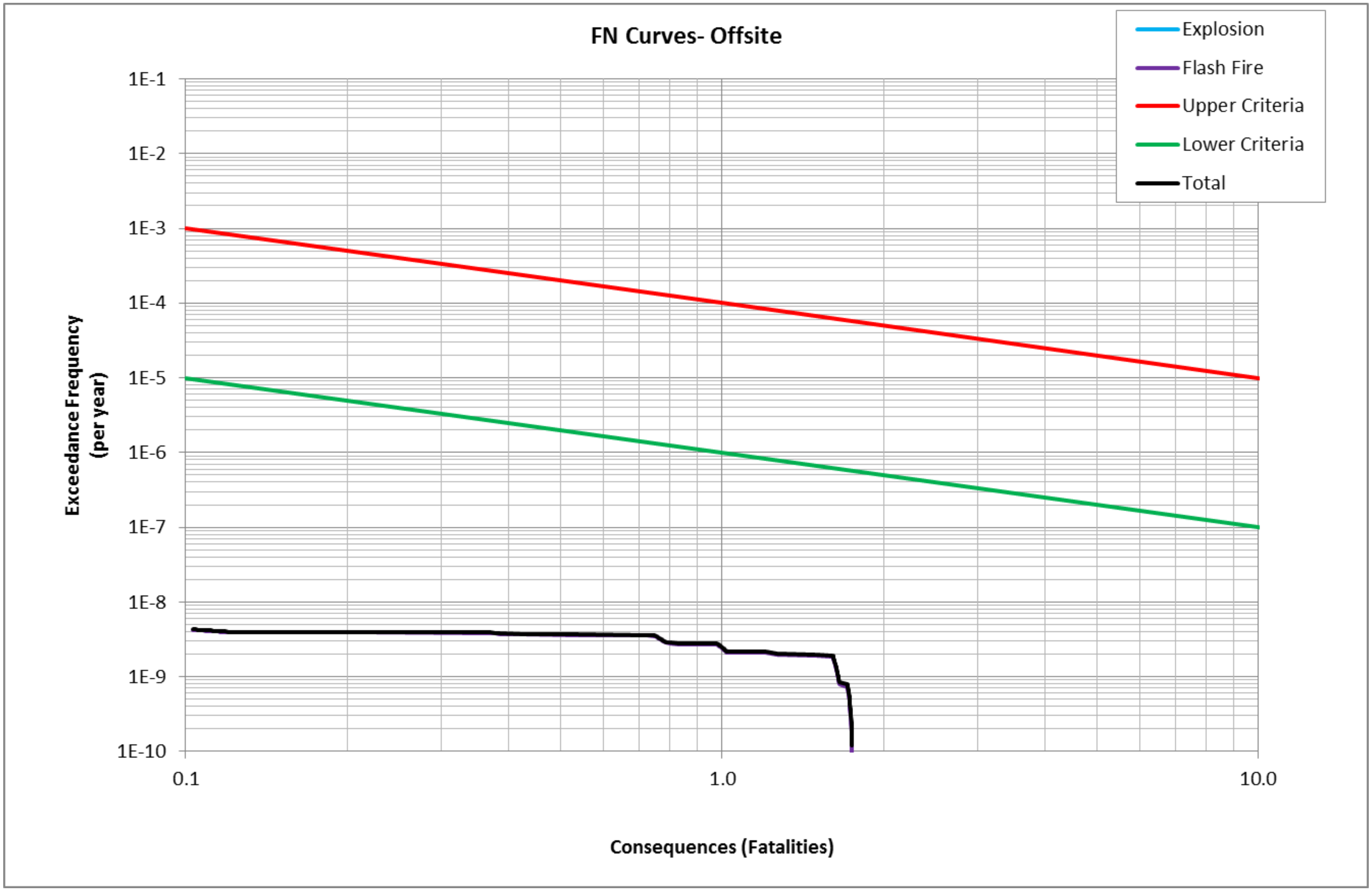

Figure ES-2. FN Curves – Offsite

Table ES-1. Onsite Building/Area Societal Risk

Building/Area	Baseline Societal Risk (fatalities/year)					% of Total	
	Explosion	Flash Fire	Toxic	Jet / Pool Fire	Total	Building / Area	Cumulative
Train Unloading Area	**	**4.6E-4**	**	5.7E-6	4.7E-4	67%	67%
Boiler Building	**1.9E-4**	7.8E-12	**	**	1.9E-4	27%	93%
Control Room- Train Loading	**4.7E-5**	7.1E-7	**	3.1E-8	4.7E-5	7%	100%
Fire Pump Building- Train Loading	**1.9E-7**	1.3E-7	**	6.2E-11	3.2E-7	0.05%	100%
Storage Tank Area	**	**8.5E-8**	**	5.1E-8	1.4E-7	0.02%	100%
Storage Building	7.2E-12	**1.4E-8**	**	**	1.4E-8	0.002%	100%
Control Room/Dock Building	**	**	**	**1.8E-9**	1.8E-9	0.0003%	100%
Fire Pump Building- Dock	**7.2E-10**	3.5E-11	**	2.2E-12	7.6E-10	0.0001%	100%
Marine Unloading Area	**	4.8E-11	**	**5.5E-11**	1.0E-10	< 0.0001%	100%
Admin Building	**9.3E-11**	**	**	**	9.3E-11	< 0.0001%	100%
Locker Room/Break Room	**3.9E-11**	**	**	**	3.9E-11	< 0.0001%	100%
VCU Area	**	8.8E-12	**	**2.0E-11**	2.9E-11	< 0.0001%	100%
Fire Pump Building- Tanks	**7.2E-12**	**	**	**	7.2E-12	< 0.0001%	100%
Totals	**2.3E-4**	**4.6E-4**	**Negligible**	**5.7E-6**	**7.0E-4**		
	33%	**66%**		**1%**			

* Highlighted cells represent outdoor areas
** Cells with ** represent negligible risk
***Bold values represent the largest risk contributor for each building

Table ES-2. Offsite Building/Area Societal Risk

Building/Area	Baseline Societal Risk (fatalities/year)					% of Total	
	Explosion	Flash Fire	Toxic	Jet / Pool Fire	Total	Building / Area	Cumulative
Offsite- Farwest Steel Main Building	**	**5.0E-9**	**	**	5.0E-9	94%	94%
Offsite- Tidewater Office	**2.8E-10**	**	**	**	2.8E-10	5%	99%
Offsite- BPA Alcoa Substation Building	**2.6E-11**	**	**	**	2.6E-11	0.5%	100%
Offsite- County Jail Building 3	**1.2E-11**	**	**	**	1.2E-11	0.2%	100%
Offsite- Tidewater Storage/Shop	**1.9E-13**	**	**	**	1.9E-13	0.004%	100%
Offsite- Tidewater Storage	**6.6E-14**	**	**	**	6.6E-14	0.001%	100%
Offsite- County Jail Building 2	**	**	**	**	**	< 0.0001%	100%
Offsite- County Jail Building 1	**	**	**	**	**	< 0.0001%	100%
Offsite- CPU River Road Building 2	**	**	**	**	**	< 0.0001%	100%
Offsite- Tidewater Shop	**	**	**	**	**	< 0.0001%	100%
Offsite- Tidewater Office 2	**	**	**	**	**	< 0.0001%	100%
Offsite- CPU River Road Building 3	**	**	**	**	**	< 0.0001%	100%
Offsite- Tidewater Old Warehouse	**	**	**	**	**	< 0.0001%	100%
Offsite- CPU River Road Building 1	**	**	**	**	**	< 0.0001%	100%
Offsite- NGL Energy Partners Trailer	**	**	**	**	**	< 0.0001%	100%
Offsite- AWC Port Services	**	**	**	**	**	< 0.0001%	100%
Offsite- Farwest Steel Building	**	**	**	**	**	< 0.0001%	100%
Offsite- County Jail Trailer	**	**	**	**	**	< 0.0001%	100%
Offsite- Tidewater Warehouse	**	**	**	**	**	< 0.0001%	100%
Offsite- Propane Tank Area	**	**	**	**	**	< 0.0001%	100%
Totals	**3.1E-10**	**5.0E-9**	**Negligible**	**Negligible**	**5.3E-9**		
	6%	**94%**					

* Highlighted cells represent outdoor areas
** Cells with ** represent negligible risk
***Bold values represent the largest risk contributor for each building

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Table ES-3. Source Risk Contribution

Source	Baseline Societal Risk (fatalities/year)					% of Total	
	Explosion	Flash Fire	Toxic	Jet / Pool Fire	Total	Source	Cumulative
01-SouthRail	2.0E-5	**3.1E-4**	**	**	3.3E-4	47%	47%
35-Boiler3	**1.4E-4**	**	**	**	1.4E-4	20%	66%
02-P2001	1.6E-6	**1.2E-4**	**	4.0E-6	1.3E-4	18%	85%
04-NorthRail	2.3E-5	**2.4E-5**	**	**	4.7E-5	7%	91%
34-Boiler2	**4.4E-5**	**	**	**	4.4E-5	6%	98%
05-P2006	1.6E-6	**2.5E-6**	**	9.5E-7	5.0E-6	0.7%	98%
33-Boiler1	**4.1E-6**	**	**	**	4.1E-6	0.6%	99%
06-HeatedRail	2.2E-7	**3.8E-6**	**	**	4.0E-6	0.6%	100%
36-Boiler Building	**1.6E-6**	**	**	**	1.6E-6	0.2%	100%
07-P2011	2.6E-8	2.5E-7	**	**7.2E-7**	1.0E-6	0.1%	100%
03-PIPE	1.3E-8	**1.7E-7**	**	1.5E-8	2.0E-7	0.03%	100%
17-P3001	**	**1.0E-7**	**	5.1E-8	1.5E-7	0.02%	100%
08-PIPE	**	3.5E-9	**	**1.1E-8**	1.4E-8	0.002%	100%
17-PIPE	**	**5.1E-9**	**	3.1E-10	5.4E-9	0.001%	100%
18-PIPE	**	1.9E-11	**	**1.6E-9**	1.6E-9	0.0002%	100%
22-Railcar	1.2E-11	**9.7E-10**	**	**	9.8E-10	0.0001%	100%
25-VCU001A	**7.2E-10**	**	**	**	7.2E-10	0.0001%	100%
20-PIPE	**	**	**	**7.5E-11**	7.5E-11	< 0.0001%	100%
19-PIPE	**	**7.3E-11**	**	**	7.3E-11	< 0.0001%	100%
15-PIPE	**	**1.9E-11**	**	**	1.9E-11	< 0.0001%	100%
19-VaporReturn	**	**1.9E-11**	**	**	1.9E-11	< 0.0001%	100%
21-PIPE	**	**7.8E-12**	**	**	7.8E-12	< 0.0001%	100%
37-Tank1	**7.2E-12**	**	**	**	7.2E-12	< 0.0001%	100%
40-Tank4	**7.2E-12**	**	**	**	7.2E-12	< 0.0001%	100%
23-Railcar	**	**4.9E-12**	**	**	4.9E-12	< 0.0001%	100%
16-PIPE	**	**8.1E-13**	**	**	8.1E-13	< 0.0001%	100%
Totals	**2.3E-4**	**4.6E-4**	**Negligible**	**5.7E-6**	**7.0E-4**		
	33%	**66%**		**1%**			

*Bold values represent the largest risk contributor for each source
** Cells with ** represent negligible risk

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1.0 INTRODUCTION

BakerRisk® was hired to perform an FSS and QRA for the Vancouver Energy Terminal in the Port of Vancouver, Washington. Tesoro Savage personnel knowledgeable in operations, processes, and emergency services provided input for the analyses. The analyses were performed using BakerRisk personnel knowledgeable in key areas of process safety and blast analysis.

This report is divided into several sections and includes a brief introduction followed by the study objectives in Section 2.0 and a Terminal description in Section 3.0. Section 4.0 documents the method of consequence and risk analysis used in this assessment, and Section 5.0 defines inputs used in the analysis. Section 6.0 provides consequence analysis, and Section 7.0 documents risk calculations and results. Section 8.0 presents conclusions of the analysis, and Section 9.0 includes references. Additional information is contained within the appendices.

2.0 OBJECTIVES

The primary objectives for this study were as follows:

- Define representative sources and locations to capture significant consequence contributors for the existing facility.
- Create a model of congestion and confinement of the Terminal to support blast calculations.
- Calculate potential flash fire, toxic and internal explosion impacts to building occupants.
- Calculate blast loads and resulting BDLs for buildings assessed. Determine the maximum blast loads and the scenarios causing those loads for each building assessed.
- Determine societal risks associated with Terminal operations for onsite and offsite personnel.
- Characterize significant sources of risk and their contribution to overall risk.
- Model potential deflagration inside the atmospheric storage tanks to estimate the debris throw distance and an equivalent BST blast load.
- Characterize the amount of risk incurred by occupants of each building or outdoor area assessed.
- Evaluate building individual risk.
- Develop a model that allows safety benefits to be quantified for risk mitigation strategies identified.

3.0 TERMINAL DESCRIPTION

This analysis assessed risk posed by the proposed Vancouver Energy Terminal which will transfer pipeline quality crude oil from railcars to marine vessels. The Terminal will receive an average of four unit trains per day and will transfer an average of 360,000 barrels (bbl) of crude oil per day. The crude oil will be stored in up to six double-bottom, internal floating-roof aboveground storage tanks (ASTs) located in Area 300. These tanks will be approximately 50 feet in height and 240 feet in diameter with a shell capacity of approximately 400,000 barrels each. The maximum amount of product stored in each tank will be approximately 360,000 barrels. A transfer pipeline system will be used to convey crude oil from rail unloading to storage and from storage to the marine terminal for vessel loading. The transfer pipeline system can also be operated to move crude oil from rail unloading directly to the marine terminal. The Terminal will operate 24 hours per day, 7 days per week.

The Terminal will include the following areas, as illustrated in Figure 1:

- Area 200 – Rail Unloading and Office
- Area 300 – Storage
- Area 400 – Marine Terminal
- Area 500 – Transfer Pipelines
- Area 600 –Boiler Building
- Rail Infrastructure

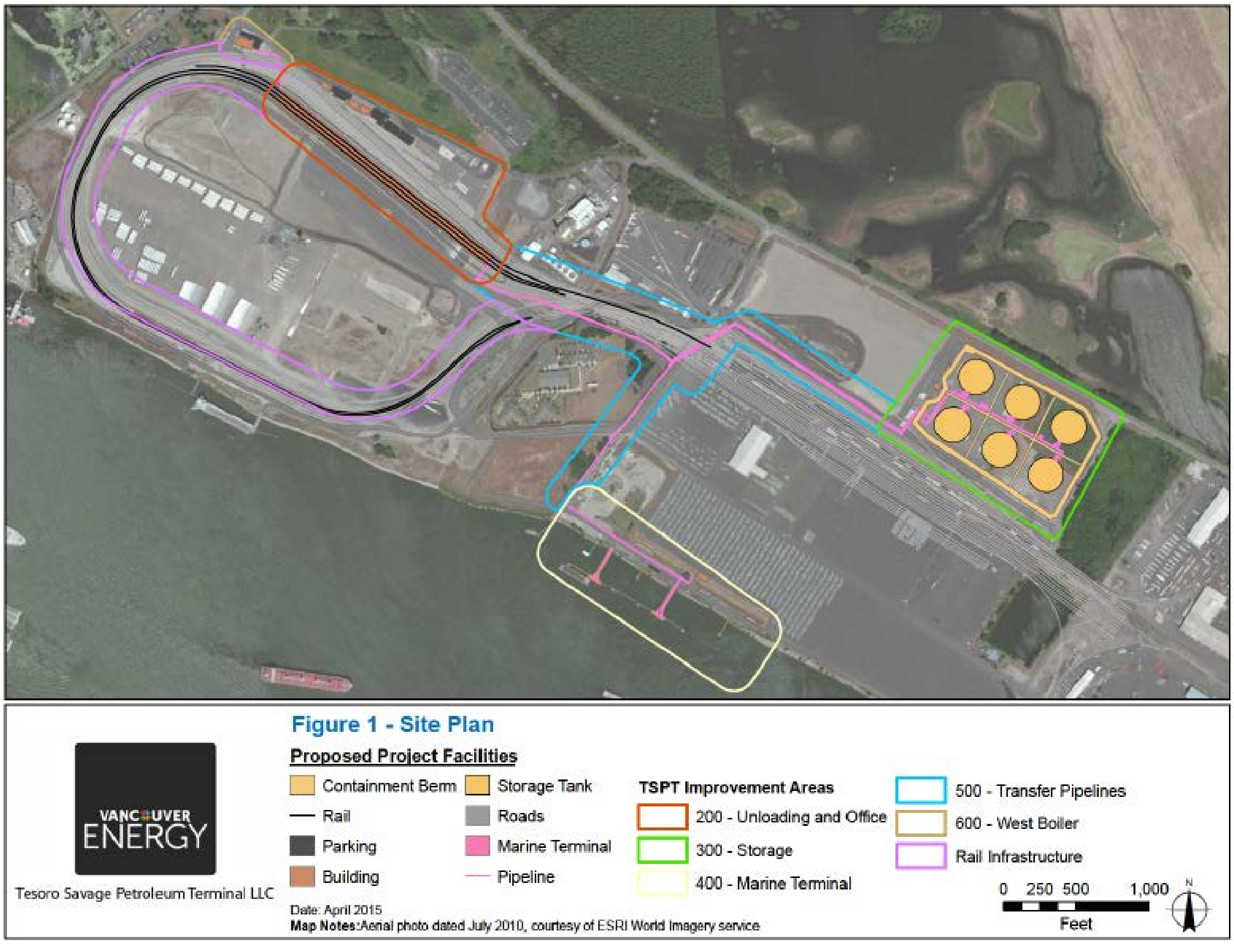

Figure 1. Plot Plan of Vancouver Energy Terminal

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4.0 Consequence and Risk Analysis Method

4.1 Hazard Identification

In this study, hazard identification input data was obtained from reviewing plot plans and process flow diagrams (PFDs) to determine an appropriate set of sources to represent the hazards of fire, explosion, and toxic exposure. The release cases were modeled for the most hazardous conditions of each defined process section. For each release location, 0.5-inch, 2-inch, and full bore rupture (up to 6-inch) release cases were modeled.

4.2 Consequence Analysis

For each release scenario, consequences are predicted in a sequential manner. Key steps are explained below.

- **Define Process Conditions:** The process equipment pressure, temperature, size, and contents (material composition) were obtained from the PFDs. Two types of crude oil were considered to represent the types expected to be transferred in this Terminal: one to represent the light crude oil (Bakken) and one to represent the lower API crude oil (WCS/Canada). The compositions for these crudes were based on average crude oil compositions and the experience of BakerRisk® with a wide variety of refining and crude oil transport facilities. Each crude composition was estimated to contain up to a conservatively high worst case maximum possibility of 5,000 ppm hydrogen sulfide based on recommendations from Tesoro Savage.
- **Define Environment:** Based on local meteorological data, four statistically significant weather conditions B1.7, D2.3, D7.0, and F1.2 were assessed for each release.
- **Model Release Cases:** BakerRisk's $SafeSite_{3G}$© computer code was used to model the release rates and subsequent dispersions. Each release scenario was modeled to last until steady state conditions are reached or until sixty minutes have lapsed. The release was assumed to be oriented horizontally and aligned with the wind to yield the largest downwind plume. For explosion impacts, vapor clouds were directed in 16 evenly spaced horizontal release/wind directions to provide a thorough assessment of potential explosion scenarios.
- **Results:** $SafeSite_{3G}$© was used to model discharge, dispersion, fire, and explosions. $SafeSite_{3G}$© uses the BST methodology,[2,3] a leading edge explosion model, validated and tested with large-scale vapor cloud explosion (VCE) field tests. The software was used to determine the intersection, in three dimensions, between the dispersed material and the volumes of congestion. The energy within these areas of congestion is then used in predicting the pressure and impulse from a VCE. Appendix A describes more information on vapor explosion prediction methodology.

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[1] Baker, Q. A., M.J. Tang, E. A. Scheier and G. J. Silva, "Vapor Cloud Explosion Analysis," 28th Annual Loss Prevention Symposium, July 19, 1994.

[2] Baker, Q. A., C. M. Doolittle, G. A. Fitzgerald and M. J. Tang, "Recent Developments in the Baker-Strehlow VCE Analysis Methodology," 31st Loss Prevention Symposium, April 9-13, 1997.

- In the unlikely event that a release of flammable material occurs and subsequently explodes, this study evaluates blast loads on the buildings being studied. Pressure plots are generated to provide a visual indication of the magnitude of energy resulting from each scenario. Detailed building information was not available at the time of this study, so a single, relatively weak building model type was used to predict structural response for each building assessed. By combining blast overpressure and impulse with the building construction type, BDLs and occupant vulnerabilities are calculated.
- Internal explosions were also considered as part of this evaluation. Combustion zones, or fireboxes for the vapor combustion units (MVCUs) and boilers, were evaluated as fill cases with medium reactivity fuels filling 100% of the combustion section with a stoichiometric mixture and then igniting. The Boiler Building was also assessed for a potential internal explosion caused by a leak in the natural gas piping into the building.
- The FLame ACceleration Simulator (FLACS) computational fluid dynamics (CFD) computer code was used to model potential deflagration inside the atmospheric storage tanks to estimate the debris throw distance and an equivalent BST VCE source based on transient internal and external blast loads. See Appendix G for the detailed analysis.
- Effects of flammable and toxic gas releases on building occupants are based on the concentration of gases predicted to occur at the building. Results were reported in terms of concentration categories (> UFL, > LFL, or > ½ LFL for the flammable concentration at each building, >90% lethality concentration, >10% lethality concentration, >1% lethality concentration for toxic gas concentration and associated lethality at each building). Results were reported in terms of the most severe end point predicted to occur at each building.
- Occupant vulnerability values for people inside onsite buildings due to thermal impacts (jet/pool fires) are assessed by assuming that occupants evacuate the building at the wall farthest from the fire source and evacuate away from the fire source. Vulnerability is evaluated as a function of a probit equation, with the probit coefficients determined by fitting to lethality data for exposure to fireballs taken from a report by the International Association of Oil and Gas Producers.[4] An assumed evacuation rate (3 m/s for this study) was used with into SafeSite$_{3G}$© to determine the integral of the thermal flux, which corresponds to the thermal dose or total thermal flux received during evacuation. SafeSite$_{3G}$© calculates an occupant vulnerability value for each building assessed based on every specified jet or pool fire scenario. Occupants for offsite buildings are assumed to remain in the building during a release.
- Occupant vulnerability values for people inside buildings due to toxic impacts are assessed by assuming that occupants for onsite buildings evacuate the building cross wind. An assumed evacuation rate of 1 m/s is input into SafeSite3G© to determine the toxic dose incurred during evacuation. Occupants for offsite buildings are assumed to remain in the building during a release.

[4] Vulnerability of Humans, International Association of Oil and Gas Producers, Report No 434-14.1 (2010)

4.4 Risk Assessment

This section briefly describes the method used to model consequences associated with the accidental release of process materials and to convert those consequences into risk results using occupancy and frequency. The following is a summary of the method used for this analysis.

- Defined outdoor areas where personnel may be present and estimated average occupancy for each time slot for each defined area and building. For outdoor personnel, the number of personnel impacted from explosions, fires and toxics based on overpressure contours, flammable clouds, toxic lethality contours, and thermal lethality contours that were defined in the consequence assessment.
- Used equipment failure rate data (see Section 5.0, Table 5), and equipment count data was obtained by reviewing PFDs and piping and instrumentation diagrams (P&IDs), and pipe size/length data, estimate release frequencies.
- Estimated jet/pool fire, flash fire, toxic and explosion frequencies by considering conditional probabilities of ignition for crude oil based on the presence of ignition sources and controls.
- Calculated risks to onsite personnel (inside and outside of buildings) based on release frequencies, conditional probabilities, and consequences of each scenario type.
- Reported risk results in terms of societal (aggregate) risk values. Societal risk results were presented in terms of FN curves and tables that list source contribution and building/outdoor area contribution to focus attention on candidate sources and buildings for risk mitigation.
- Reported risk results in terms of building and outdoor area individual risk. Building and outdoor area individual risk provide insights into areas and buildings on site where occupancy should be minimized and areas and buildings with low risk, where people should be located to the extent practicable.

4.5 Scenario Development

Scenarios must be developed for the QRA once the inputs are defined. The event tree provided in Figure 2 shows a simplified version of how potential scenarios are developed. The event tree headers are described below.

- *Initiator*: The starting point is a release of hazardous material from the process. Note that other events such as firebox explosion are not processed using this event tree.
- *Source Location:* The first branch splits indoor scenarios (releases inside buildings) from outdoor releases.
- *Size:* The second branch splits each release into a range of release sizes. Outdoor scenarios are assessed for small, medium, and large releases (0.5-inch, 2-inch, and full bore up to 6-inch diameter). Indoor scenarios may only distinguish between cases predicted to overwhelm ventilation and those that are small enough to behave like outdoor dispersion cases. A small indoor release is assumed to only impact people within the building where the release occurs if it is a fire or toxic event (not shown on event tree), but it is treated the same as an outdoor release for explosion scenarios.

- *Weather Conditions:* This branch is only applicable to outdoor release scenarios. Each release is typically assessed for a range of two or four statistically significant weather conditions.
- *Wind Direction:* Each dispersion is assessed in 16 evenly-spaced horizontal directions.
- *Flammability:* Hazards are split into flammable and non-flammable (toxic only) categories.
- *Ignition:* Outdoor flammable releases are assessed for early, late, and non-ignition.
    - Early ignition scenarios are assessed as jet or pool fire, depending on the material conditions.
    - Late ignition and non-ignition scenarios are further divided later in the event tree.
    - Indoor cases are split into three categories for delayed ignition (early, medium, and late). These represent the portion of the room that is filled with a flammable mixture at the time of ignition. They are assessed as causing 25%, 50%, and 90% of the blast energy of a stoichiometric mixture for the entire room volume.
- *Toxicity:* Flammable non-toxic releases that are not ignited have no consequences. Flammable releases that are toxic and are not ignited are grouped together with non-flammable toxic sources and are treated together hereafter.
- *Building:* This branch is only applicable to outdoor delayed ignition scenarios. It splits scenarios into outdoor areas, open buildings, and closed buildings. Open buildings are assessed as congestion/confinement zones and are assessed for blast and flash fire effects. Closed buildings and outdoor impacts are further split later in the event tree.
- *Sheltering:* This branch is only applicable to toxic impacts. It splits the scenario into outdoor populations, non-shelter-in-place (non-SIP) buildings, and SIPs. Impacts to outdoor populations are based on lethality of toxic concentration thresholds and assumed duration within the plume. Impacts to occupants of non-SIP buildings are evaluated for a person evacuating the building and traveling crosswind to a safe location. Scenarios impacting SIPs are further refined later in the tree.
- *HVAC Isolation:* This branch splits into two possibilities the scenarios in which flammable or toxic vapors reach a closed building. One branch has HVAC successfully isolated, and the other reflects continued HVAC operation (HVAC running).
- *Plume Duration:* This branch is applicable to closed buildings for flammable impacts and SIPs for toxic impacts.
    - <u>Closed Buildings</u>: This branch splits into a range of durations the flammable scenarios that impact closed buildings. For a closed building with HVAC successfully isolated, an indoor explosion is only considered possible if the plume lasts a very long time (infiltration will eventually allow indoor concentration to exceed LFL). Those cases are shown as a transfer to the indoor explosion branch (although these scenarios can be dismissed, as occupants would likely evacuate the building before the bulk of the concentration reached flammable levels). Shorter duration plumes would not have a significant impact within the building, so they transfer to the branch treating outdoor dispersions. If HVAC is not successfully isolated (HVAC running), the same two outcomes are possible, but they are shorter duration events because of ingression through the HVAC system.
    - <u>SIP</u>: For toxic scenarios impacting a SIP, the indoor concentration profile is calculated, and the resulting exposure is converted to occupant vulnerability. The

concentration vs. time profile is more severe for the case in which HVAC is not successfully isolated (HVAC running), and vulnerability calculations account for this effect.

- *Congestion/Confinement:* This branch shows how flammable clouds are evaluated for delayed ignition. If the flammable plume is outside of congestion/confinement, the scenario is a flash fire, followed by a jet fire from the source. If the plume intersects low congestion, a deflagration is predicted, followed by a jet fire. Intersection with medium or high congestion has a range of possible outcomes so those scenarios are further split later in the event tree. Although it is unrelated to congestion/confinement, toxic impacts at SIPs are split under this heading into scenarios where people either evacuate or they remain in the building. This is done to show that the site may have a backup plan in which the SIP is equipped with indoor toxic monitoring, and occupants don escape packs and evacuate if the toxic concentration in the SIP reaches a certain threshold.
- *Fuel Reactivity:* Scenarios involving a flammable plume encountering medium or high congestion are split into low or medium reactivity fuel cases and high reactivity fuel cases. Low and medium reactivity fuel plumes are predicted to deflagrate followed by a jet fire. High reactivity fuel scenarios are predicted to detonate followed by a jet fire.
- *Scenario:* This heading is not associated with further splitting scenarios into more branches. It describes the type of scenario each branch represents.

The event tree does not show the split of time slots (regular business hours, off shift, weekend hours) for each scenario. Each scenario is assessed for consequences, which depend on the number of people present. Because the number of people present depends on the time of day, each scenario is evaluated for each time slot. The event tree also does not distinguish between liquid and vapor scenarios. Fire scenarios are evaluated for jet fire when flammable vapors are generated and pool fires for liquid releases.

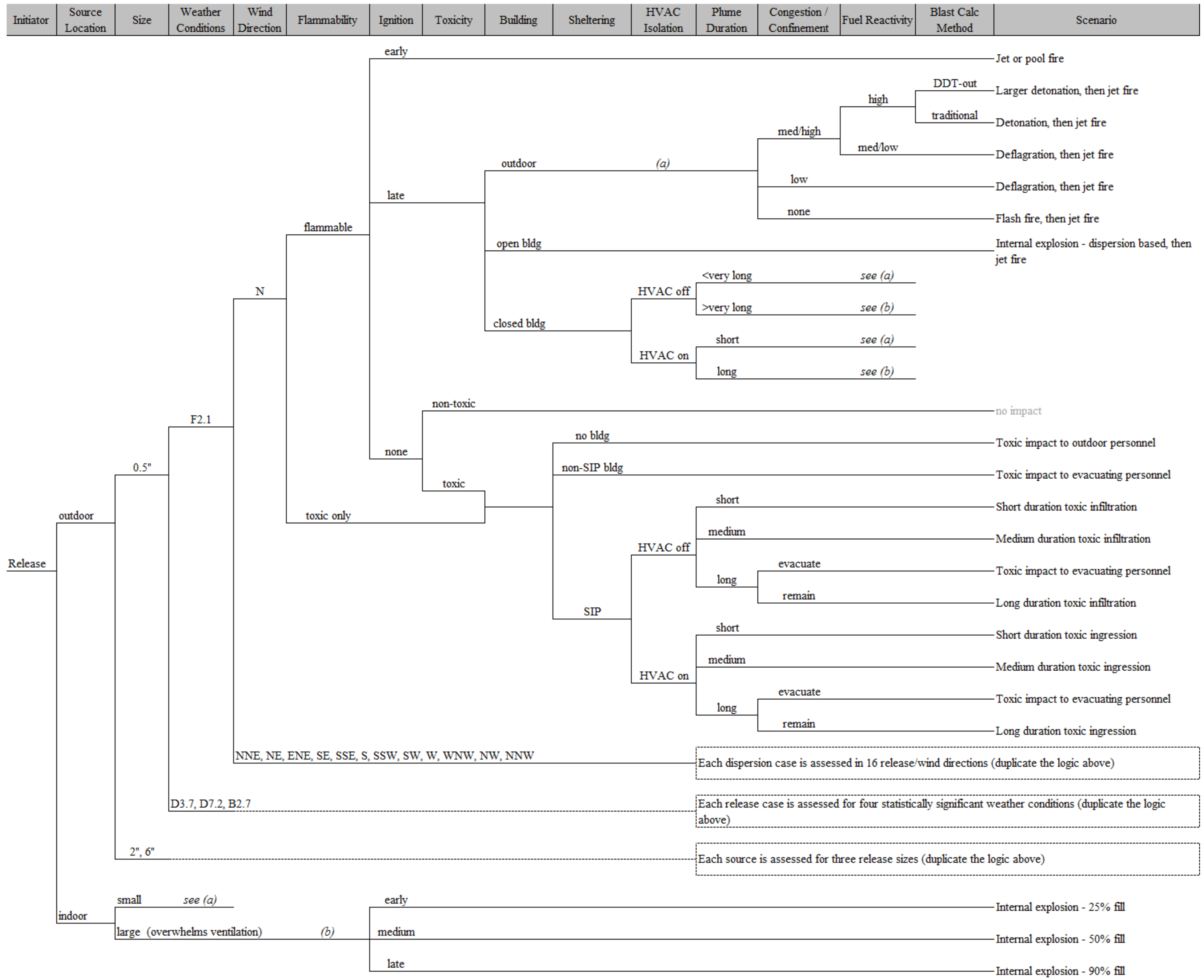

Figure 2. Sample Event Tree

5.0 ANALYSIS INPUT

5.1 Release Cases

Representative sources were identified by reviewing PFDs and holding discussions with Tesoro Savage personnel knowledgeable of the process. Highlighted PFDs for the representative sources are provided in Appendix C. Input conditions used for dispersion modeling are summarized in Appendix E, ***Sources*** tab, and point source locations are shown in Figure 3. Information regarding pipelines including associated release sources, source spacing, and pipeline lengths are summarized in Appendix E, ***Pipelines*** tab. Piping routes for these sources are shown in Figure 4.

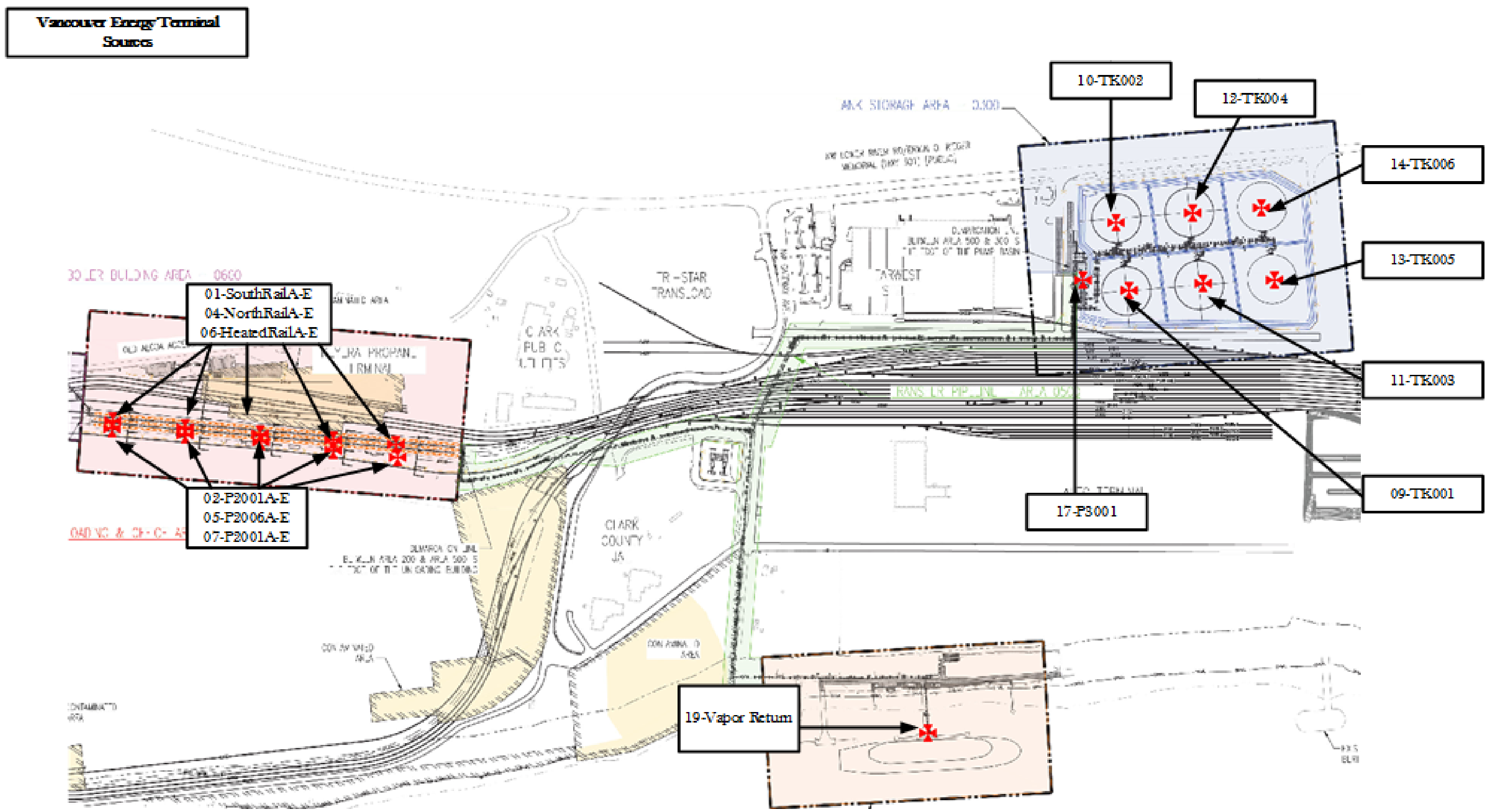

Figure 3. Release Source Locations

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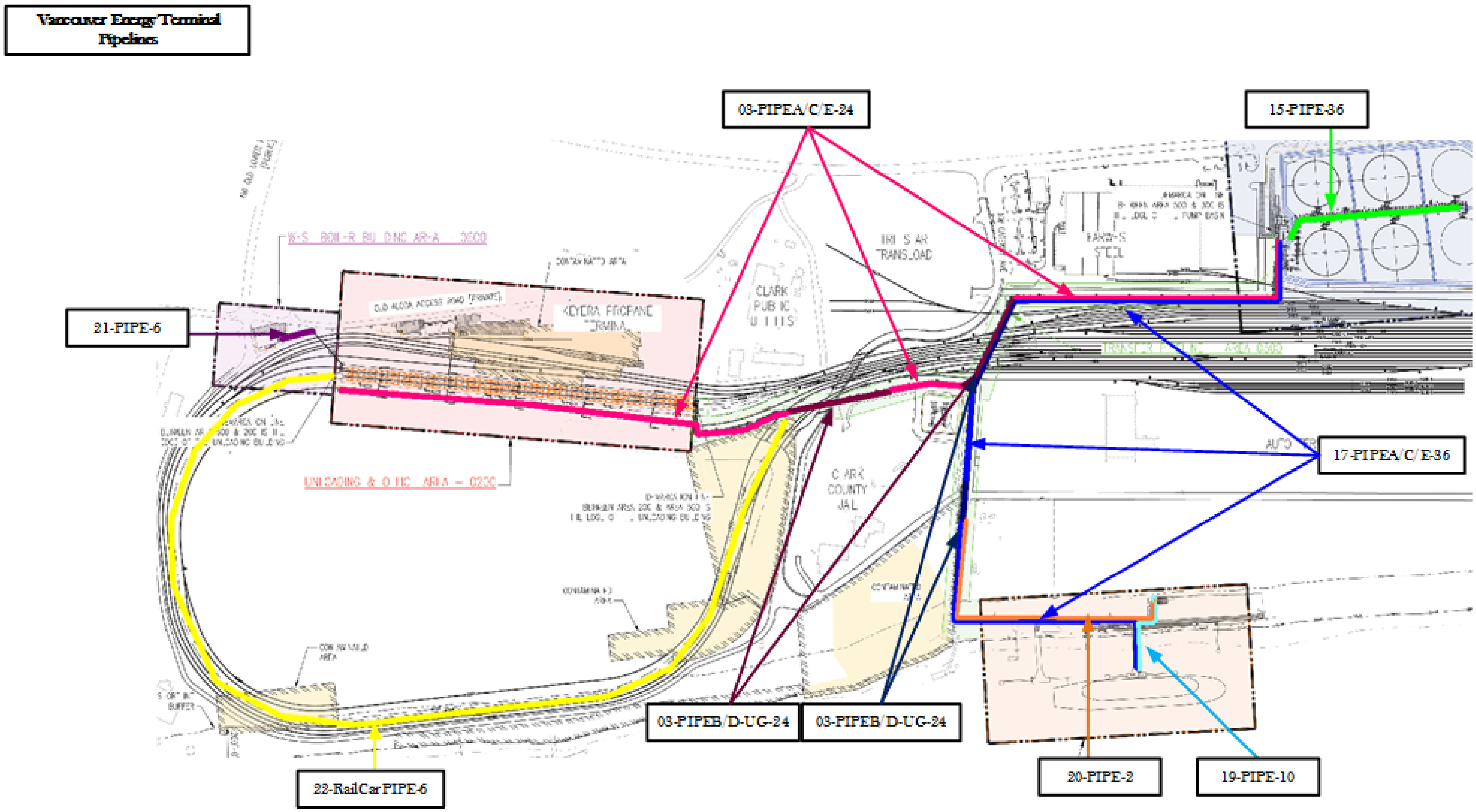

Figure 4. Pipeline Routes

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5.2 Materials

Table 1 summarizes the flammable materials used for the release cases modeled. Fuel reactivity is related to the fuel laminar burning velocity. Common low reactivity fuels include methane, hydrogen sulfide, and carbon monoxide. Common high reactivity fuels include hydrogen, acetylene, ethylene, ethylene oxide, and propylene oxide. Most other hydrocarbons are classified as medium reactivity.

Two types of crude oil were used in this model: one to represent the light crude oil (Bakken) and one to represent the lower API crude oil (WCS/Canada) that could come to this Terminal. The compositions for these crudes were based on average crude oil compositions and the experience of BakerRisk® with a wide variety of refining and crude oil transport facilities. Each crude oil composition was estimated to contain up to a conservatively high worst case maximum possibility of 5,000 ppm hydrogen sulfide based on recommendations from Tesoro Savage.

Table 2 summarizes the flammable mixtures used for the release cases and their reactivity assignments.

Table 3 summarizes the toxic concentrations that result in a 1%, 10%, and 90% lethality over a 60-minute exposure for hydrogen sulfide.

Table 1. Flammable Materials Used in the Model

Material	Fuel Reactivity
1,1,2,2-Tetraphenylethane	Medium
1,4-DI-tert-Butlybezene	Low
Ethane	Medium
Hydrogen Sulfide	Low
Isopentane	Low
Methane	Low
n-Butane	Medium
n-Docosane	Low
n-Dodecane	Low
n-Heptadecane	Low
n-Heptane	Medium
n-Hexane	Medium
n-Nonane	Low
n-Octane	Low
n-Pentane	Medium
n-Triacontane	Low
n-Undecylbenzene	Low
p-Ethyltoluene	Low
Propane	Medium

Table 2. Flammable Mixtures Used in the Model

Mixture	Lower API Crude	Light Crude	Marine Vapor	Natural Gas
1,1,2,2-Tetraphenylethane	36%			
1,4-DI-tert-Butlybezene	13%			
Ethane			3%	3%
Hydrogen Sulfide	0.5%	0.4%	0.5%	
Isopentane	0.3%			
Methane			97%	97%
n-Butane	0.4%	5%		
n-Docosane				
n-Dodecane	11%			
n-Heptadecane	9%			
n-Heptane	2%	18%		
n-Hexane	2%	7%		
n-Nonane	3%	9%		
n-Octane	3%	18%		
n-Pentane	0.4%	10%		
n-Triacontane		30%		
n-Undecylbenzene	13%			
p-Ethyltoluene	5%			
Propane	0.3%	2%		
Water	1%			
Fuel Reactivity	**Medium**	**Medium**	**Low**	**Low**

Table 3. Toxic Materials and Endpoint Concentrations from Hydrogen Suflide

Material	Probits (a, b, N)	Source	Lethality (ppm)		
			1%	10%	90%
Hydrogen Sulfide	-10.7, 1, 1.9	TNO Purple Book	132	229	882

5.3 Fill Case Scenarios

The consequences of release cases occurring inside a confined volume and having potential to fill a significant portion of the enclosed volume were modeled as fill scenarios. For these scenarios, the space was assumed to fill with a stoichiometric mixture of fuel and air, then ignite resulting in an explosion. Combustion zones, or fireboxes for the marine vapor combustion units (MVCUs) and boilers, were evaluated as well as the potential to fill the Boiler Building. Additionally, FLACS was used to model the unlikely potential of deflagration inside the atmospheric storage tanks to estimate the debris throw distance and an equivalent BST VCE source (i.e., explosion energy and flame speed).

Input conditions used for the fill zone scenario are summarized in Table 4, and their locations are displayed in Appendix C. Additional details are provided in Appendix E, ***Fill*** tab, and Appendix F.

Table 4. Fill Case Scenarios

Scenario	Description	Volume (ft3)	Total Energy (in-lb$_f$)
25-VCU001A-Fbox	Firebox explosion -VCU001A	71	7.1E+7
26-VCU001B-Fbox	Firebox explosion -VCU001B	71	7.1E+7
27-VCU001C-Fbox	Firebox explosion -VCU001C	71	7.1E+7
28-VCU001D-Fbox	Firebox explosion -VCU001D	71	7.1E+7
29-VCU001E-Fbox	Firebox explosion -VCU001E	71	7.1E+7
30-VCU001F-Fbox	Firebox explosion -VCU001F	71	7.1E+7
31-VCU001G-Fbox	Firebox explosion -VCU001G	71	7.1E+7
32-VCU001H-Fbox	Firebox explosion -VCU001H	71	7.1E+7
33-Boiler1-Fbox	Boiler 1 Firebox explosion	3,550	3.6E+9
34-Boiler2-Fbox	Boiler 2 Firebox explosion	3,567	3.6E+9
35-Boiler3-Fbox	Boiler 3 Firebox explosion	3,561	3.6E+9
36-Boiler Building-Fill25	Boiler Building fill case	232,392	5.8E+10
36-Boiler Building-Fill50	Boiler Building fill case	232,392	1.2E+11
36-Boiler Building-Fill90	Boiler Building fill case	232,392	2.1E+11
37-Tank1-Fbox	Tank explosion based on FLACS analysis	150,664	2.7E+10
38-Tank2-Fbox	Tank explosion based on FLACS analysis	150,664	2.7E+10
39-Tank3-Fbox	Tank explosion based on FLACS analysis	150,664	2.7E+10
40-Tank4-Fbox	Tank explosion based on FLACS analysis	150,664	2.7E+10
41-Tank5-Fbox	Tank explosion based on FLACS analysis	150,664	2.7E+10
42-Tank6-Fbox	Tank explosion based on FLACS analysis	150,664	2.7E+10

5.4 Zones of Congestion and Confinement

Congestion and confinement zones are the physical equipment, vegetation and obstacles present in the Terminal that create turbulence when a flammable vapor cloud is ignited. Appendix A provides additional information regarding the effects of congestion and confinement on VCE calculations. Zones of congestion and confinement of the Terminal were defined from the plot plan layout and industry experience. Detailed information about each zone can be viewed in Appendix E, ***Zones*** tab. Figure 5 shows an overview of the Terminal with zones of congestion and confinement displayed, and the legend identifying the types of zones is shown below the figure.

5.5 Buildings and Outdoor Populations

Building location information was provided by Tesoro Savage. The assessed buildings are shown in Figure 6 through Figure 8, and outdoor area locations are shown in Figure 9. Building construction type, dimensions, and toxic occupancy vulnerability parameters are listed on the ***Buildings*** tab in Appendix E. Appendix B provides detailed descriptions of the relatively weak Type 22 Modular Building used to represent all buildings in this analysis in order to estimate building damage. Actual building construction is expected to be stronger, so actual building damage is expected to be less than predicted in this study.

5.6 Population Data and Work Group Definitions

Occupancy data is based on input provided by Tesoro Savage and is documented in Appendix F, ***Occupancy & Mitigation*** *tab*. Occupancy data was estimated for buildings based on day shift (84 hr/week) and night shift (84 hr/week). Each scenario modeled is evaluated for each time slot. The probability of each time slot is incorporated into the accident scenario frequency calculation, and the occupancy is used to estimate consequences.

5.7 Frequency Data

Release frequencies are based on equipment counts generated by reviewing PFDs, pipe size/estimated length data, and industry average failure rates (References 1-11). Failure rates are summarized in Table 5. Equipment counts are provided in Appendix F. Releases from long pipelines are modeled based on sources with similar conditions along the length of the line.

5.8 Meteorological Data

Statistical meteorological data was provided to BakerRisk® based on STAR data for the Pearson Field Airport for the years 2008 to 2012. See Appendix G for details. Each release case was modeled under weather conditions B1.7, D2.3, D7.0, and F1.2. In the weather condition names, the letter represents Pasquill atmospheric stabilities and the number represents wind speeds in meters per second; therefore F1.2 refers to atmospheric stability F with a wind speed of 1.2 m/s. In the Pasquill stability classes, A is very unstable and F is very stable.

5.9 Ignition Probabilities

The probability that a flammable release will ignite is based on industry experience, and values are assigned as a function of release magnitude, as summarized in Appendix F, ***Ignition Probabilities***. Early ignition is assessed for fire impacts (jet and pool), and delayed ignition is assessed for explosion consequences and flash fire impacts. Non-ignition events are assumed to have toxic consequences for toxic sources or no impacts for non-toxic (flammable) sources.

Figure 5. Zones of Congestion and Confinement

- Building
- 3D flame expansion with high obstacle density
- 3D flame expansion with medium obstacle density
- 3D flame expansion with low obstacle density
- 2.5D flame expansion with high obstacle density
- 2.5D flame expansion with medium obstacle density
- 2.5D flame expansion with low obstacle density
- 2D flame expansion with high obstacle density
- 2D flame expansion with medium obstacle density
- 2D flame expansion with low obstacle density
- Enclosed 2.5D flame expansion with high obstacle density
- Enclosed 2.5D flame expansion with medium obstacle density
- Enclosed 2.5D flame expansion with low obstacle density
- Enclosed 2D flame expansion with high obstacle density
- Enclosed 2D flame expansion with medium obstacle density
- Enclosed 2D flame expansion with low obstacle density

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Figure 6. Buildings Overview

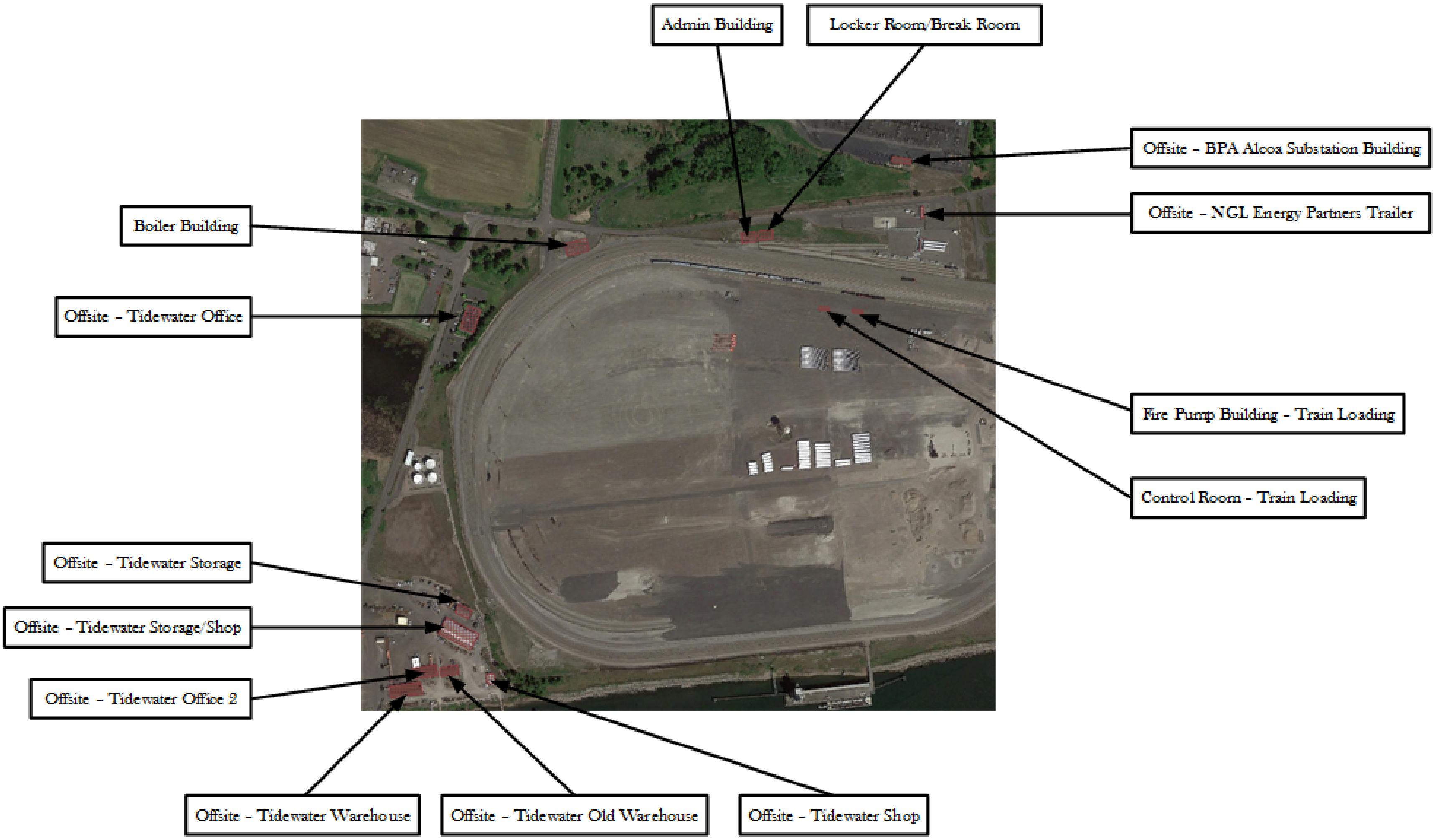

Figure 7. Buildings View 1

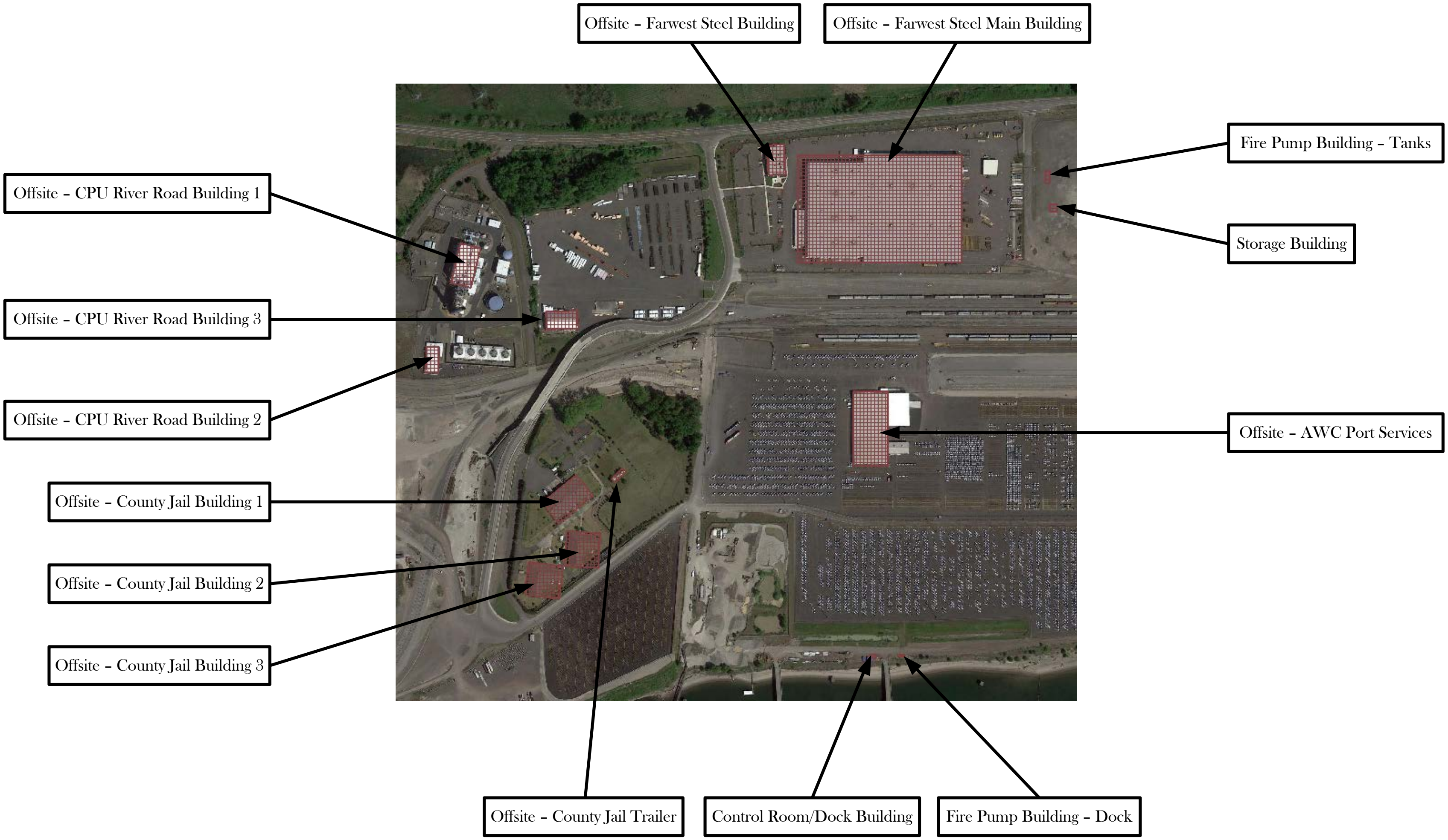

Figure 8. Buildings View 2

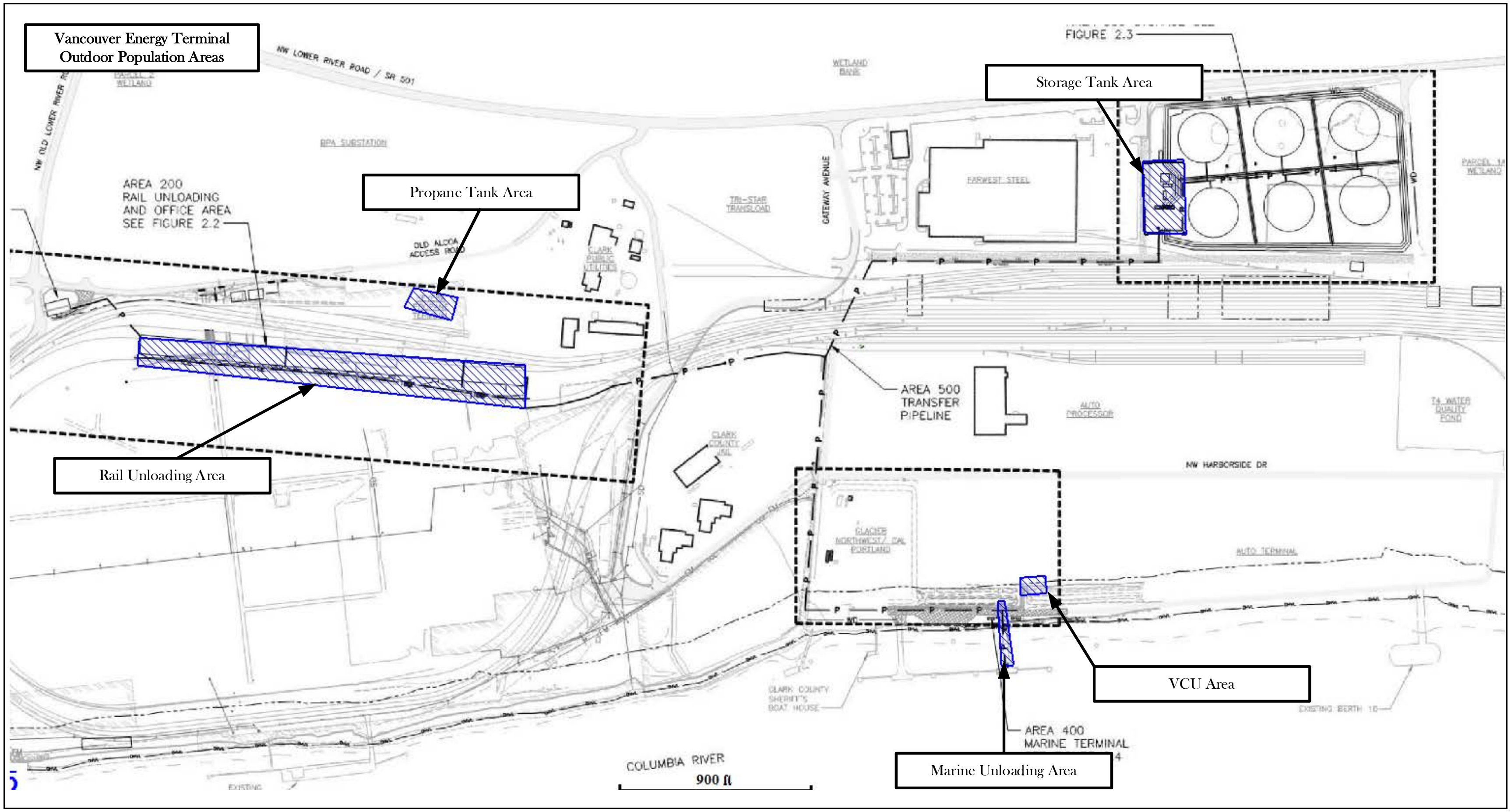

Figure 9. Outdoor Population Areas

Table 5. Failure Rates

Leak size (in. dia.)	**Centrif. Comp.**	**Recip. Comp.**		**Centrif. Pump**	**Recip. Pump**	**Lineal feet of pipe (various pipe sizes)**							**Process Pressure Vessel**	**Storage Vessel**	**Heat Exchanger (Shell-Tube) HC in Shell**	**Heat Exchanger (Fin Fan)**	**Filter**	**Loading / Unloading (per load)**
		<3MW	**>3MW**			**1-in dia**	**2-in dia**	**4-in dia**	**6-in dia**	**10-in dia**	**12-in dia**	**20-in dia**						
0.5	3.0E-3	5.0E-3	5.0E-2	3.0E-3	1.0E-2	3.0E-6	1.0E-6	1.0E-6	9.0E-7	6.0E-7	5.0E-7	3.0E-7	1.5E-4	3.0E-3	5.0E-4	1.0E-3	4.0E-4	1.3E-5
2	3.0E-4	1.0E-3	1.0E-2	5.0E-4	3.0E-3		1.5E-7	2.0E-7	2.0E-7	1.0E-7	1.0E-7	9.0E-8	3.0E-5	2.0E-4	7.0E-5	4.0E-4	6.4E-6	1.5E-6
FB	3.0E-5	5.0E-4	5.0E-3	8.0E-5	1.0E-3			6.0E-8	6.0E-8	7.0E-8	6.0E-8	4.0E-8	7.0E-6	2.0E-5	3.0E-5	2.0E-4	6.4E-6	1.5E-6

5.10 Explosion Vulnerabilities

Occupant vulnerability values are calculated using SafeSite$_{3G}^{©}$ for each building for each explosion scenario modeled. Release cases are based on those defined in the FSS, weather conditions reflect statistical weather data, and wind directions are selected as described in Appendix G. Buildings that incur no significant damage (BDL < 2.5 for all scenarios) and scenarios causing no significant building damage are excluded.

Occupant vulnerability values for people outside of buildings for explosions are assessed as a function of free field overpressure, according to values summarized in Table 6.

Table 6. Vulnerability Values for Outdoor Populations for Explosions

Pressure (psig)	Vulnerability	Non-Escape Probability	Comments
1 to 5	5%	10%	These are approximate estimates to allow for debris type injuries. Note that people in buildings/trailers would have a much higher probability of injury if the building is not designed for the blast loads.
5 to 15	10%	50%	
> 15	100%	50%	Blast pressures above 15 psig may cause lungs to rupture and are assumed to be lethal, but credit is applied to account for the possibility of escape before the explosion occurs.

5.11 Flash Fire Vulnerabilities

Occupant vulnerability values for people outside of buildings or in an open or seasonal building are assessed for flash fires as a function of flammable gas concentration, according to values summarized in Table 7. Flash fires are not evaluated for closed buildings because closed buildings are assumed to afford sufficient protection against these short duration events. Non-escape probabilities presented in this table are only applicable for outdoor personnel, but credit is given to building occupants of seasonal buildings by applying a building flammable mitigation factor of 0.5. Building classification types for all buildings are summarized in Appendix E.

Table 7. Vulnerability Values for Flash Fires

Range	Vulnerability	Non-Escape Probability	Comments
½ LFL to LFL	50%	25%	People in areas between the LFL and 1/2 LFL are less likely to be impacted and are more likely to escape the area.
LFL to UFL	100%	80%	The majority of people within the LFL are assumed to be fatally injured. Escape is credited 20%.
> UFL	100%	100%	All people in the UFL are assumed to be fatally injured and have no chance of escape.

5.12 Jet/Pool Fire Vulnerability

Occupant vulnerability values for people inside buildings that are not designed to mitigate fire impacts (non-SIPs) are assessed for jet/pool fire impacts by assuming that occupants evacuate the building at the exit farthest from the fire source and evacuate away from the fire source or to the side, depending on which gives a lower value. Vulnerability is evaluated as a function of the following probit equation:

$$Y = A + B\ln\left(\int I^{\frac{4}{3}}dt\right)$$

where Y is the probit value, I is the thermal radiation intensity in kW/m^2, and A and B were determined to be -28.242 and 4.482, respectively, by fitting data for lethality due to exposure to fireballs from a report by the International Association of Oil and Gas Producers[5]. An assumed evacuation rate of 3 m/s is used with $\text{SafeSite}_{3G}^{\copyright}$ to determine the integral of the thermal flux, which corresponds to the "thermal dose" or total thermal flux received during evacuation. $\text{SafeSite}_{3G}^{\copyright}$ calculates an occupant vulnerability value for each building based on every specified jet or pool fire scenario.

The vulnerability of personnel located in outdoor population areas is approximated using lethality contours. Lethality contours represent the vulnerability of personnel during a hazard due to their initial proximity to the hazard and expected evacuation route. To generate lethality contours, the total dose incurred during evacuation is calculated by modeling personnel traveling at a conservatively low, uniform velocity orthogonal to the hazard, and originating from various outdoor locations.

Onsite occupants are assumed to evacuate the building for fire events. Offsite occupants were evaluated based on the occupants remaining in the building for thermal consequences.

5.13 Toxic Vulnerabilities

Toxic impacts are assessed for occupants of onsite buildings in which they are directed to evacuate in case of a toxic release and for outdoor personnel. Potential toxic hazards are evaluated using lethality contours. Lethality contours represent the vulnerability of personnel during a hazard due to their initial proximity to the hazard and expected evacuation route. To generate lethality contours, the total dose incurred during evacuation is calculated by modeling personnel traveling at a conservatively low, uniform velocity orthogonal to the hazard, and originating from various outdoor locations.

Occupant vulnerability values for people inside buildings that are directed to evacuate in case of a toxic release are assessed by assuming that occupants evacuate the building at an effective rate of 1 m/s traveling cross wind to a safe location. People in outdoor areas are also assumed to evacuate at a rate of 1 m/s traveling cross wind to a safe location. Toxic dose is calculated, based on the concentration as a function of time, the probit equation below, and the probit values documented in Table 3. The probit equation relates the dosage at a point to the probability of death.

[5] Vulnerability of Humans, International Association of Oil and Gas Producers, Report No 434-14.1 (2010)

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The probit is a probability measure related to the Gaussian distribution curve of the response of individuals in a population to a given exposure to a toxic substance. It assumes the Gaussian distribution with a variance of 1 and a mean value of zero, but offsets the mean by 5 to avoid negative values:

$$Probit = a + b * \ln(t * C^n)$$

Where:

a, b and n are Probit parameters
C is the material concentration (ppm)
t is the length of time exposure (minutes)

All offsite buildings were conservatively evaluated based on the occupants remaining in the building (shelter-in-place) for toxic consequences. The impact of a toxic release on a non-evacuation building is calculated by evaluating the indoor toxic gas concentration as a function of time for the duration of the toxic gas release and deriving the associated vulnerability by integrating an applicable probit equation with respect to time to derive a dose and associated vulnerability. SafeSite$_{3G}$© calculates the concentration inside the building from the outdoor plume concentration based on the building's air exchange rate (AXR) and the duration of the release:

$$C_{indoor} = C_{outdoor} \cdot (1 - \exp(-AXR \cdot t_{release}))$$

where C_{indoor} is the indoor concentration, $C_{outdoor}$ is the plume concentration at the center of the building, $t_{release}$ is the duration of the toxic plume, and AXR is the air change rate of the building based on the air changes from the HVAC system, infiltration, or both. The OV is then determined from the indoor concentration using the following equation where $Pr\ (C_{indoor})$ is the probit value of the toxin at the indoor concentration:

$$OV = 0.5 \cdot \left(1 + \frac{\Pr(C_{indoor}) - 5}{|\Pr(C_{indoor}) - 5|} \operatorname{erf}\left(\frac{|\Pr(C_{indoor}) - 5|}{\sqrt{2}}\right)\right)$$

6.0 VULNERABILITY RESULTS

This section summarizes the results of vulnerability calculations performed for this study. They represent the predicted worst case hazards across the Terminal and do not take into account the potential release frequency. These results are then paired with the release frequency, ignition frequency and other conditions described in Section 4.5 to calculate risk. Although a large amount of data has been collected, analyzed and reviewed, it is presented in summary tables to minimize the report volume. Complete results are presented in Appendix E.

6.1 Discharge and Dispersion

Discharge calculations were performed for each release case modeled using SafeSite$_{3G}$©. Results provided in the Appendix E, ***Discharge*** tab, include mass flow rate, expansion velocity, and the discharge coefficient.

Discharge results are used by dispersion routines included in the SafeSite$_{3G}$© model to estimate the distance to UFL, LFL, and ½ LFL and to toxic concentrations of interest (90%, 10%, and 1% lethality probabilities). Dispersion distances are reported in Appendix E, ***Flam-Dist*** tab, for flammable dispersion distances and ***Tox-Dist*** for toxic dispersion distances.

Figure 10 shows a cloud side view graph for the downwind distance to UFL, LFL, and ½ LFL together with the cloud centerline (Case 05-P2006A-6:F1.2). The horizontal axis shows downwind distance in feet and the vertical axis shows the cloud height (note the scales on each axis differ to maximize the viewable area).

Figure 11 shows an aerial view of the cloud for release of flammable material. The cloud LFL boundary is shown in the orange and ½ LFL is shown in green.

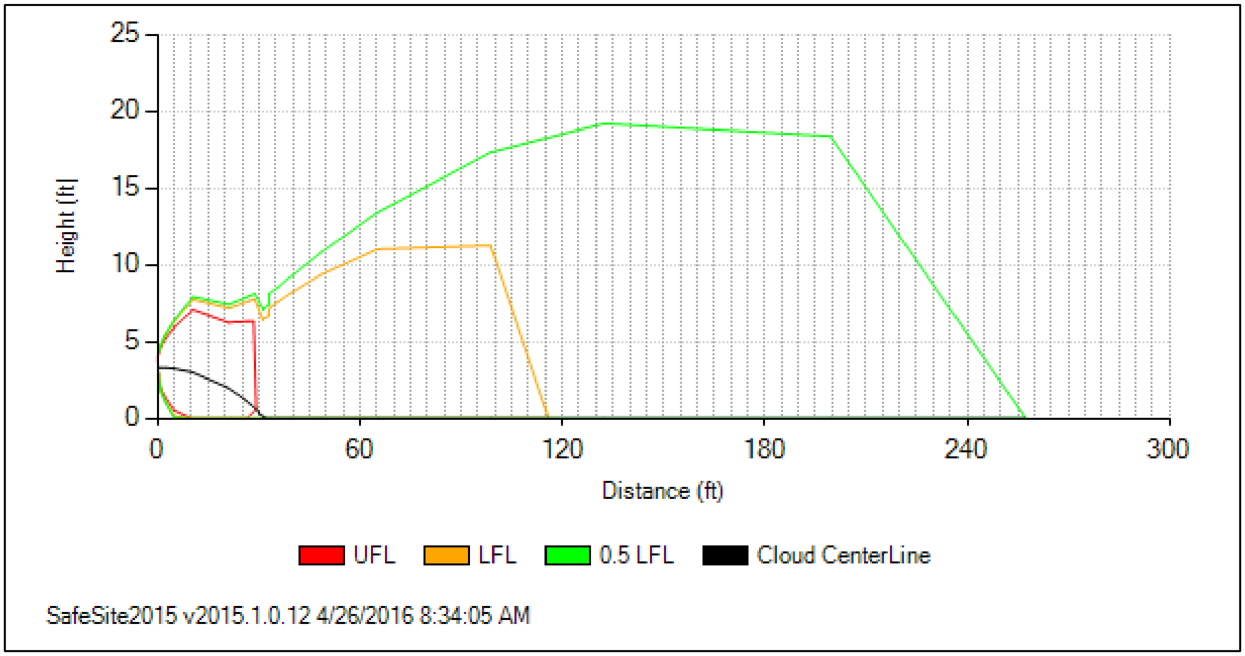

Figure 10. Example Side View of Vapor Cloud for Release Case 05-P2006A-6:F1.2

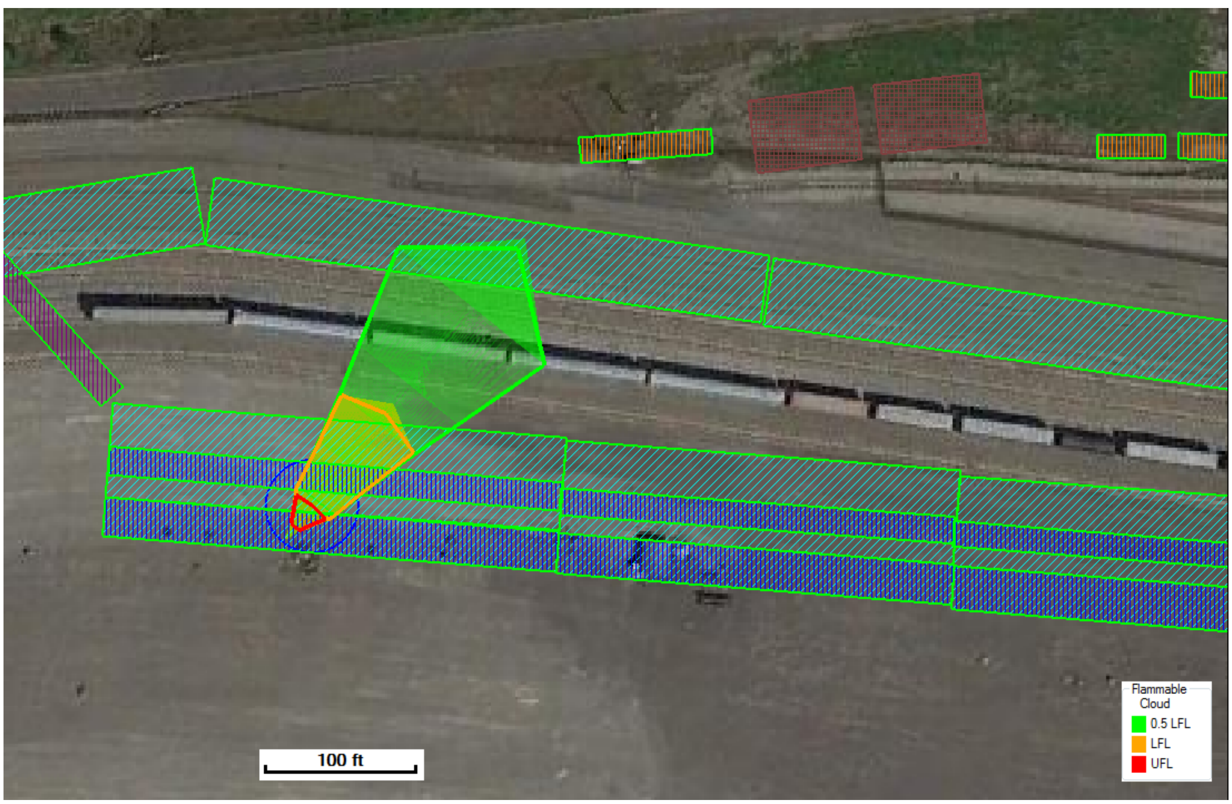

Figure 11. Example Aerial View of Vapor Cloud for Release Case 05-P2006A-6:F1.2

In addition to tabulating dispersion results and showing side view or plan views of such releases, it is also possible to show 3D views of releases (see Figure 12). The 3D views assist with understanding how a flammable gas cloud interacts with congestion and confinement for explosion energy term calculations. Once release cases are included in the $\text{SafeSite}_{3G}^{©}$ model, it is straightforward to rotate any of the gas releases, calculate the energy terms, flame speeds, and associated blast loads.

6.2 Flash Fire

Flash fires are assumed to cause fatal injuries to outdoor personnel within the flammable cloud at the time of ignition. To account for expansion as the flammable cloud burns, personnel within the 50% LFL cloud are also assumed to be impacted. Table 7 (above) summarized the rule set applied for assessing vulnerability for personnel from flash fires and the amount of credit given for escape. Dispersion plumes generated by $\text{SafeSite}_{3G}^{©}$ are processed to determine flammable concentrations and areas they covered. The overall composite contours of UFL, LFL, and ½ LFL are shown in Figure 13 for 0.5-inch cases, in Figure 14 for 2-inch cases, and in Figure 15 for all release cases assessed.

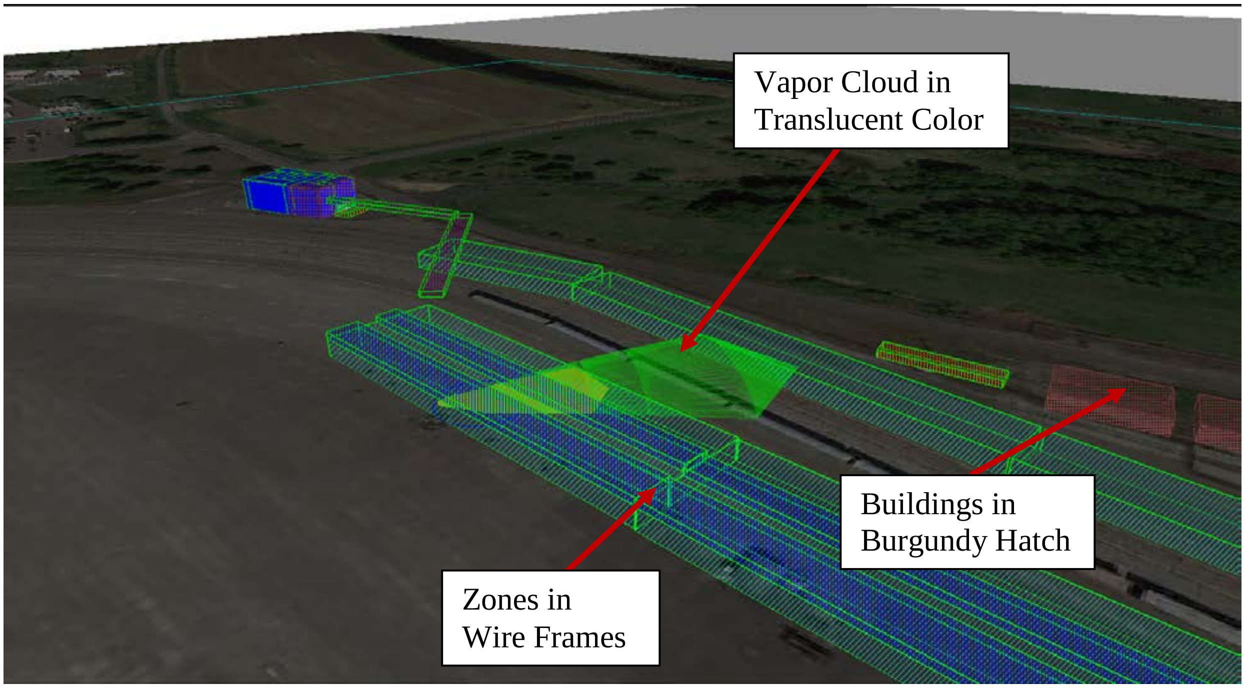

Figure 12. Example 3D View of the Vapor Cloud for Release Case 05-P2006A-6:F1.2

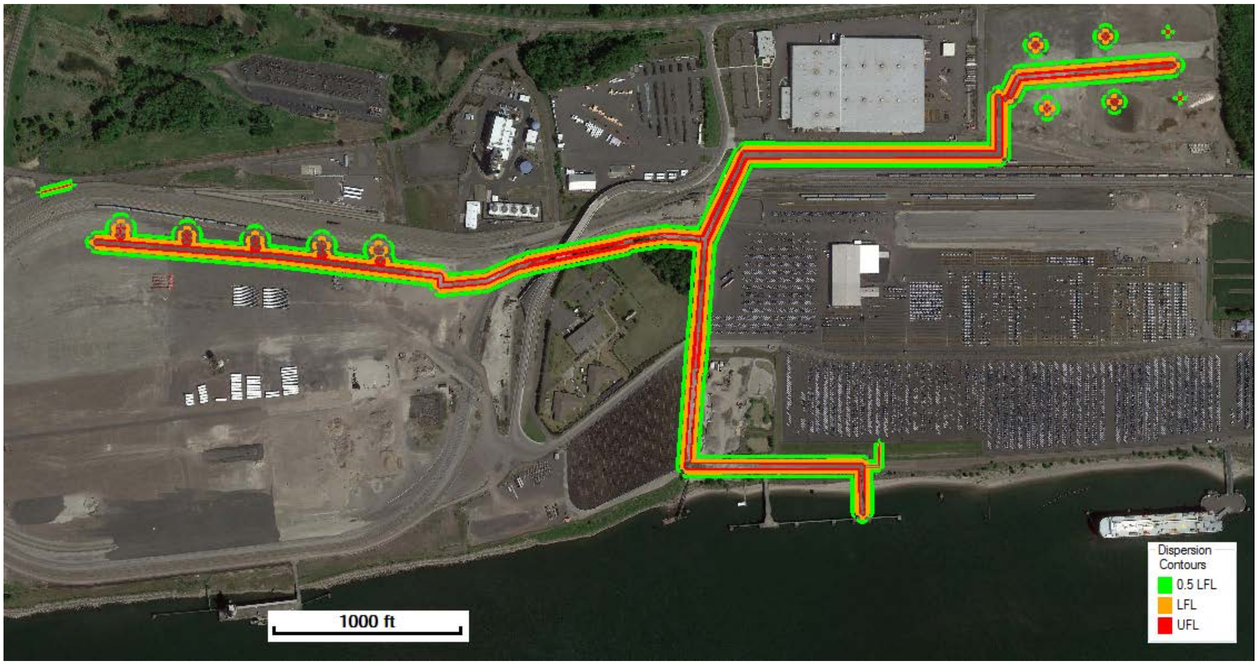

Figure 13. Composite Flammability Contours (Up to 0.5-inch Release)

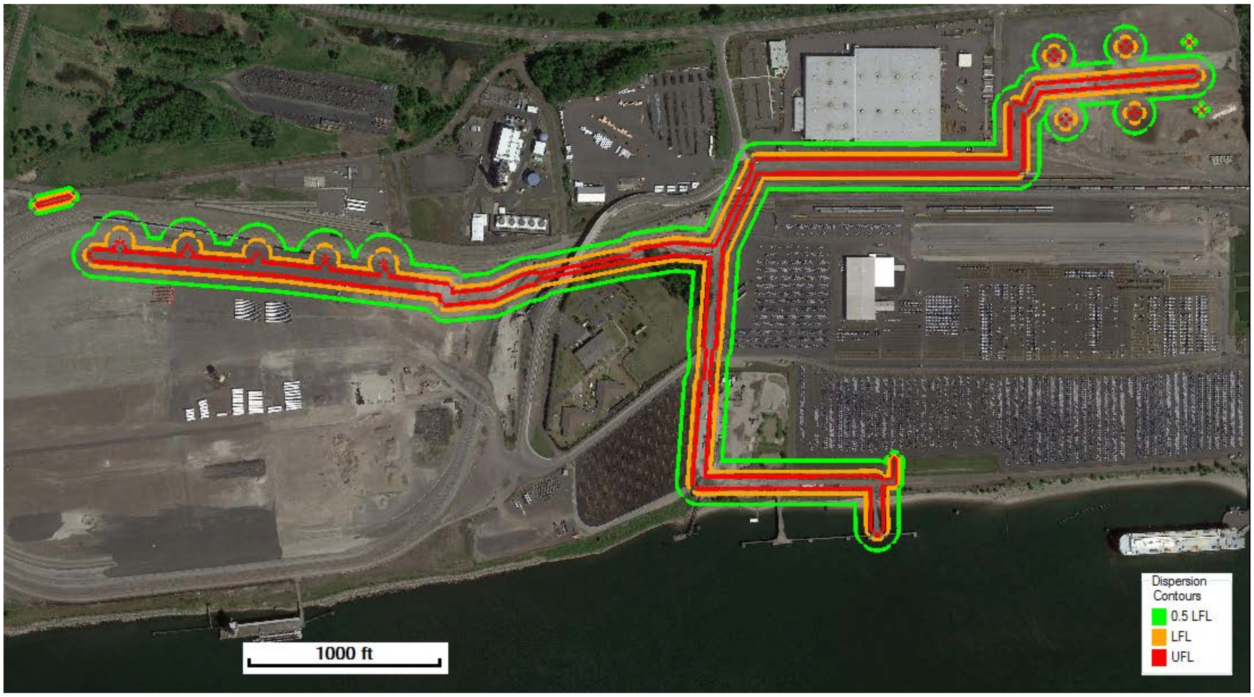

Figure 14. Composite Flammability Contours (Up to 2-inch Release)

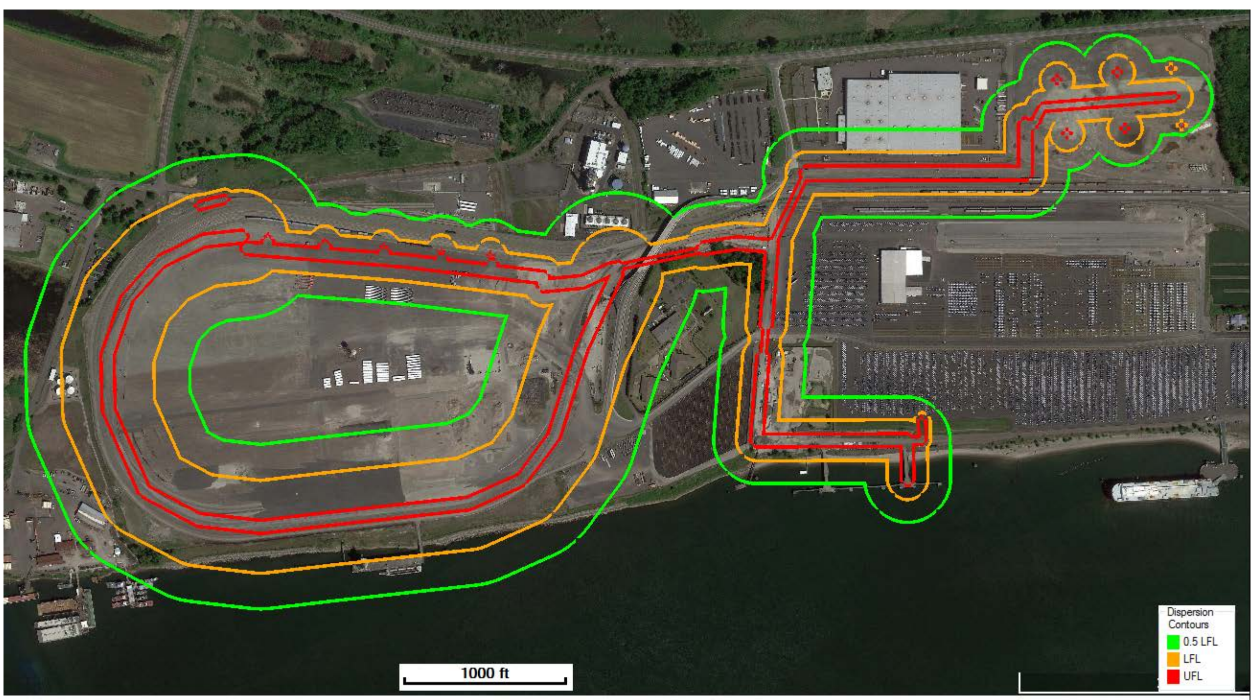

Figure 15. Composite Flammability Contours (Full-Bore Release, Up to 6-inches)

6.3 Toxic Vulnerability

Potential toxic hazards are evaluated based on the concentration of toxic gases predicted to occur at each building or potentially affecting outdoor personnel. Toxic impacts are reported in terms of probit concentration levels for 1%, 10%, and 90% lethality levels or probability of fatality for 60-minute exposure durations for hydrogen sulfide. The most severe toxic level predicted to occur at each building is provided in the summary table of the FSS results spreadsheet (Appendix E, ***Summary*** tab). Detailed results for each toxic dispersion case for each building assessed are presented in Appendix E, ***Tox-Conc*** tab.

Toxic concentration composite contours for toxic end points predicted to cause 1%, 10%, and 90% probability of fatality to those exposed to hydrogen sulfide for 60 minutes are shown in Figure 16 for 0.5-inch cases, Figure 17 for 2-inch cases, and Figure 18 for all releases cases assessed.

Figure 16. Composite Toxic Contours (Up to 0.5-inch Release)

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Figure 17. Composite Toxic Contours (Up to 2-inch Release)

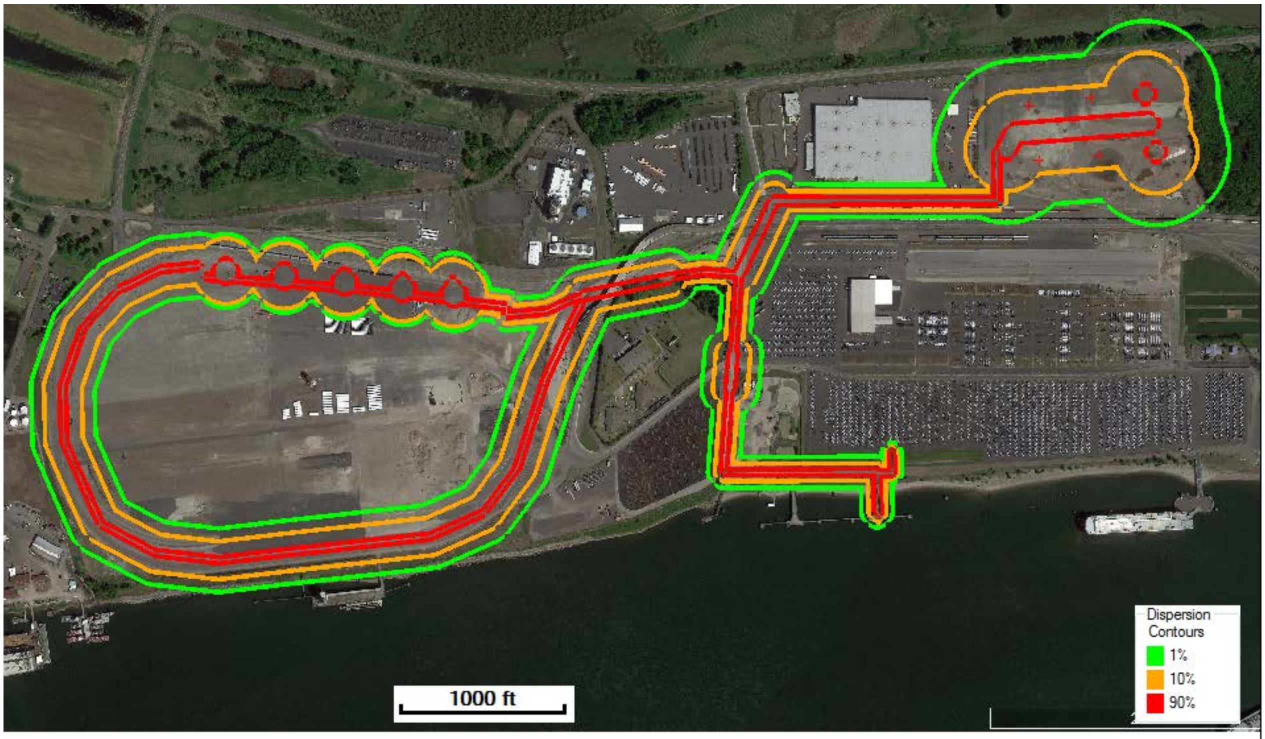

Figure 18. Composite Toxic Contours (Full-Bore Release, Up to 6-inches)

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6.4 Thermal Radiation

Jet and pool fires were assessed for each flammable release scenario identified. The majority of potential fires for this Terminal are pool fires, which are generally less consequential than jet fires. A jet fire is the combustion of pressurized, flammable vapors as they are dispersed into air; and a pool fire is the combustion of a flammable liquid. Thermal radiation vulnerability values generated by each fire scenario on each building evaluated are provided in Appendix E, ***Fire-Building*** tab, and the resulting vulnerability is presented in Appendix E, ***Fire OV*** tab.

Figure 19, Figure 20, and Figure 21 below show the thermal radiation impacts of fires based on 0.5-inch, 2-inch, and full bore up to 6-inch release cases. Thermal radiation contours are shown to end points of 4, 12.5, and 37.5 kW/m^2.

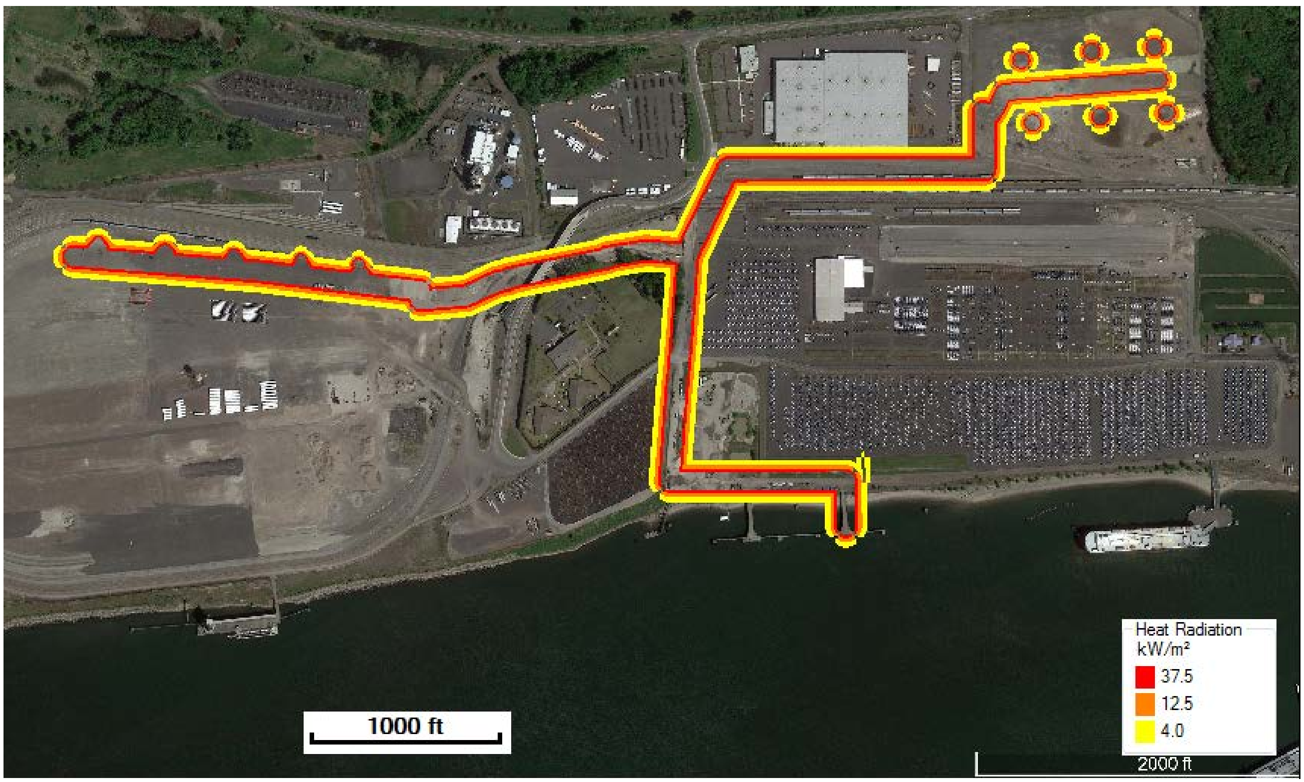

Figure 19. Composite Thermal Radiation Contours (Up to 0.5-inch Release)

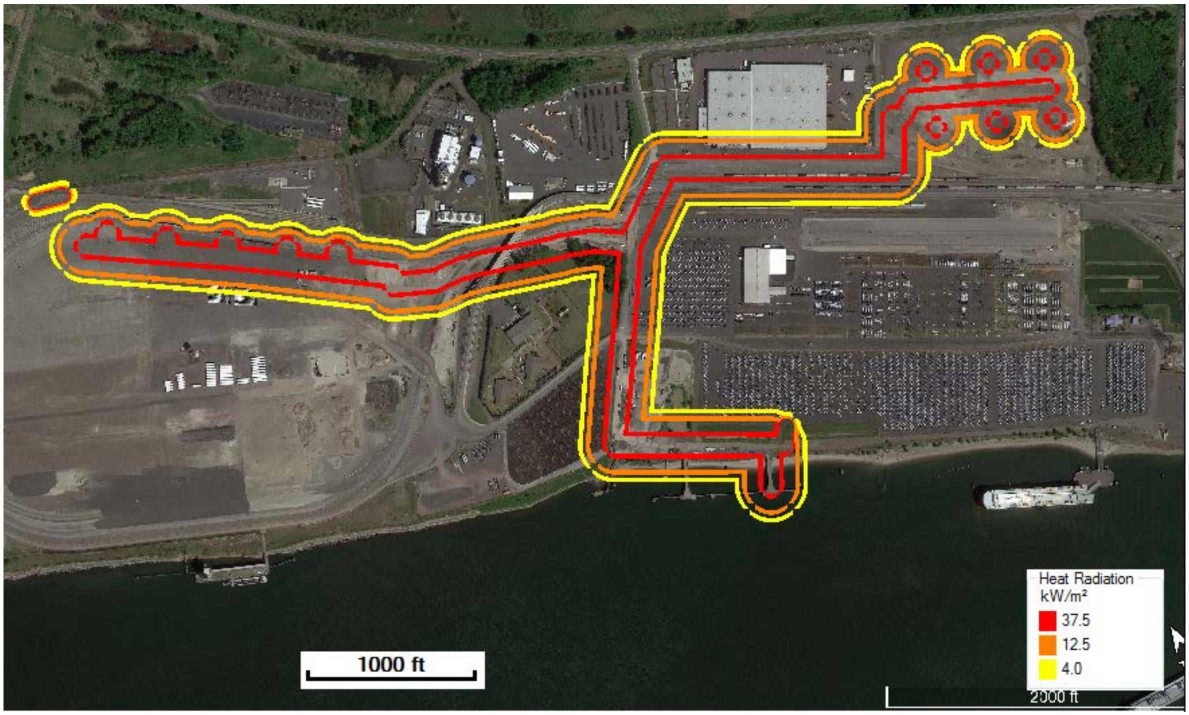

Figure 20. Composite Thermal Radiation Contours (Up to 2-inch Release)

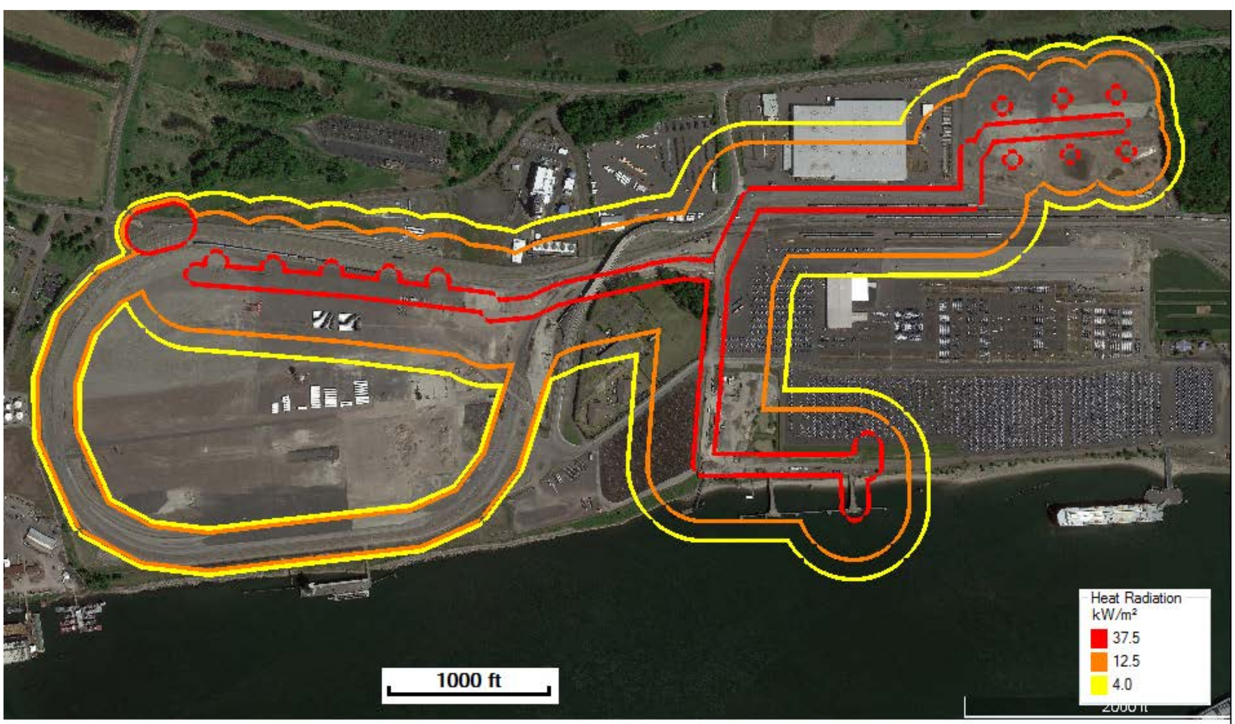

Figure 21. Composite Thermal Radiation Contours (Full-Bore Release, Up to 6-inches)

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6.5 Explosion Blast Loads

This section summarizes consequences of explosions modeled. This study uses the BST methodology for generating blast loads associated with potential explosion incidents. Each case is assessed for a release occurring in 16 evenly-spaced horizontal directions.

Figure 22, Figure 23, and Figure 24 summarize the envelope side-on overpressure contours for 0.5-inch, 2-inch, full bore up to 6-inch releases assessed. Figure 25 shows the envelope side-on overpressure contours for all of the fill cases assessed. The envelope plot represents the worst-case overpressure at each point on the map for the releases considered and does not represent the case where more than one release occurs simultaneously. Simultaneous releases and explosions are beyond the scope of this study.

Overpressure maps for each scenario predicted to cause the maximum blast load on one or more building surfaces are presented in Appendix D. Tables of overpressure and impulse values for significant blast loads (cases predicted to cause BDL 2.5 or higher), and maximum blast loads for each building (four sides and roof surfaces) assessed are summarized in Appendix E, ***Pressure***, ***Impulse***, and ***Max Loads*** tabs.

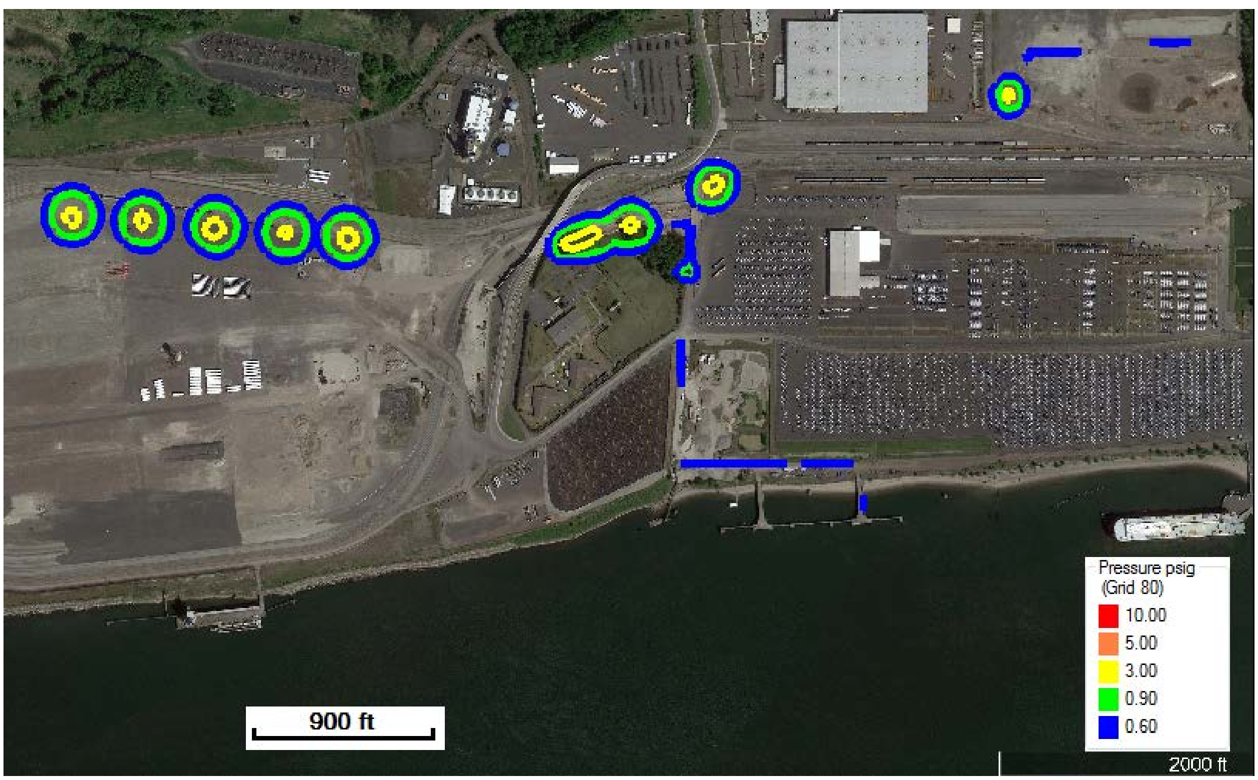

Figure 22. Composite Side-on Overpressure Contours (Up to 0.5-inch)

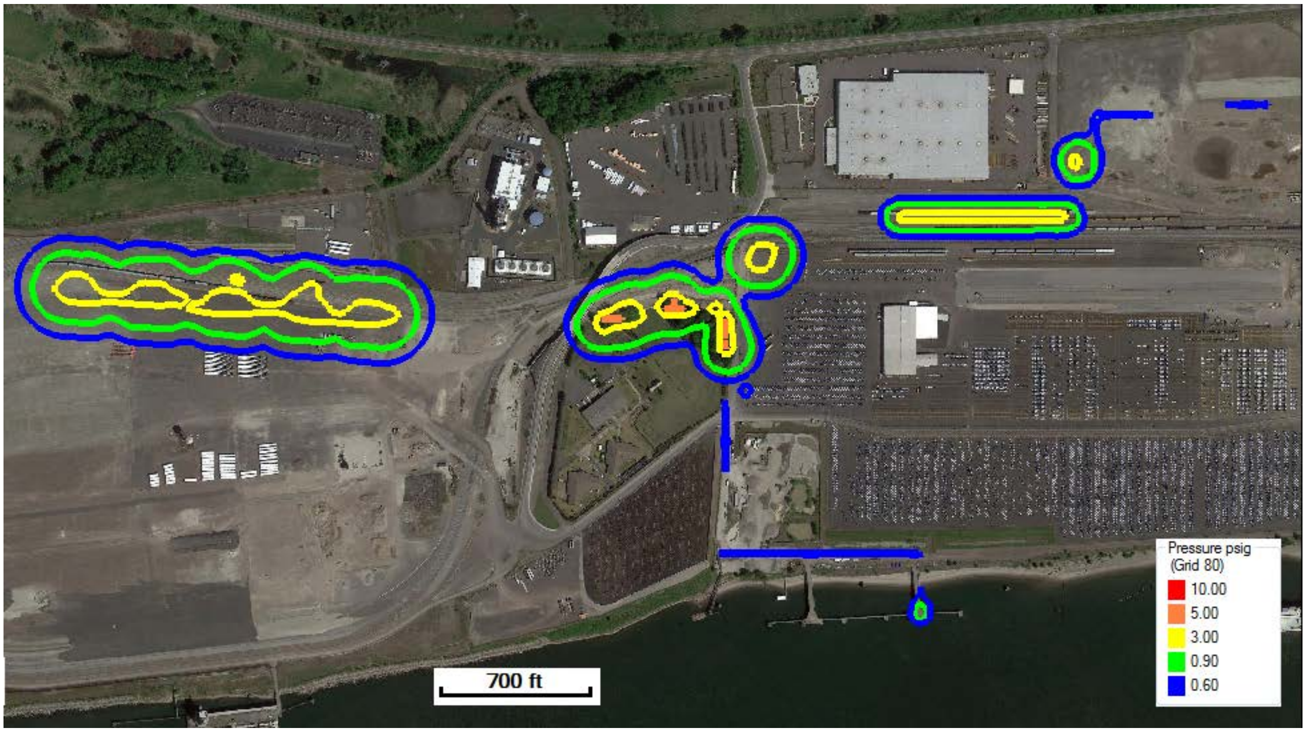

Figure 23. Composite Side-on Overpressure Contours (Up to 2-inch)

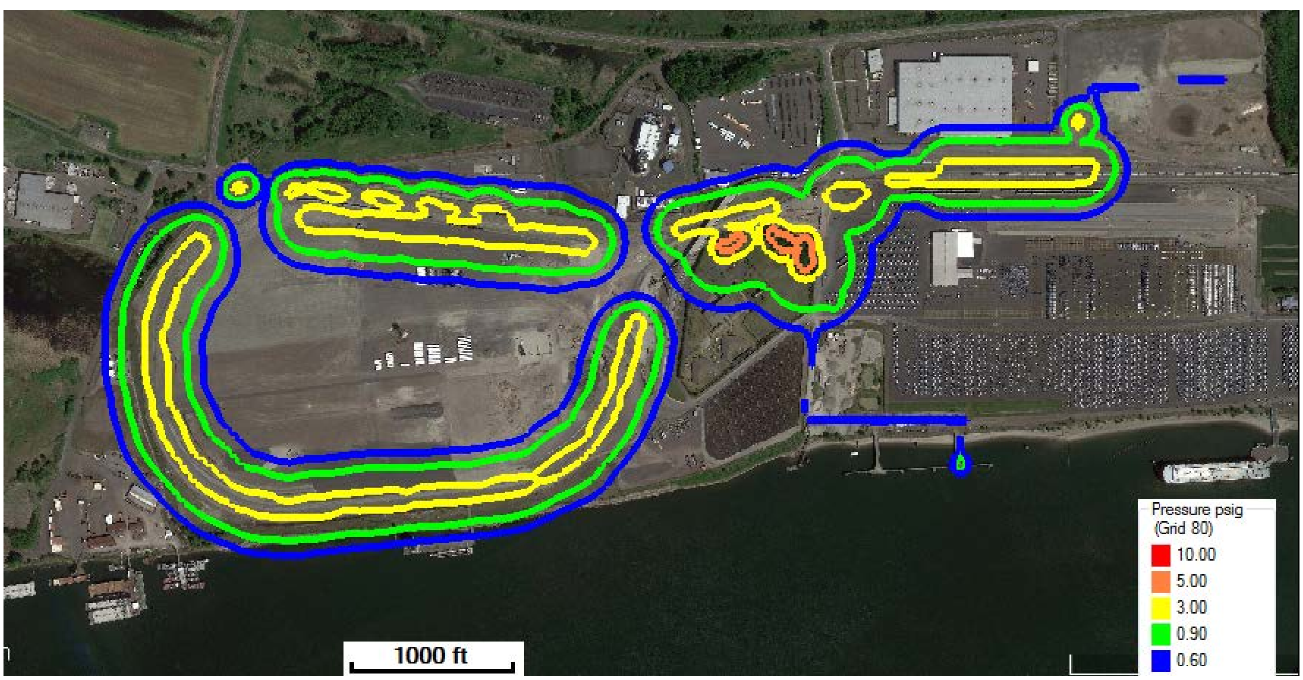

Figure 24. Composite Side-on Overpressure Contours (Full Bore Release, Up to 6-inch)

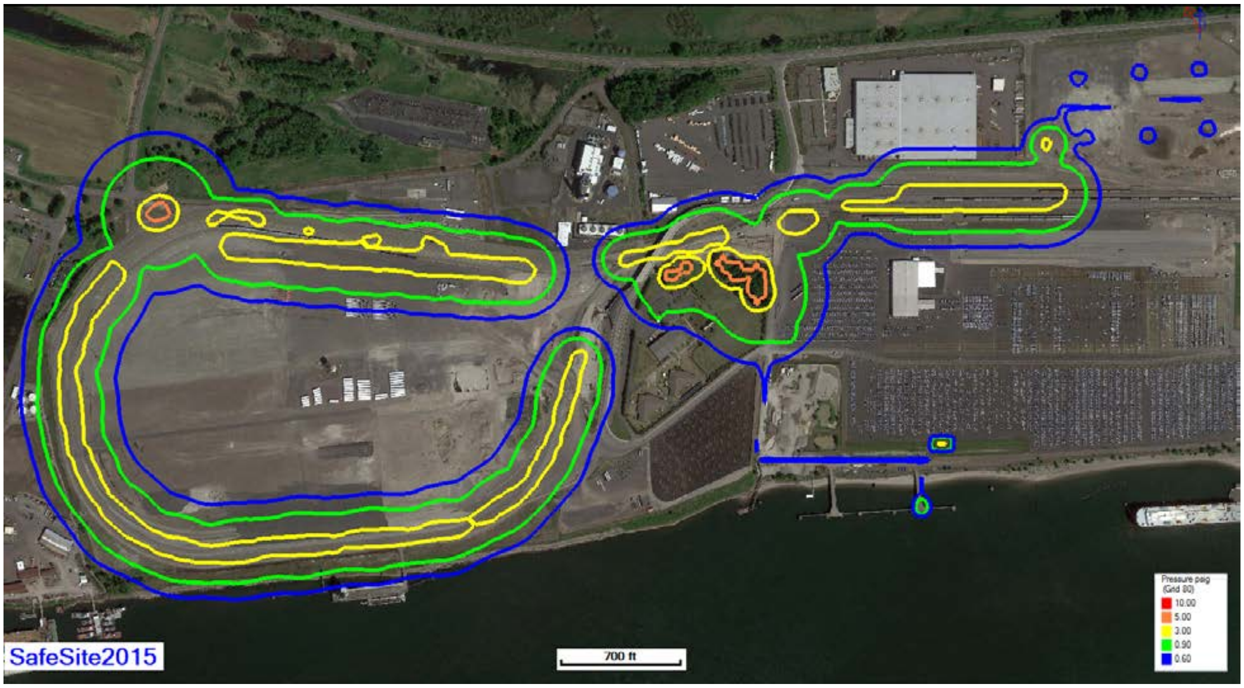

Figure 25. Composite Side-on Overpressure Contours (All Scenarios)

6.6 Building Damage Levels & Occupant Vulnerability

BDLs are binned on a scale of 1 (low) through 4 (high), as described in Table 8. Note that if a flammable concentration accumulates throughout a building and ignites, severe damage (BDL=4) would be predicted. The BDL values do not account for internal explosion scenarios.

Table 8. Building Damage Levels Definitions

Building Damage Level	Damage Description
1	Onset of visible damage to building walls facing explosive source. Repairs only needed for cosmetic reasons. Building is reusable following an explosion.
2	Localized building damage, primarily to components on building walls facing the explosive source. Building performs function and can be used; however, major repairs are required to restore integrity of structural envelope. Total cost of repairs is moderate.
2.5	Widespread building damage. Building cannot be used until major repairs are completed. Total cost of repairs is significant, approaching replacement cost of building.
3	Building has lost structural integrity and may collapse due to environmental conditions (i.e. snow or wind). Total repair cost exceeds replacement cost of building.
4	Building fails completely. Repair is not feasible.

Occupant vulnerability is defined as the probability that a given person within the building suffers severe injuries and would require immediate medical treatment. For the purposes of this study, these injuries are considered to be fatalities. Occupant vulnerability within buildings due to explosions largely depends on the BDL. Other important factors are building type, occupant distribution, and the amount of debris hazards generated during an explosion. In an explosion, window fragments and non-structural items such as those mounted above the ceiling and items located behind exterior walls can become debris with the potential for life-threatening injuries or death.

Table 9 shows the color codes used for highlighting occupant vulnerability values.

Table 9. Color Codes for Occupant Vulnerability Values

Color	Occupant Vulnerability
(pink)	OV ≥ 0.45
(orange)	0.1 ≤ OV < 0.45
(yellow)	0.005 ≤ OV < 0.1

7.0 RISK CALCULATIONS AND RESULTS

7.1 Consequence Calculations

Risk is calculated for each accident scenario by estimating consequences (number of fatalities) and the frequency of the event. The following sections provide a discussion of the analysis approach for each type of accident assessed.

7.1.1 Early Ignition

Early ignition of flammable material release scenarios are evaluated as jet fires for vapor and two-phase materials and pool fires for liquid releases. Jet and pool fire consequences are calculated for each building by multiplying the vulnerability values calculated by $SafeSite_{3G}^{©}$ by the occupancy of the building.

$$C_{bldg\text{-}fire} = OV_{bldg\text{-}fire} \text{ x } Pop_{bldg}$$

Jet and pool fire consequences are calculated for outdoor personnel by determining the area of each defined outdoor area that is impacted by previously defined thermal lethality contours. QRATool© of BakerRisk® is used to overlay thermal lethality contours on the site map to calculate the intersection of those contours with outdoor population areas. The consequence is equal to the product of the fraction of the outdoor area intersected by the thermal lethality contour, the occupancy in that process area, and the corresponding occupant vulnerability.

$$C_{area\text{-}fire} = I_{area\text{-}fire} \text{ x } Pop_{area} \text{ x } OV_{area\text{-}fire}$$

7.1.2 Delayed Ignition

Delayed ignition of flammable material release scenarios are evaluated as explosions and flash fires. Flash fire consequences are assumed to have negligible impacts to occupants of closed buildings, but are evaluated for outdoor personnel and occupants of open or seasonal buildings. Consequences of flash fires are assessed for outdoor personnel by determining the area of each outdoor area that is impacted by the previously defined flammability concentration categories. BakerRisk's QRATool© is used to overlay flammability contours on the site map to calculate the intersection of those contours with outdoor area populations and open buildings. The consequence for people outdoors is equal to the product of the fraction of the outdoor area intersected by the flammability contour, the occupancy in that area, and the corresponding occupant vulnerability and non-escape probability.

$$C_{area\text{-}flash} = I_{area\text{-}flash} \text{ x } Pop_{area} \text{ x } OV_{flash} \text{ x } NE_{flash}$$

The consequence of a flash fire for open buildings is equal to the product of the fraction of the building intersected by the flammability contour, the occupancy in that building, and the corresponding occupant vulnerability. Seasonally open buildings are treated as open buildings with a mitigation factor that accounts for the fraction of time they are closed (not vulnerable to flash fire).

$$C_{bldg\text{-}flash} = I_{bldg\text{-}flash} \text{ x } Pop_{bldg} \text{ x } OV_{flash} \text{ x } MF_{flash}$$

Explosion consequences are calculated for outdoor personnel by determining the area of each outdoor area that is impacted by the previously defined overpressure values. BakerRisk's QRATool© is used to overlay overpressure contours on the site map to calculate the intersection of those contours with outdoor area populations. The consequence is equal to the product of the fraction of the outdoor area intersected by the overpressure contour, the occupancy in that process area, and the corresponding occupant vulnerability and non-escape probability.

$$C_{area\text{-}exp} = I_{area\text{-}exp} \text{ x } Pop_{area} \text{ x } OV_{area\text{-}exp} \text{ x } NE_{area\text{-}exp}$$

Explosion consequences are calculated for each building by multiplying the corresponding occupant vulnerability value calculated by SafeSite_{3G}© by the occupancy of the building.

$$C_{bldg\text{-}exp} = OV_{bldg\text{-}exp} \text{ x } Pop_{bldg.}$$

7.1.3 Non-Ignition

Toxic impacts are calculated for buildings and outdoor personnel. For buildings, toxic consequences are calculated by multiplying the occupant vulnerability (based on the occupants evacuating the building and traveling crosswind) by occupancy of the building and the building toxic mitigation factor. The building toxic mitigation factor allows PPE to be credited, as appropriate.

$$C_{bldg\text{-}tox} = OV_{bldg\text{-}tox} \text{ x } Pop_{bldg} \text{ x } MF_{bldg\text{-}tox}$$

Toxic consequences are calculated for outdoor personnel by determining the area of each outdoor area that is impacted by the previously defined toxic lethality contours. BakerRisk's QRATool© is used to overlay lethality contours on the site map to calculate the intersection of those contours with outdoor area populations. The consequence is equal to the product of the fraction of the outdoor area intersected by the lethality contour, the occupancy in that process area, and the corresponding occupant vulnerability. The occupant vulnerability directly incorporates evacuation. The area toxic mitigation factor is provided to allow PPE to be credited, as appropriate.

$$C_{area\text{-}tox} = I_{area\text{-}tox} \text{ x } Pop_{area} \text{ x } OV_{area\text{-}tox} \text{ x } MF_{area\text{-}tox}$$

7.2 Frequency Calculations

The frequency of each accident sequence is calculated by multiplying the release frequency by the applicable conditional probabilities (see event tree given as Figure 2 as an example of accident sequences and conditional probabilities). Release frequencies are estimated by multiplying equipment failure rates by equipment counts. Conditional probabilities account for weather conditions and wind direction (Appendix G), ignition probability, and time slot probability.

$$F_{scenario} = R_{eqpt} \text{ x } C_{eqpt} \text{ x } P_{weather} \text{ x } P_{wind} \text{ x } P_{ignition} \text{ x } P_{time}$$

7.3 Risk Calculations

Risk is defined as the product of consequence (fatalities/event) and frequency (events/year) and is presented in terms of fatalities per year.

$$Risk_{scenario} = F_{scenario} \text{ x } Consequence_{scenario}$$

Risk is additive, so it is calculated for each scenario, and results are summed to determine the total risk.

$$Risk_{total} = R_{scenario\text{-}1} + R_{scenario\text{-}2} + \ldots R_{scenario\text{-}N}$$

7.4 Societal Risk

The total risk to groups of people is commonly called the societal (or aggregate) risk. Societal risk is presented in terms of the contribution of risk posed by the most significant sources in Table ES-3. Complete results are presented in Appendix F.

Source risk information may be useful in developing risk mitigation strategies because it focuses attention on sources that pose the highest risk. It may be appropriate to further refine the analysis (e.g., remove conservatism in the calculations) for high risk sources. If refined analysis still shows the risk for a source to be significant, it may be possible to cost effectively mitigate risk by reducing the frequency of accidental releases (e.g., improved maintenance and testing, etc.) or mitigating consequences (e.g., reduced system pressure and/or available inventory, etc.).

Societal risk results are also presented in terms of the amount of risk incurred by occupants of each building and outdoor area. Table ES-1 shows the amount of risk incurred by onsite occupants of each building and outdoor area assessed. Results indicate that approximately 67% of the onsite risk is incurred by personnel in the *Train Unloading Area* due mostly to flash fire risk.

Table ES-2 shows the amount of risk incurred by offsite persons of each building and outdoor area assessed. Results indicate that the building with the most risk incurred by personnel is the *Farwest Steel Main Building* and almost of all of that risk is from flash fire hazards. However, as identified in the analysis, that predicted risk is negligible. Complete results are presented in Appendix F.

7.5 Building Individual Risk

Individual risk can be assessed in multiple ways. Building individual risk (BIR) was assessed to identify the level of risk to building occupants and people in outdoor areas at the Terminal. Worker individual risk (WIR), discussed in the following section, was assessed to identify the amount of risk incurred by each work group assessed based on the amount of time they spend in each building/outdoor area and the associated level of risk.

The level of risk incurred by a person who is continuously present (24 hours a day, 365 days a year) in a given building or outdoor area is called the BIR. BIR values can be used to minimize risk by locating personnel in the lowest risk buildings and outdoor areas to the extent practical, and to guide building design/upgrade decisions. BIR values for onsite buildings and offsite buildings are shown below in Table 10 and Table 11, respectively.

Table 10. Onsite Building Individual Risk

Building: Section or Population Areas	Location Individual Risk (APoD)				
	Explosion	Flash Fire	Toxic	Jet/Pool Fire	Total
Control Room- Train Loading	**2.6E-4**	4.0E-6	**	1.7E-7	2.6E-4
Boiler Building	**2.1E-4**	8.6E-12	**	**	2.1E-4
Train Unloading Area	**	**7.6E-6**	**	9.3E-8	7.7E-6
Fire Pump Building- Train Loading	**1.1E-6**	7.3E-7	**	3.5E-10	1.8E-6
Storage Tank Area	**	**4.7E-7**	**	2.8E-7	7.6E-7
Storage Building	4.0E-11	**8.0E-8**	**	**	8.0E-8
Fire Pump Building- Dock	**4.0E-9**	1.9E-10	**	1.2E-11	4.2E-9
Control Room/Dock Building	**	**	**	**2.0E-10**	**2.0E-10**
VCU Area	**	1.8E-11	**	**4.0E-11**	5.7E-11
Marine Unloading Area	**	2.2E-11	**	**2.6E-11**	4.8E-11
Fire Pump Building- Tanks	**4.0E-11**	**	**	**	**4.0E-11**
Admin Building	**1.2E-11**	**	**	**	**1.2E-11**
Locker Room/Break Room	**1.2E-11**	**	**	**	**1.2E-11**

*Highlighted cells represent outdoor areas
** Cells with ** represent negligible risk

Table 11. Offsite Building Individual Risk

Building: Section or Population Areas	Location Individual Risk (APoD)				
	Explosion	Flash Fire	Toxic	Jet/Pool Fire	Total
Offsite- Farwest Steel Main Building	**	**3.6E-11**	**	**	**3.6E-11**
Offsite- Tidewater Office	**1.2E-11**	**	**	**	**1.2E-11**
Offsite- BPA Alcoa Substation Building	**1.2E-11**	**	**	**	**1.2E-11**
Offsite- County Jail Building 3	**7.4E-14**	**	**	**	**7.4E-14**
Offsite- Tidewater Storage	**5.5E-14**	**	**	**	**5.5E-14**
Offsite- Tidewater Storage/Shop	**2.5E-14**	**	**	**	**2.5E-14**
Offsite- County Jail Building 1	**	**	**	**	**
Offsite- CPU River Road Building 2	**	**	**	**	**
Offsite- Tidewater Shop	**	**	**	**	**
Offsite- County Jail Building 2	**	**	**	**	**
Offsite- Tidewater Old Warehouse	**	**	**	**	**
Offsite- CPU River Road Building 3	**	**	**	**	**
Offsite- County Jail Trailer	**	**	**	**	**
Offsite- Tidewater Office 2	**	**	**	**	**
Offsite- NGL Energy Partners Trailer	**	**	**	**	**
Offsite- CPU River Road Building 1	**	**	**	**	**
Offsite- Tidewater Warehouse	**	**	**	**	**
Offsite- AWC Port Services	**	**	**	**	**
Offsite- Farwest Steel Building	**	**	**	**	**
Offsite- Propane Tank Area	**	**	**	**	**

*Highlighted cells represent outdoor areas
** Cells with ** represent negligible risk

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7.6 Worker Individual Risk

Worker individual risk (WIR) for onsite populations are provided in Table 12. WIR is based on an assumed 2,000 hours per year at the Terminal. A typical industry criterion for excessive risk to onsite workers is 1E-4 annual probability of death and values below 1E-6 are often considered to be negligible. All workgroups are well below typical industry criterion for excessive risk and most fall below the criterion for negligible risk.

Table 12. Onsite Worker Individual Risk

Work Group	WIR (APoD)
Unloaders	3.1E-6
Switchmen/Engineer	1.7E-6
Car inspectors	1.2E-6
Mechanics	8.8E-7
Supervisors	4.4E-7
Safety Manager	4.4E-7
Maint/Logistics Manager	4.4E-7
Director of Operations	1.8E-7
Operations Manager	1.8E-7
Dock PICs	2.9E-11
Agents and Gaugers	1.1E-11
Line Handlers	1.1E-11
Marine Loss Control	1.1E-11
Financial Coordinators	2.7E-12
Logistics Coordinators	2.7E-12

WIR is more difficult to calculate for offsite populations because there is no simple way to determine the number of hours that such populations spend near the Terminal. For the sake of comparison, however, the WIR for offsite populations is provided in Table 13. The additional risk posed by the Terminal to the offsite populations is predicted to be well below 1E-6, the typical tolerable level for offsite populations, and would be considered a negligible increase in risk to offsite populations.

7.7 Fatality Rate

The fatality rate is defined as the number of fatalities per year divided by the total number of people in the applicable population or the number of deaths per person per year. The fatality rate from the Terminal to the onsite population is 8.0E-6 fatalities per person per year and 5E-12 fatalities per person per year for offsite populations. For comparison, the fatality rate of common non-industrial accidents is shown in Table 14.

Table 13. Offsite Persons Individual Risk

Work Group	WIR (APoD)
*Farwest Steel Main	8.3E-12
*Tidewater Office	2.7E-12
*BPA Alcoa Substation	2.7E-12
*County Jail Building 3	1.7E-14
*Tidewater Storage	1.3E-14
*Tidewater Storage/Shop	5.6E-15
*County Jail Building 1	Negligible
*CPU River Road Building2	Negligible
*Tidewater Shop	Negligible
*County Jail Building 2	Negligible
*Tidewater Old Warehouse	Negligible
*CPU River Road Building3	Negligible
*Tidewater Office 2	Negligible
*NGL Energy Partners	Negligible
*CPU River Road Building1	Negligible
*Tidewater Warehouse	Negligible
*AWC Port Services	Negligible
*Farwest Steel Building	Negligible
*Keyera Propane	Negligible

Table 14. Fatality Rate of Common Non-Industrial Accidents6

Activity	Fatality Rate
Smoking	5E-3
Car Accident	1.7E-4
Rock Climbing	4E-5
Leukemia	8E-5
Lightning	1E-7
Meteorite	6E-11

[6] Frank P. Lees, *Loss Prevention in the Process Industries,* 2nd ed. (London: Butterworths, 1996), p. 9/96.

8.0 CONCLUSIONS

The results of this study confirm the qualitative statements BakerRisk® previously provided on this project in a letter dated January 22, 2016. The results show that predicted onsite risk is tolerable (slightly above the green line in Figure ES-1, but well below the red line). Onsite risk mitigation options should be actively sought, but only implemented if deemed to be practicable.

The fatality rate predicted from the Terminal for onsite populations is 8.0E-6 fatalities per person per year. This risk is far less severe than commonly accepted risks such as travelling by car. The predicted fatality rate for offsite populations is 5E-12 fatalities per person per year, which is a well below the fatality rate for lightning strikes.

Table ES-1 shows that approximately 67% of the predicted onsite risk is incurred by personnel in the *Train Unloading Area* and 27% in in the *Boiler Building.* Flash fire is the primary hazard in the *Train Unloading Area* and explosion is the primary hazard in the *Boiler Building*. The risk to the *Train Unloading Area* is primarily due to the large number of people assigned to the area.

Table ES-2 shows the predicted amount of risk incurred by offsite persons of each building and outdoor area assessed. The building where the most risk is incurred by personnel is the *Farwest Steel Building* and almost of all of that risk is from flash fire hazards. The results of this study show that the risk to offsite outdoor populations from the assessed hazards is negligible.

9.0 REFERENCES

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APPENDIX A.
EXPLOSION ANALYSIS METHODOLOGY

This appendix summarizes the vapor cloud explosion (VCE) prediction methodology used in this study.

A.1 Congestion

As a volume of gas combusts, it expands, which also forces the unburned gas ahead of it to flow. If there are obstacles in the path of the unburned expanding gas, they will induce turbulence in the expanding flow. This turbulence enhances the combustion process through mixing and increased flame surface area. These obstacles are referred to as congestion.

The flame speed and blast wave resulting from a VCE depends on the level of congestion. A higher level of congestion results in a higher flame speed and a more severe blast wave. In the Baker-Strehlow-Tang (BST) methodology, congestion is classified into three categories – low, medium, and high. Examples of low, medium, and high congestion levels are depicted in Figure A- 1 through Figure A-3.

Figure A- 1. Example of Low Congestion

Figure A-2. Example of Medium Congestion

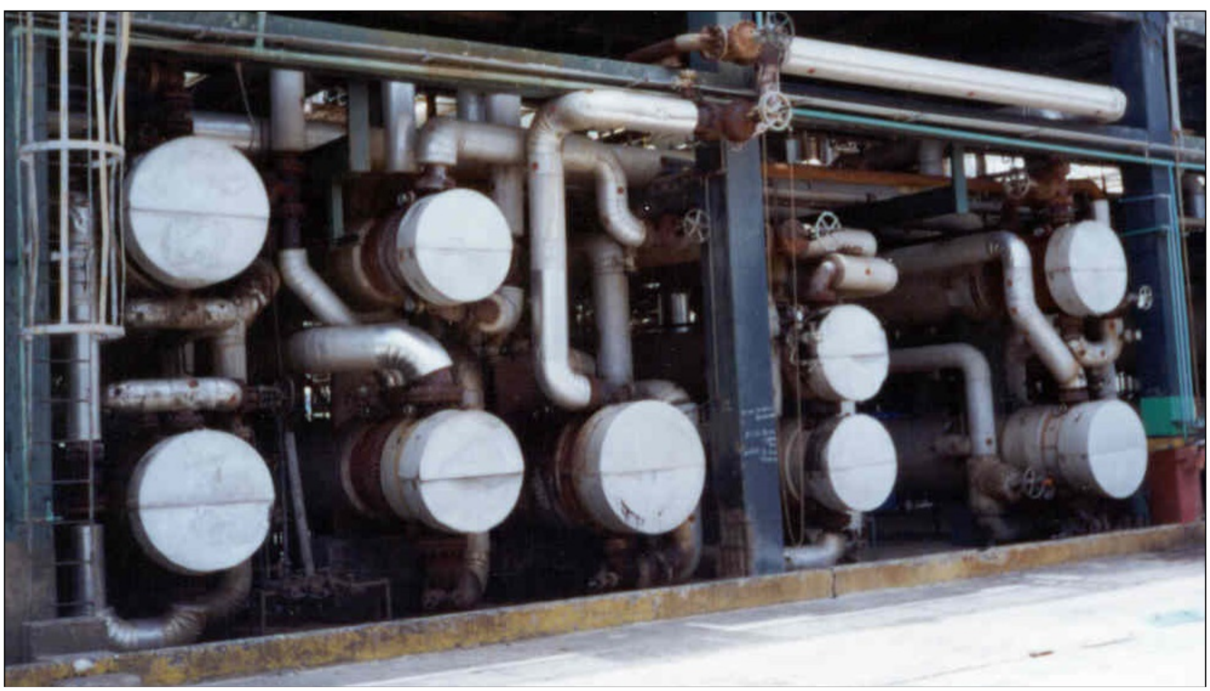


Figure A-3. Example of High Congestion

A.2 Confinement

If a roof or other restraint is present, a burning cloud cannot expand in the restrained direction, and gases flow in the remaining directions at a higher rate. This restraint is referred to as confinement because it confines the dimensionality of the combusting cloud's expansion. For example, a solid roof prevents vertical expansion and is considered to be 2D confinement. In the BST methodology, confinement is classified into dimensions in which the cloud is free to expand – 3D, 2.5D, and 2D.

The flame speed and blast wave resulting from a VCE depends on the level of confinement. A more confined flammable cloud causes a higher flame speed and a more severe blast wave. In the BST methodology, confinement is classified into three categories – 3D (unconfined), 2.5D (confined at a level between 3D and 2D), and 2D (free to expand in 2 dimensions). Examples of these confinement levels are depicted in Figure A-4 through Figure A-6.

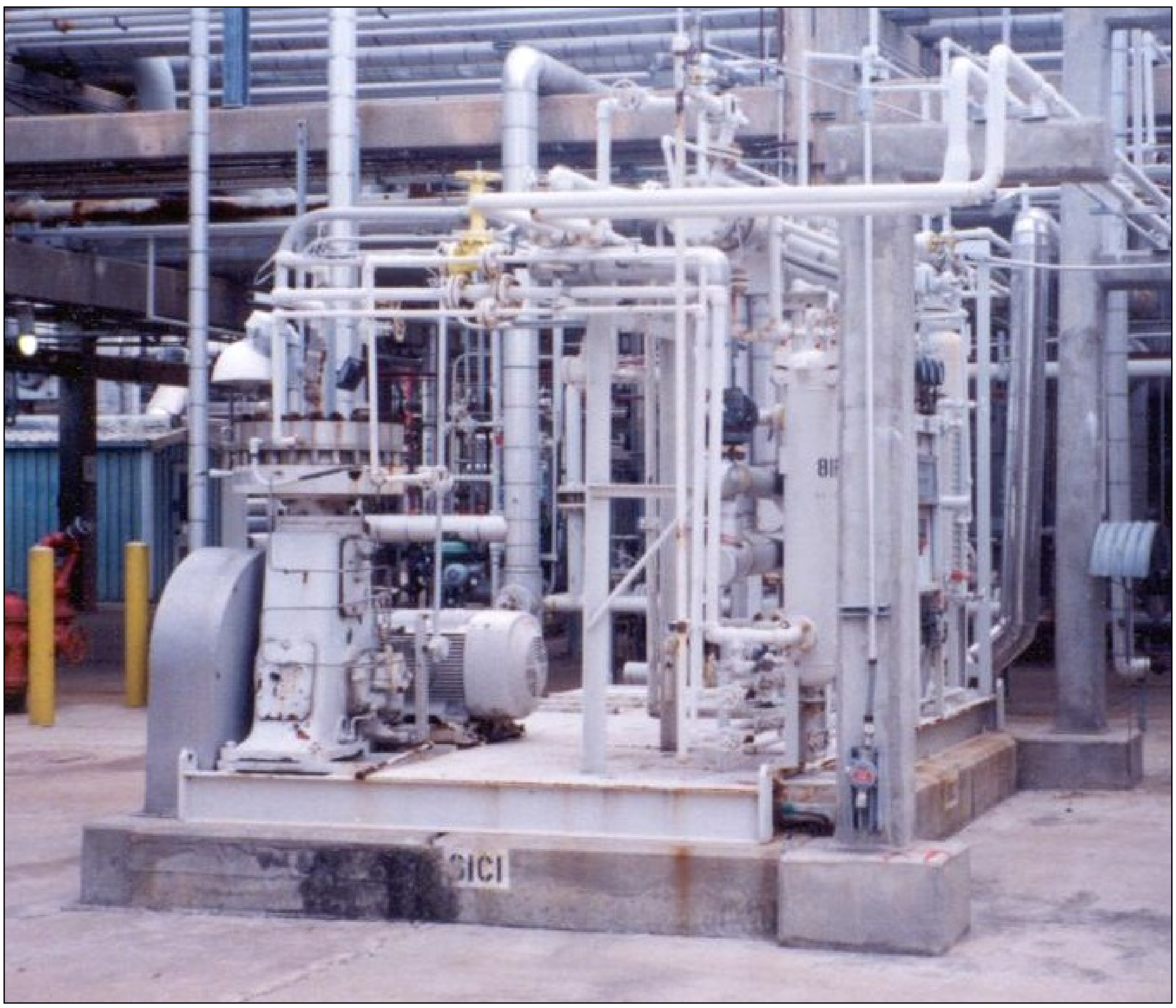


Figure A-4. Example of 3D Confinement

Figure A-5. Example of 2.5D Confinement

Figure A-6. Example of 2D Confinement

A.3 Fuel Reactivity

A fundamental property of combustion is the laminar burning velocity (LBV), whereby it describes the reaction rate at which a particular fuel will burn. The higher the burning velocity the more reactive the fuel, therefore the faster it will burn and produce a stronger blast wave. In the BST methodology, fuel reactivity is classified into three categories of LBV – low, medium, and high.

The combination of congestion, confinement, and reactivity is used to predict an effective flame speed, which is presented as a Mach number. This Mach number, along with the energy contained in the cloud, can be used to predict pressure and impulse (defined as the integral of pressure over time) by interpolating between the numerically modeled BST blast curves.

Years of research into VCEs through experimental programs, numerical modeling, and literature reviews have produced a proprietary extended version of the BST methodology. BakerRisk® has also extended the methodology to account for the effect of multiple volumes of congestion and confinement being involved in a single explosion. This methodology produces blast contours that account for the shape, extents, and variations in the physical congested and confined volumes typical of industrial facilities.

Through the investigation of hundreds of industrial accidental explosions and hundreds of medium-scale experiments, the BST methodology has been refined and verified to provide good predictions of blast loads produced by VCEs.

A.4 An Overview of Blast Waves and Structural Interaction

As discussed above, the accelerated flame front of the VCE can drive a pressure wave through the atmosphere. Figure A-7 illustrates the propagation of such a wave. Once the wave leaves the source of the explosion (congested volume, pressure vessel, or high explosive charge), it may reduce in speed, but the pressure wave will continue to expand out from the source in all directions, decaying in magnitude with distance.

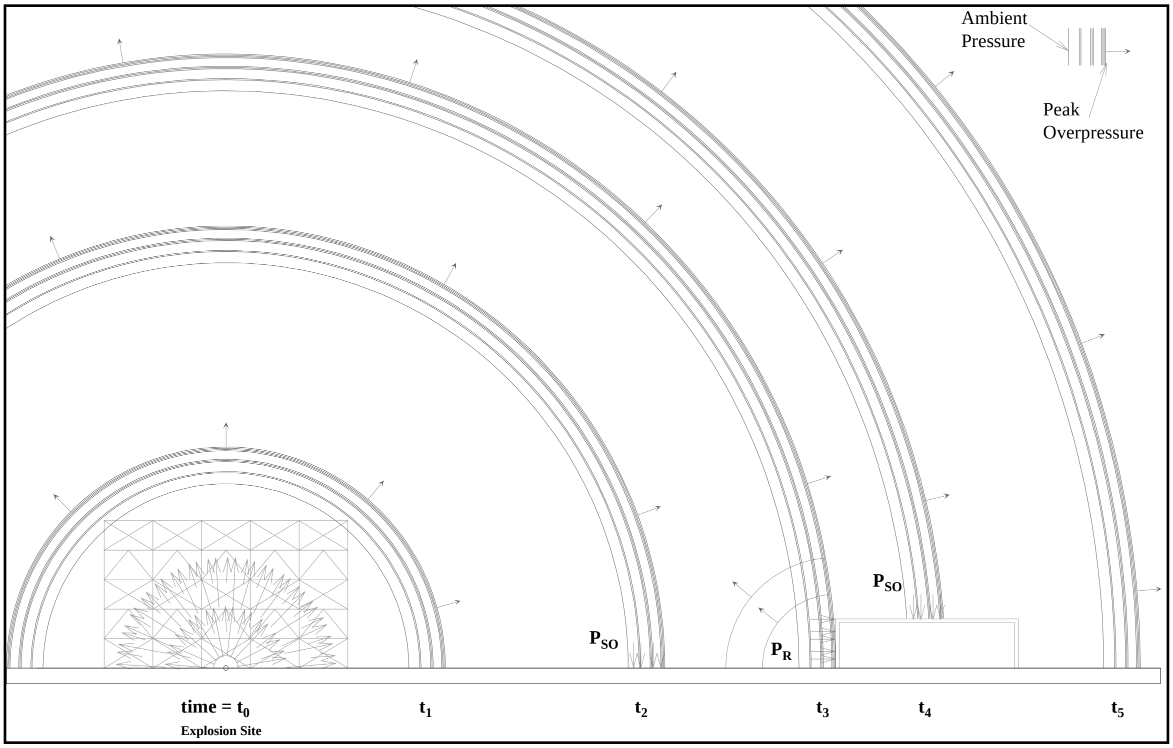


Figure A-7. Pressure Wave Illustration

The blast pressure wave expands as a hemispherical shell of pressure bounded at the bottom by the ground surface. As it sweeps over the ground, this blast wave applies pressure on the ground surface (see Figure A-7 at time t_2). A blast wave traveling over open ground or a flat building roof is an example of a side-on orientation (see time t_4 in Figure A-7). A blast wave sweeping side-on over an area without regard to reflecting surfaces is also called free-field. Blast loads are traditionally illustrated with free field pressure contours.

A blast wave interacting with a building surface will vary in its pressure magnitude depending on the orientation of the blast wave relative to the building surface. A blast wave that loads walls facing the source will produce a reflected blast load. Figure A-7 depicts this at time t_3, when the shock wave strikes the building wall at a normal orientation (i.e., the direction to the explosion is perpendicular to the reflecting surface). This reflection process causes the pressure and impulse to be increased above their side-on values. The result is that the blastward surfaces of a structure receive a higher blast load than the roof, side, or rear walls.

Figure A-8 shows the ratio of reflected (P_r) to side-on (P_{so}) pressure over a range of pressures typical for VCEs. From this figure, a ratio between side-on and reflected pressure is found and referred to as the reflection factor. This factor starts at 2 for very low side-on pressures and increases as the side-on pressure increases. For example, at 10 psi, the reflection ratio is about 2.5 and at 20 psi, the ratio is almost 3. This load reflection occurs over the full duration of the wave. Thus, the reflected pressure history is characterized by the peak reflected over-pressure at the start, reducing to ambient pressure over a time equal to the blast load duration.

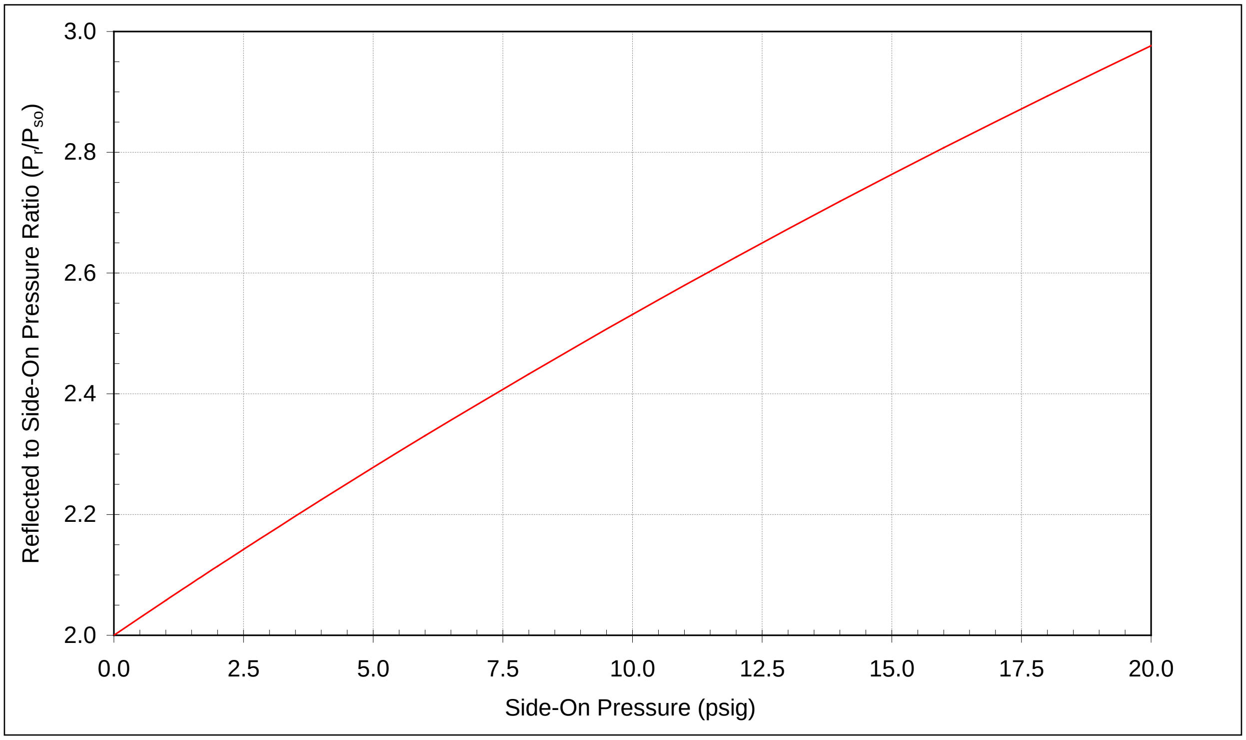


Figure A-8. Reflection Factor as a Function of Side-on Pressure

The relationship shown in Figure A-8 is for a normal reflection of a blast wave by a surface. The reflection factor is reduced when the blast wave interacts with a surface at an oblique angle, with a limit of 1 (no amplification) at a side-on orientation.

APPENDIX B:
SAFESITE$_{3G}$© BUILDING CONSTRUCTION TYPES

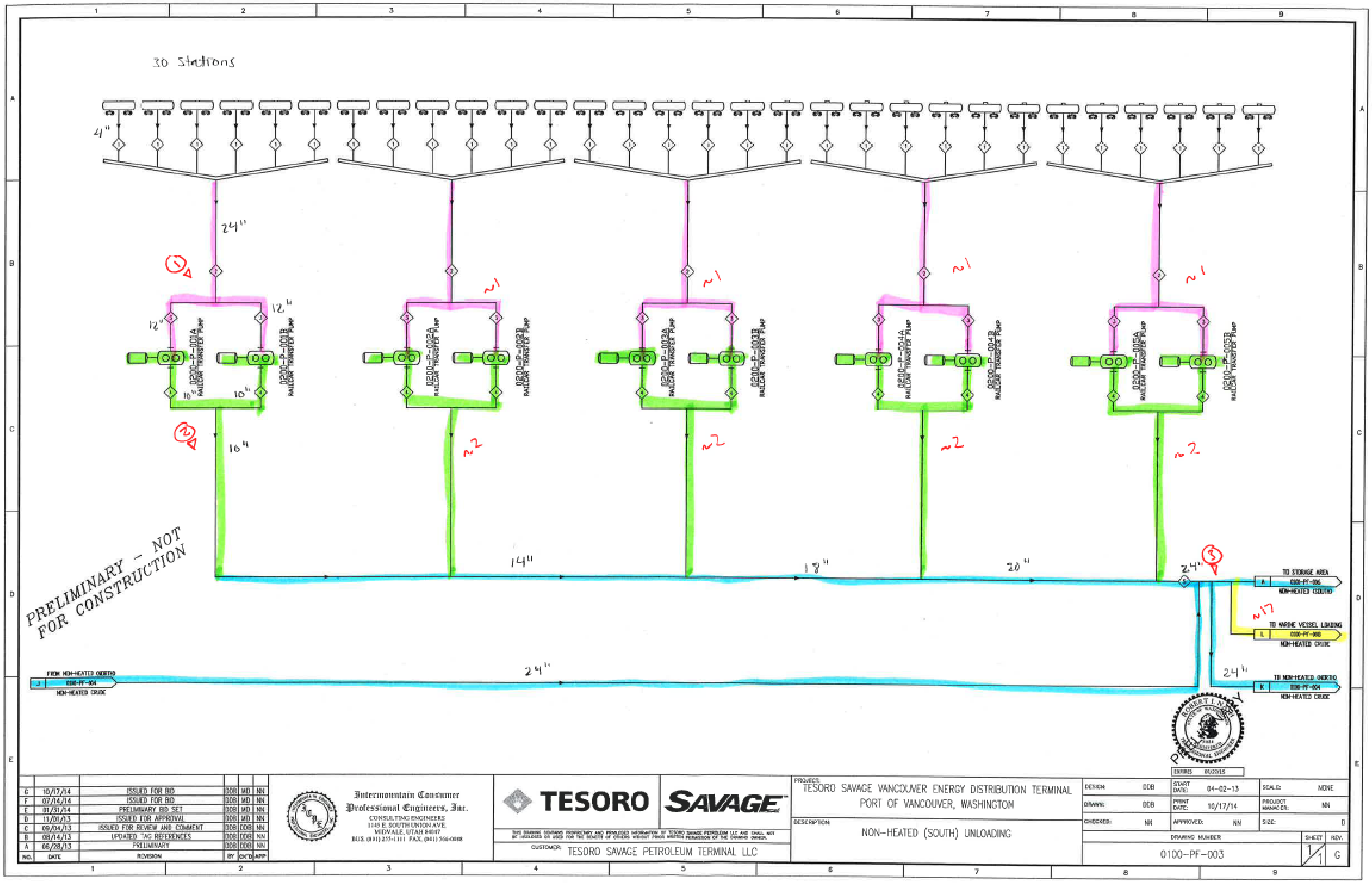
Type 22. Modular Building Construction Type was the only construction type used in this analysis and is described in this appendix.

B.1 Construction Type 22. Modular Building

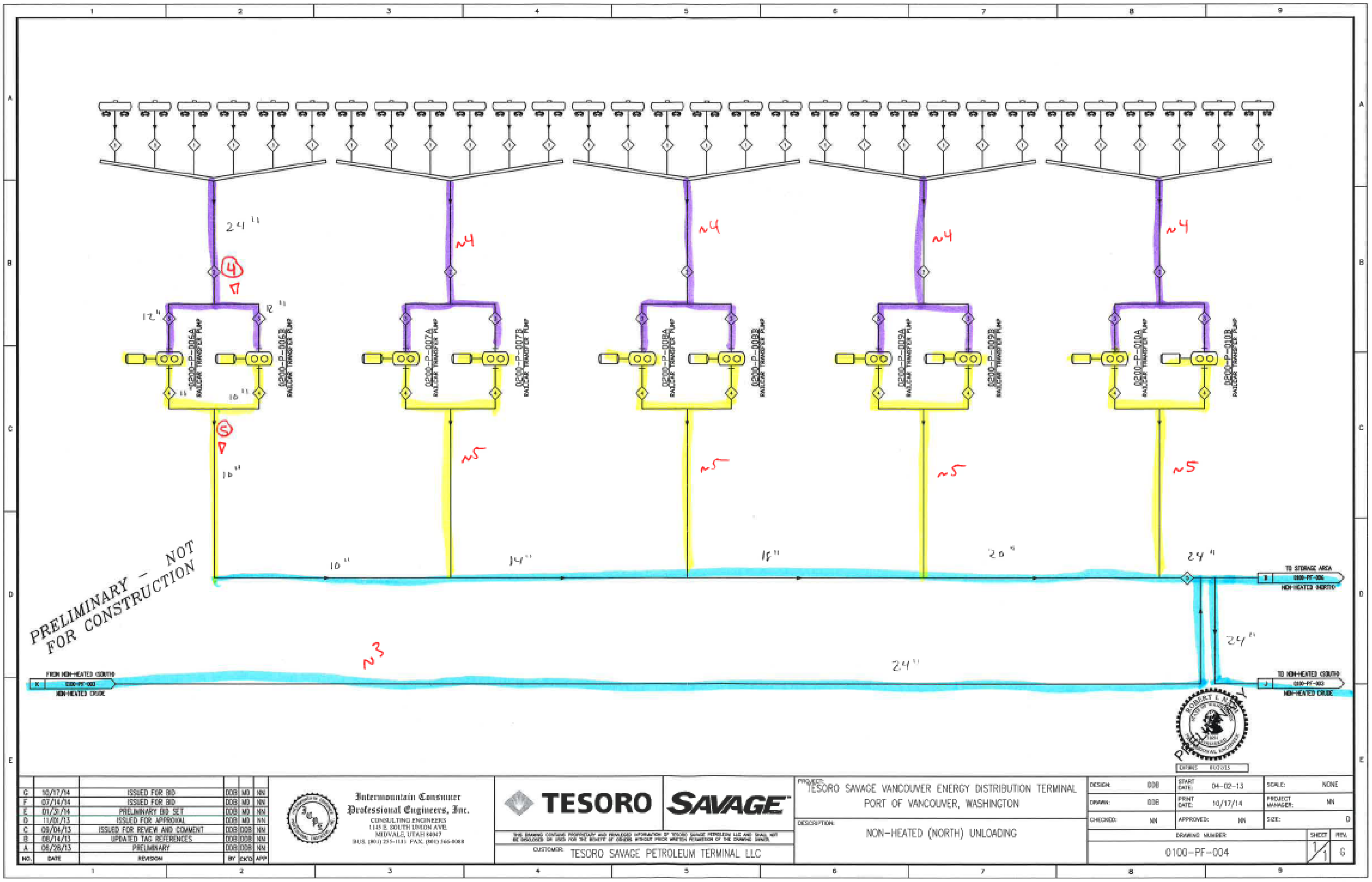
Building Type 22 is a small modular building with a wood frame, such as a portable shed building or other light construction. These buildings typically have wood stud walls with light gauge metal panels. These buildings have little inherent blast resistance and were used to model building blast results, illustrating a worst-case result. Using actual structural models would likely reduce the assessed blast risk.

APPENDIX C.
REPRESENTATIVE SOURCE DEFINITIONS

Highlighted PFDs defining the sources used in the study are shown in this appendix.



EX-0001-008194-PCE



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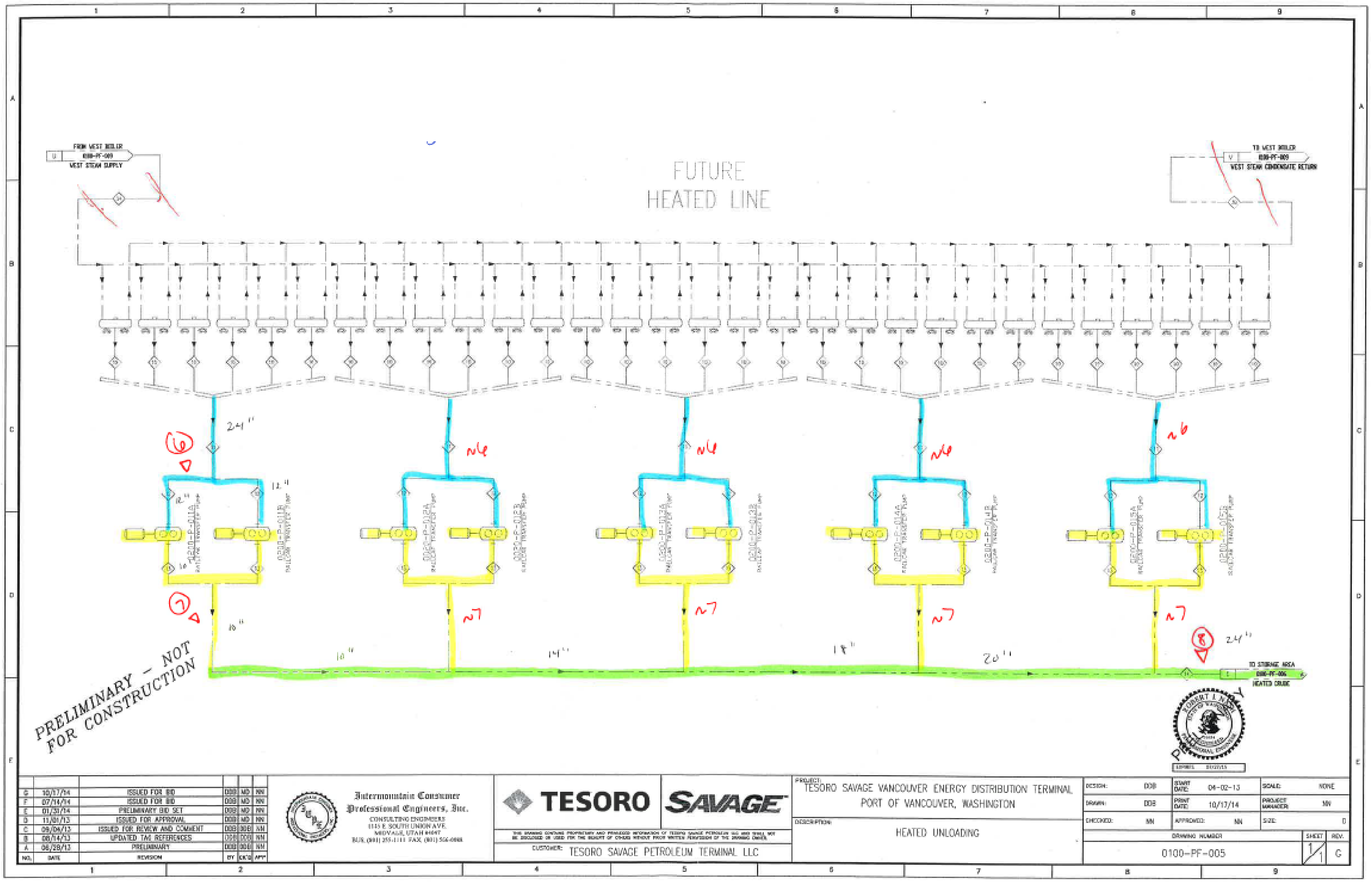

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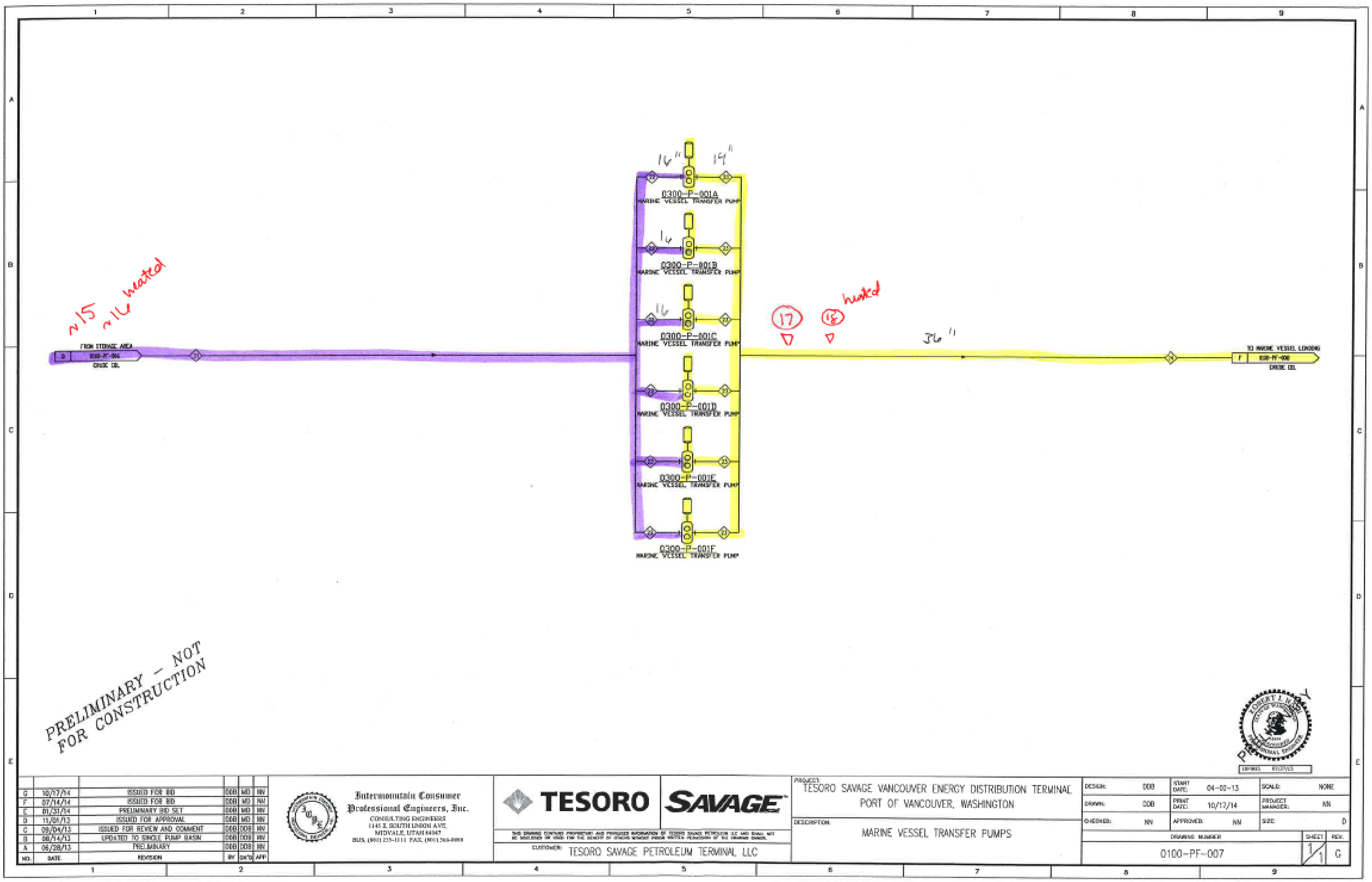

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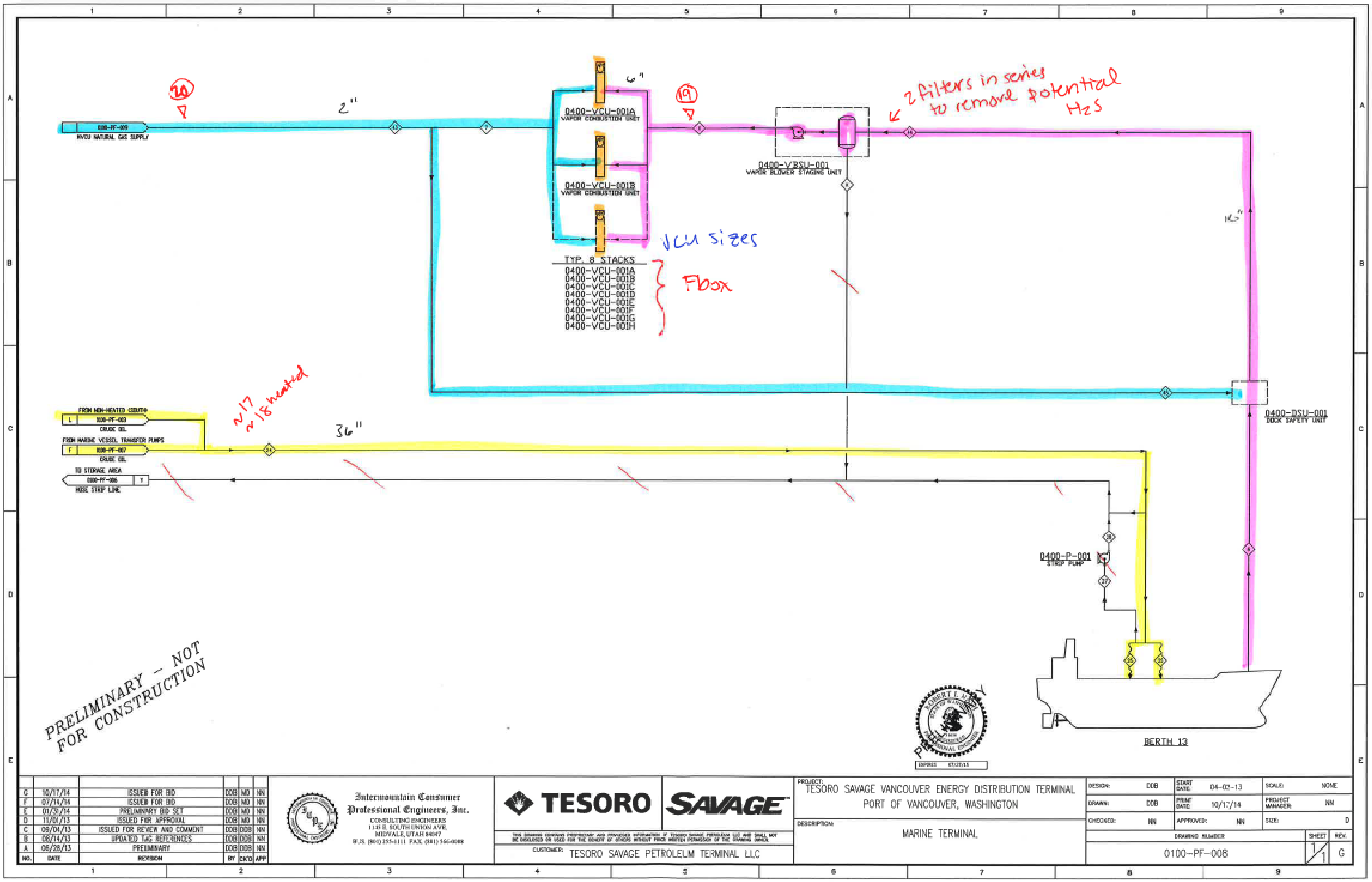

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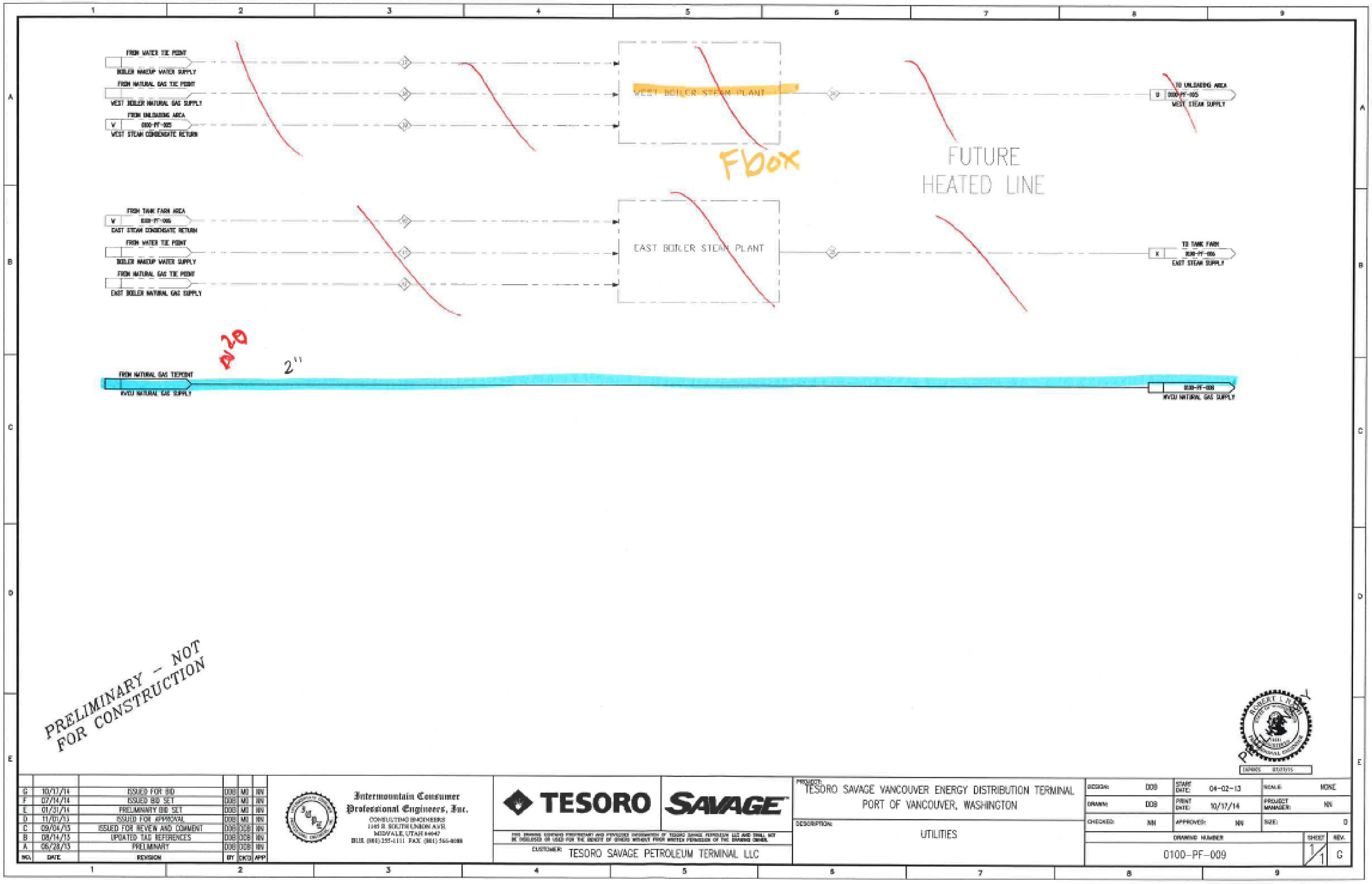

EX-0001-008199-PCE

APPENDIX D.
DISPERSION AND BLAST WAVE RESULTS

This appendix shows dispersion results for limiting flammable cases (sources predicted to cause the maximum blast damage to one or more surface of one or more buildings). Each source shows a plan view of flammable dispersion and side view of flammable dispersion for one of the weather conditions assessed, and composite overpressure contours for the source. Each release case is assessed for a range of weather conditions and dispersed in 16 evenly spaced horizontal directions to ensure that potential blast results are thoroughly assessed. The BST methodology is applied for predicting the resulting blast waves generated.

The plot plan view of dispersion results includes a circle around the location where it is modeled and a dispersion plume. The circle indicates the areas where the flammable plume is predicted to impact. The dispersion plume gives an idea of how wide the plume is predicted to be.

The plan view shows the cloud extent to ½ LFL, LFL, and UFL overlaid on an aerial map. The side view shows the downwind distance to ½ LFL, LFL, and UFL together with the cloud centerline. The horizontal axis shows downwind distance and the vertical axis shows the cloud height (note the scales on each axis differ to maximize the viewable area). Additional results can be provided upon request.

Zone shading shown in the figure is as follows:

- Building
- 3D flame expansion with high obstacle density
- 3D flame expansion with medium obstacle density
- 3D flame expansion with low obstacle density
- 2.5D flame expansion with high obstacle density
- 2.5D flame expansion with medium obstacle density
- 2.5D flame expansion with low obstacle density
- 2D flame expansion with high obstacle density
- 2D flame expansion with medium obstacle density
- 2D flame expansion with low obstacle density
- Enclosed 2.5D flame expansion with high obstacle density
- Enclosed 2.5D flame expansion with medium obstacle density
- Enclosed 2.5D flame expansion with low obstacle density
- Enclosed 2D flame expansion with high obstacle density
- Enclosed 2D flame expansion with medium obstacle density
- Enclosed 2D flame expansion with low obstacle density

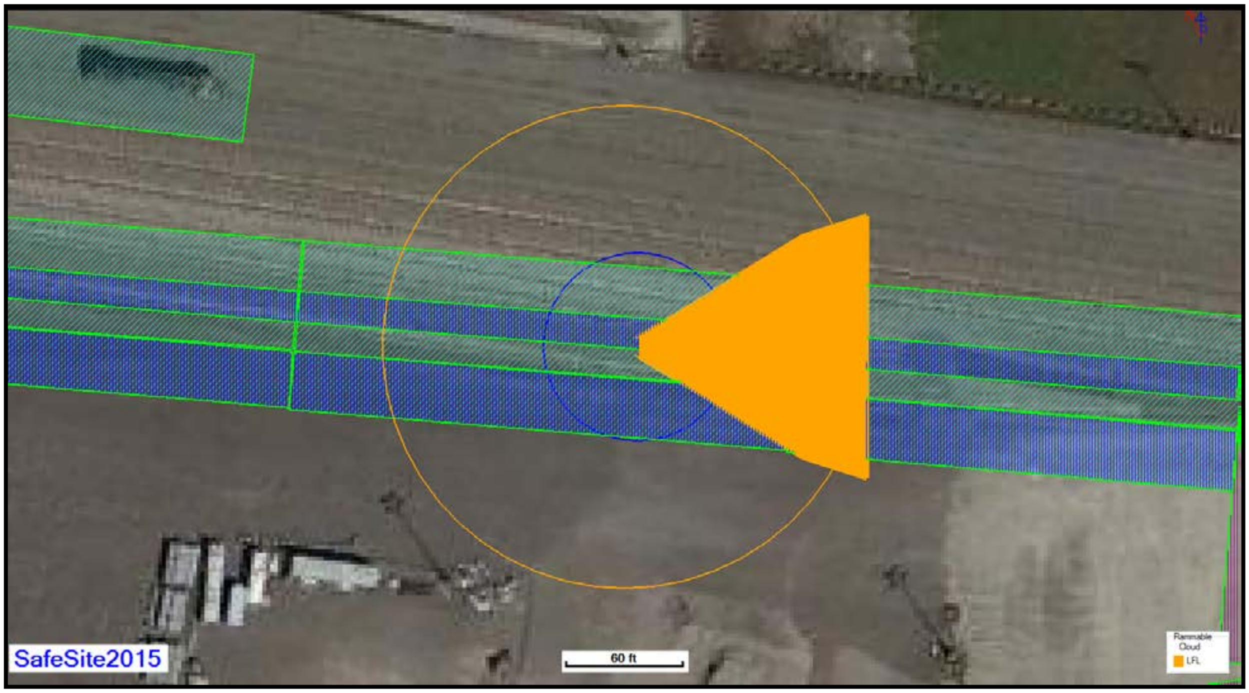

Figure D- 1. 01-SouthRailE-4:F2.0 - Plan View

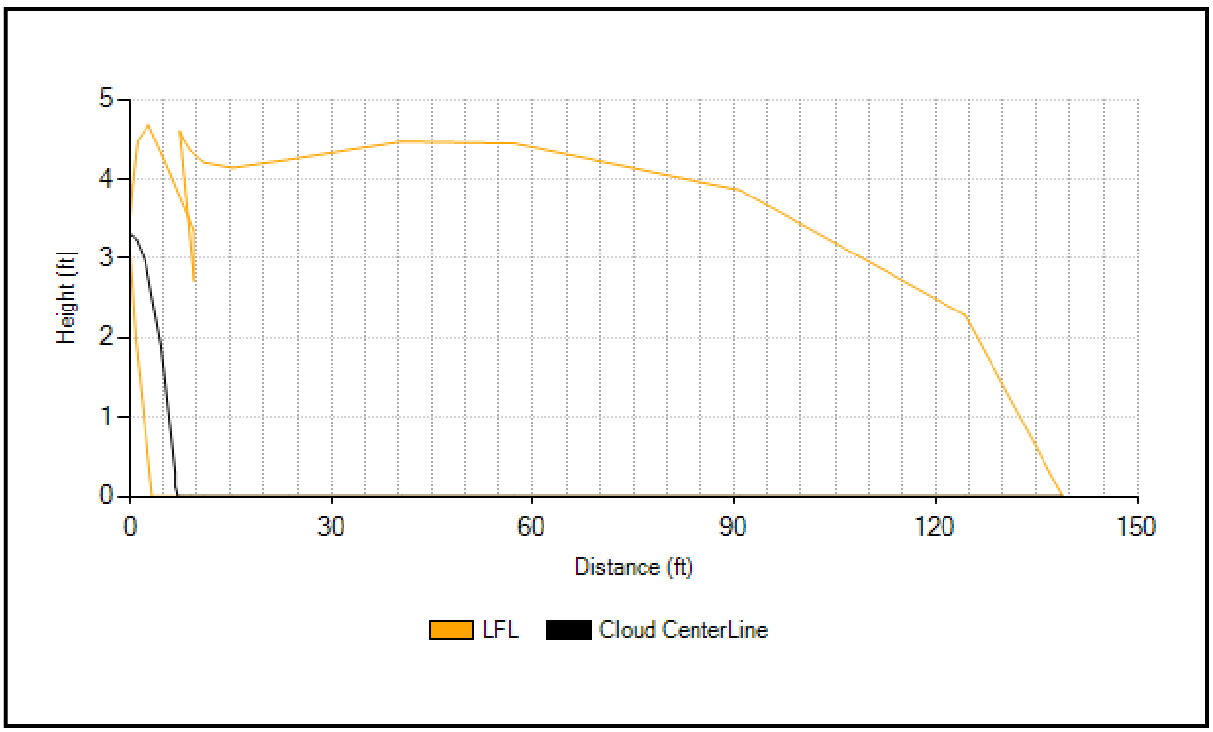

Figure D- 2. 01-SouthRailE-4:F2.0 - Side View

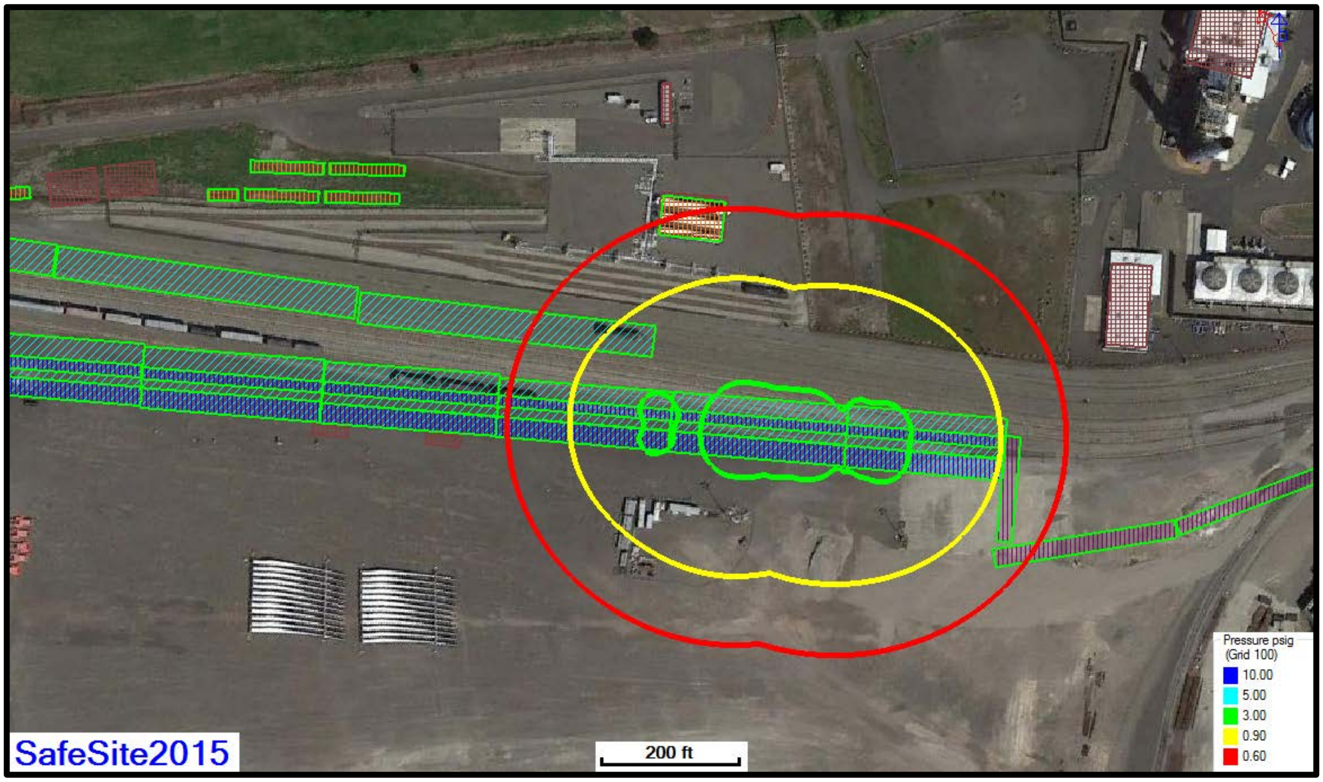

Figure D- 3. 01-SouthRailE-4:F2.0 - Pressure Contours

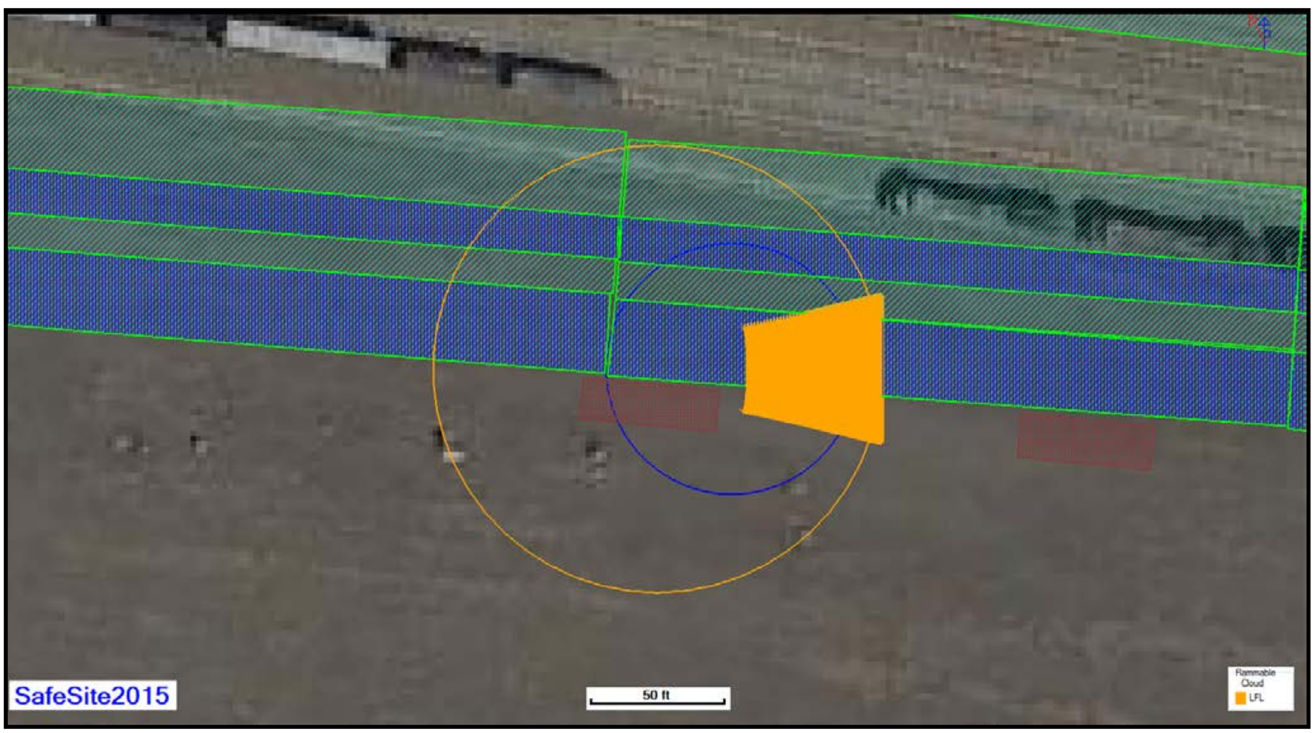

Figure D- 4. 02-P2001C-6:F2.0 - Plan View

EX-0001-008204-PCE

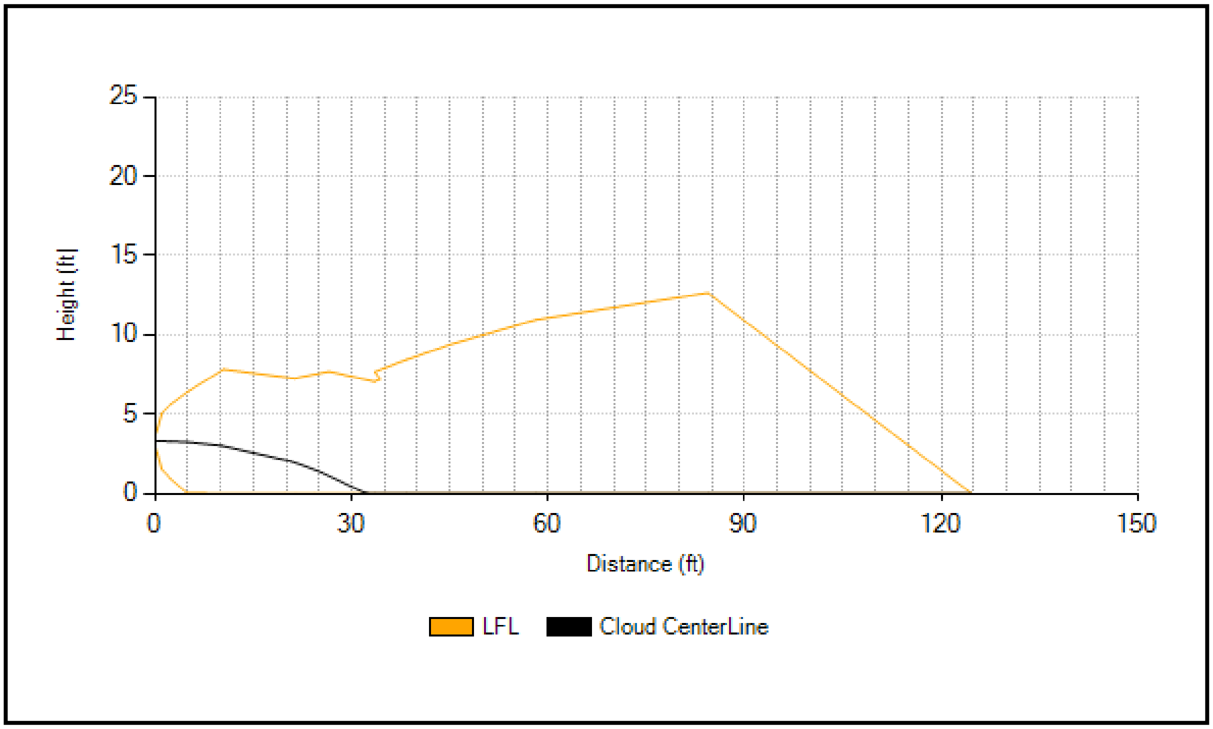

Figure D- 5. 02-P2001C-6:F2.0 - Side View

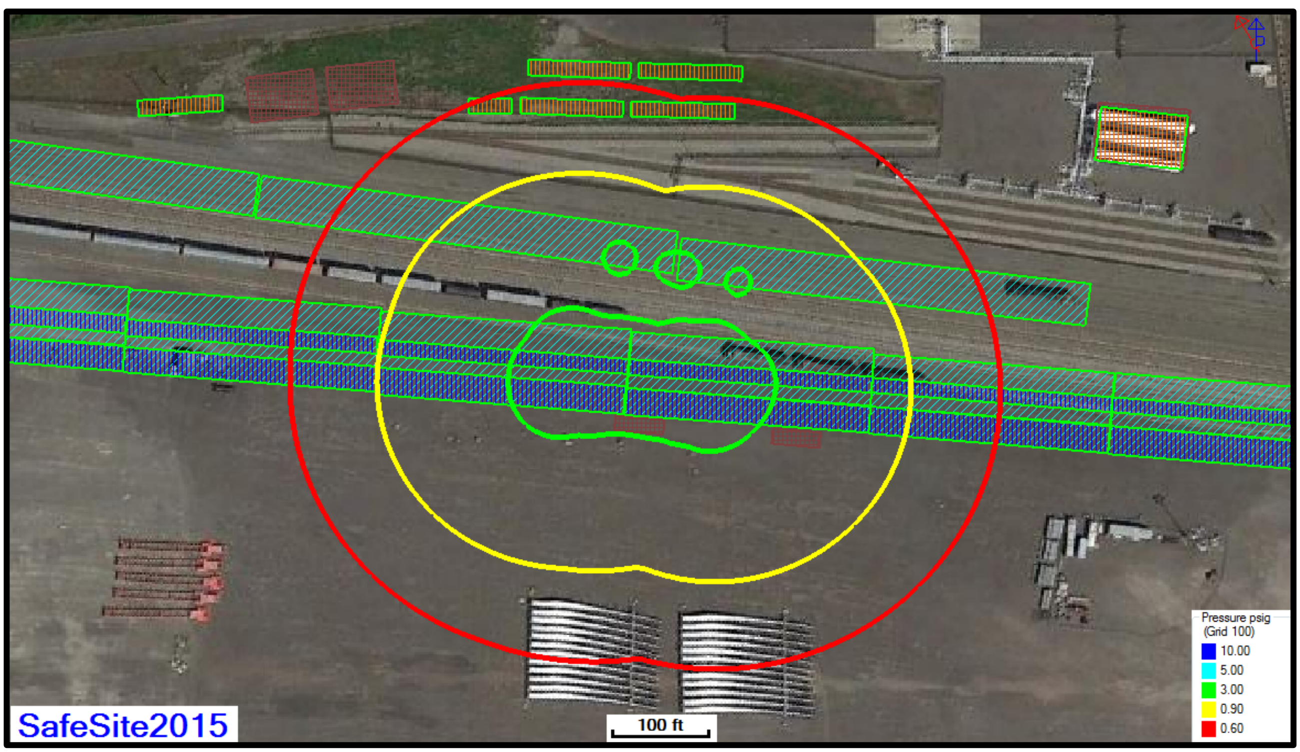

Figure D- 6. 02-P2001C-6:F2.0 - Pressure Contours

EX-0001-008205-PCE

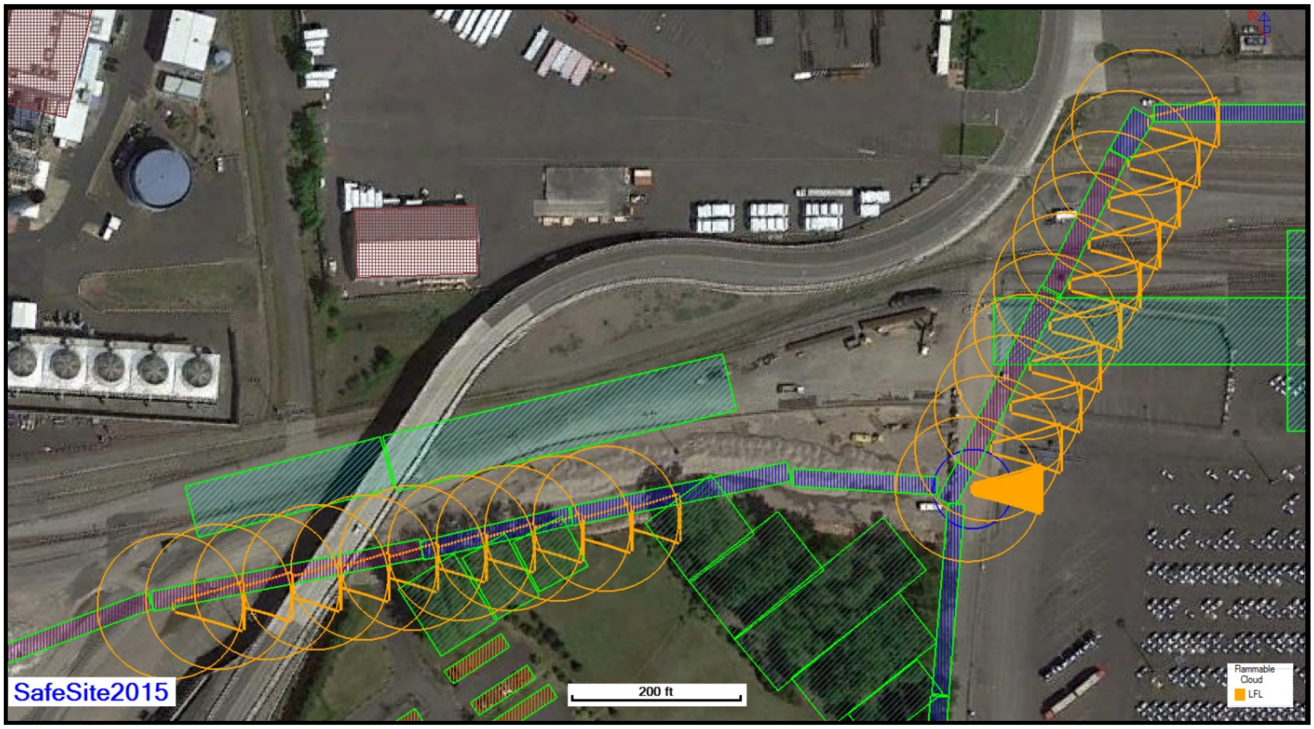

Figure D- 7. 03-PIPE-UG-6:F2.0 - Plan View

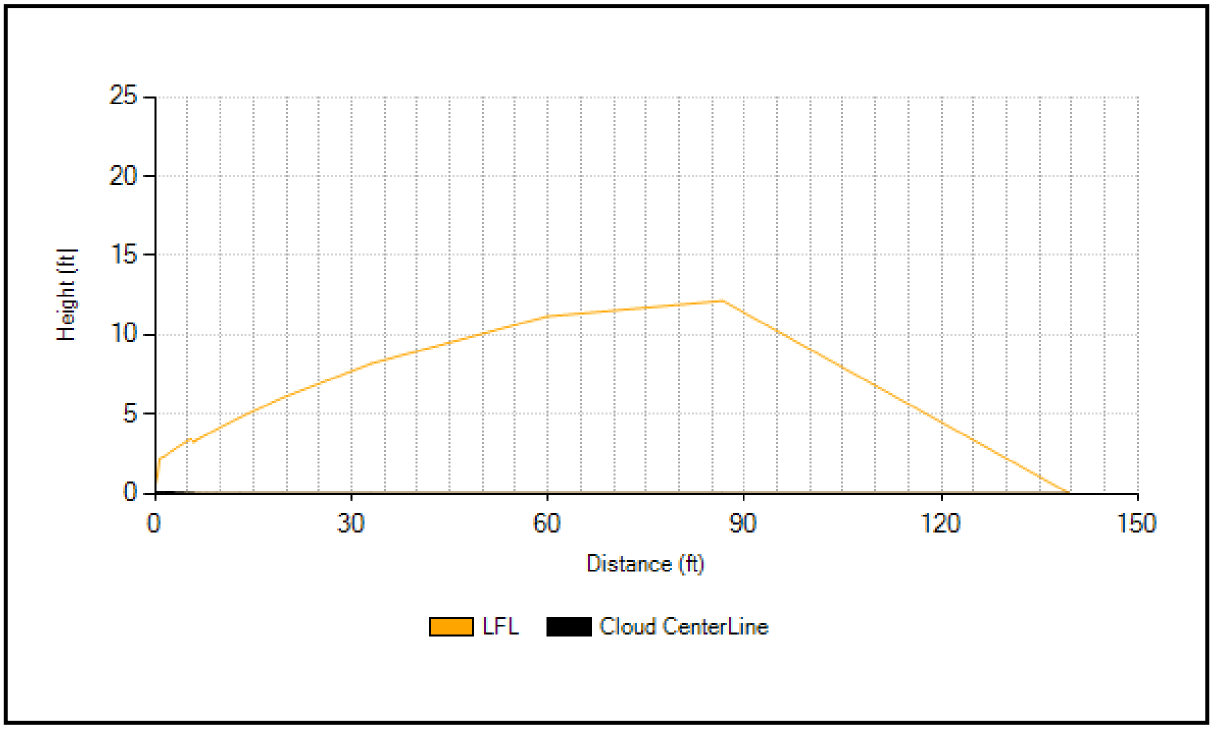

Figure D- 8. 03-PIPE-UG-6:F2.0 - Side View

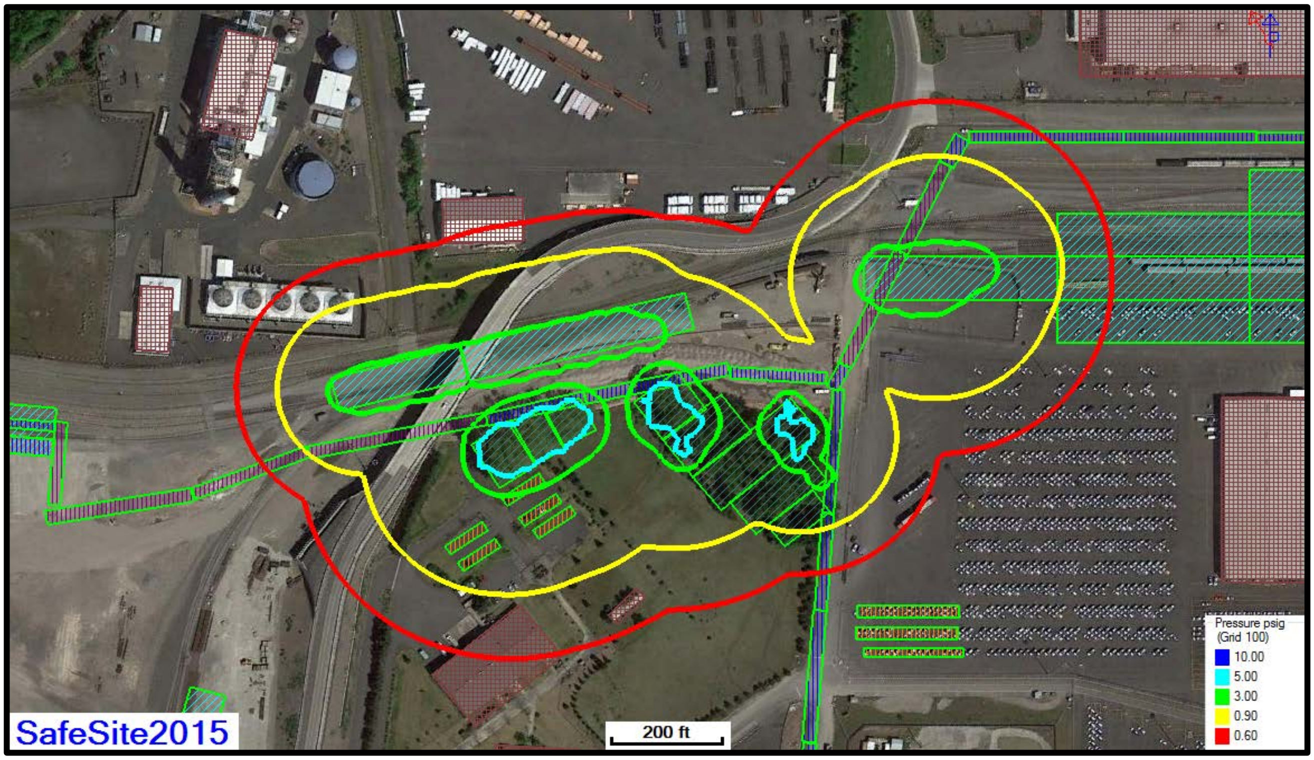

Figure D- 9. 03-PIPE-UG-6:F2.0 - Pressure Contours

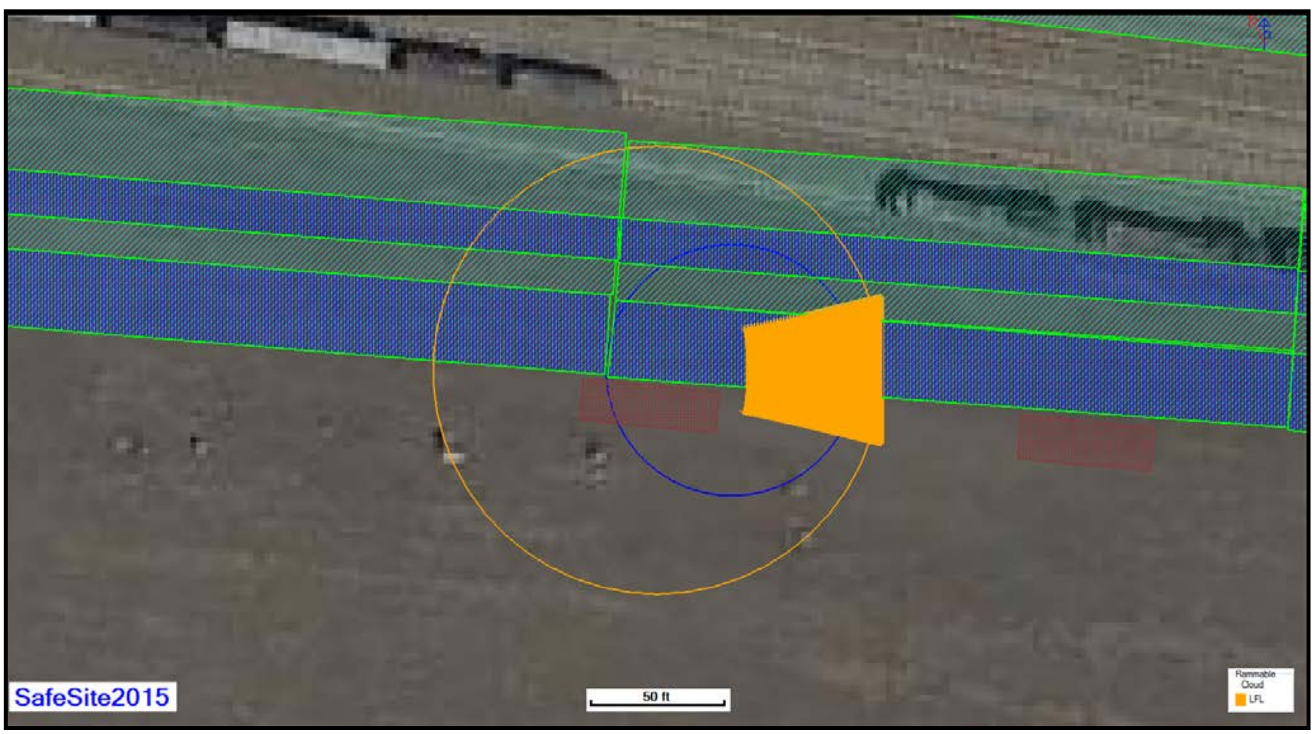

Figure D- 10. 05-P2006C-6:F2.0 - Plan View

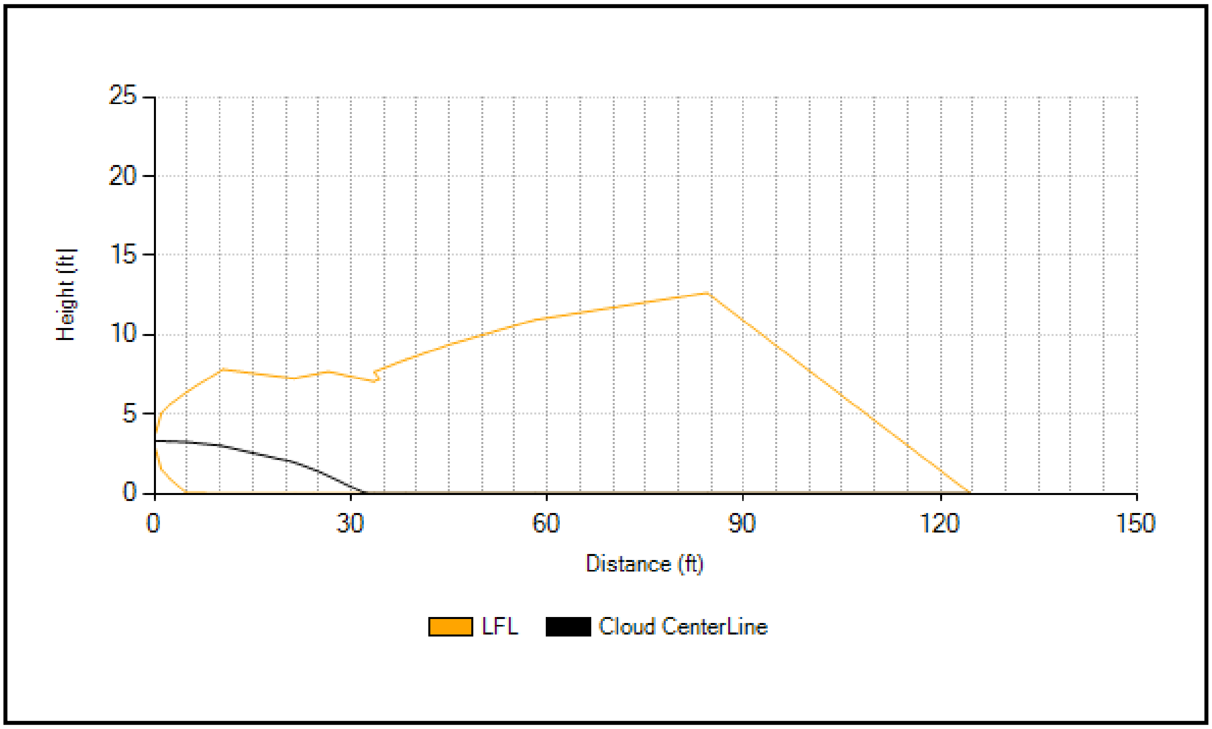

Figure D- 11. 05-P2006C-6:F2.0 - Side View

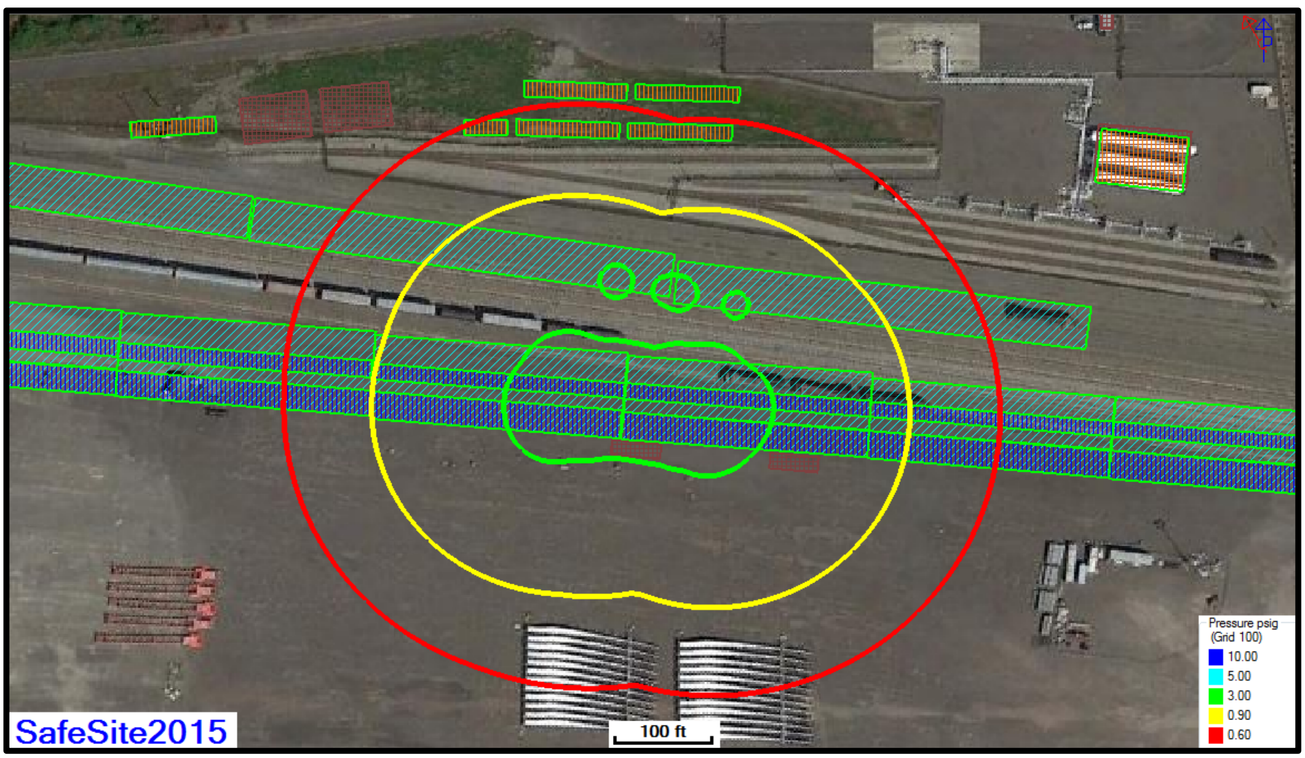

Figure D- 12. 05-P2006C-6:F2.0 - Pressure Contours

EX-0001-008208-PCE

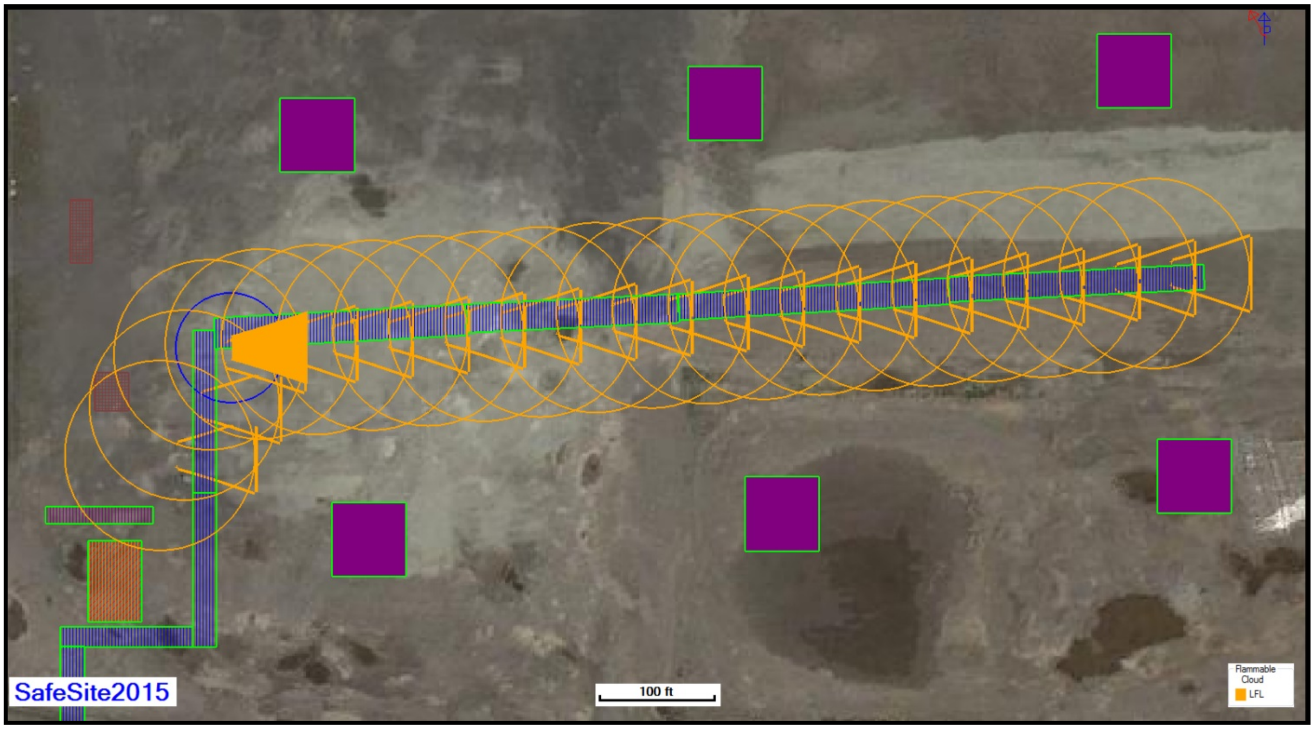

Figure D- 13. 15-PIPE-6:F2.0 - Plan View

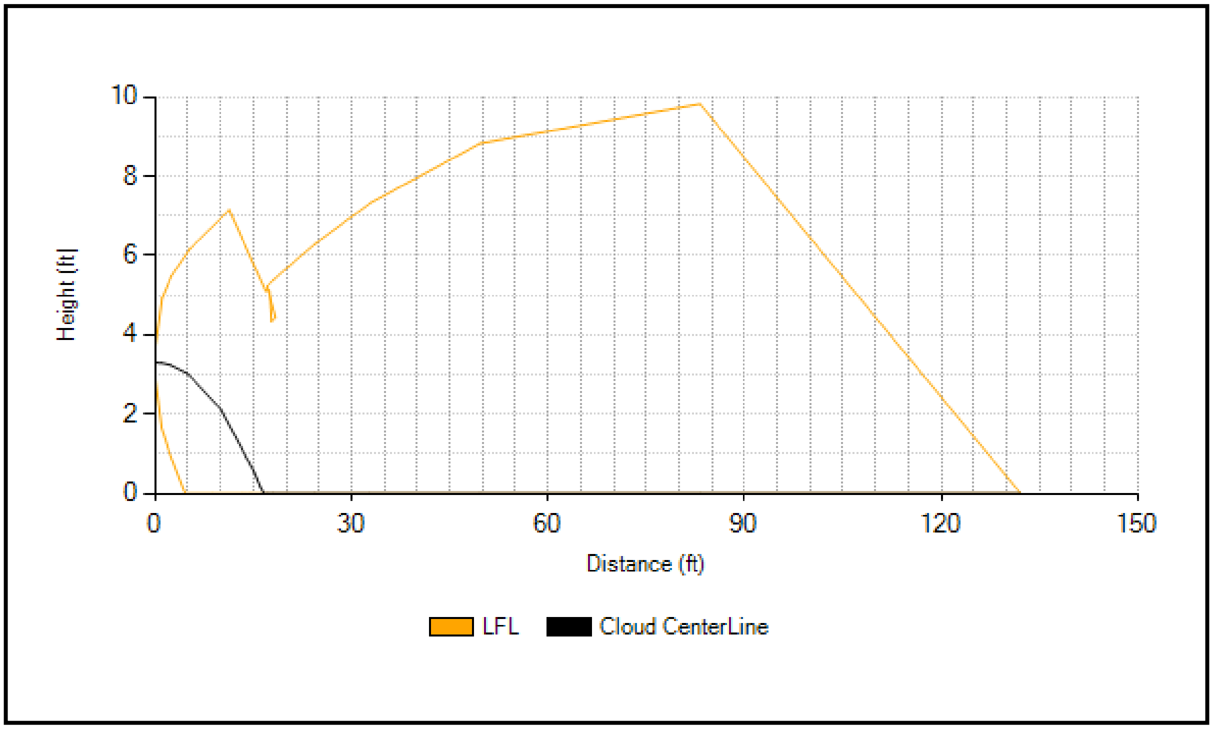

Figure D- 14. 15-PIPE-6:F2.0 - Side View

EX-0001-008209-PCE

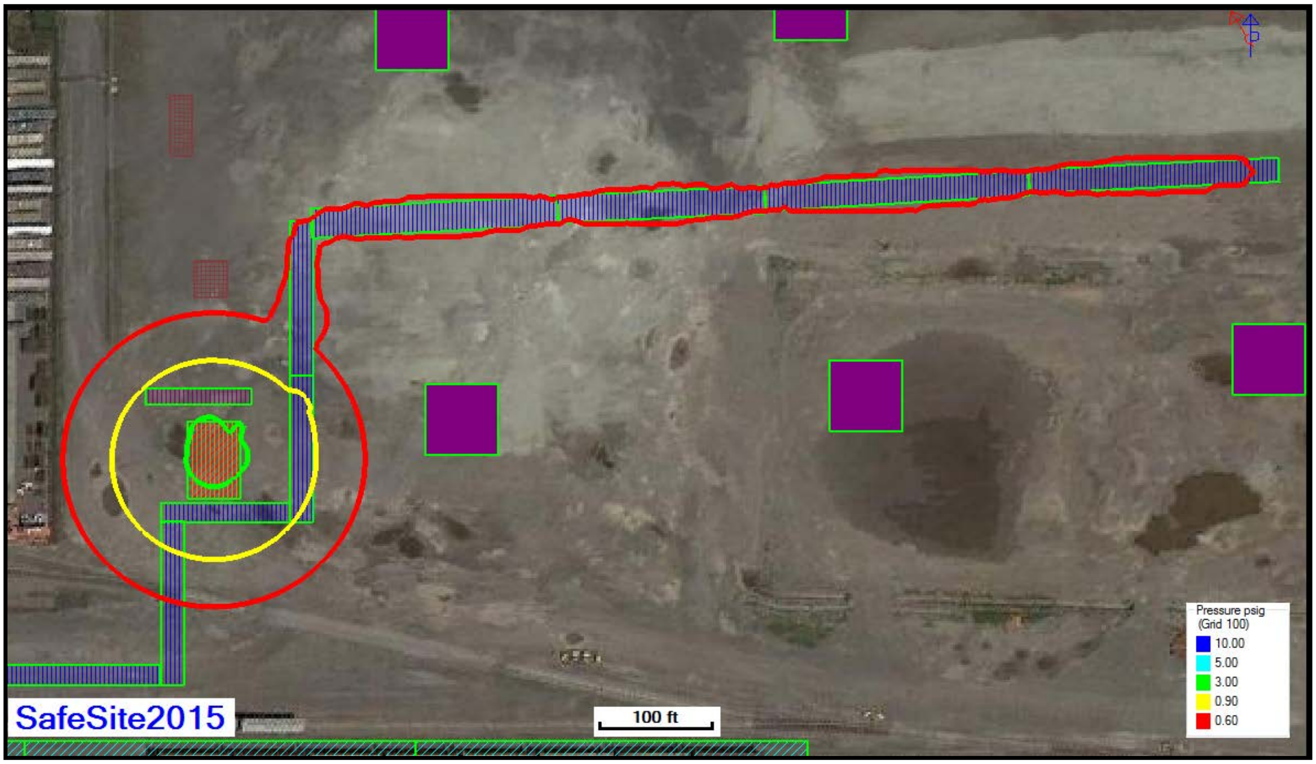

Figure D- 15. 15-PIPE-6:F2.0 - Pressure Contours

Figure D- 16. 17-PIPE-UG-6:F2.0 - Plan View

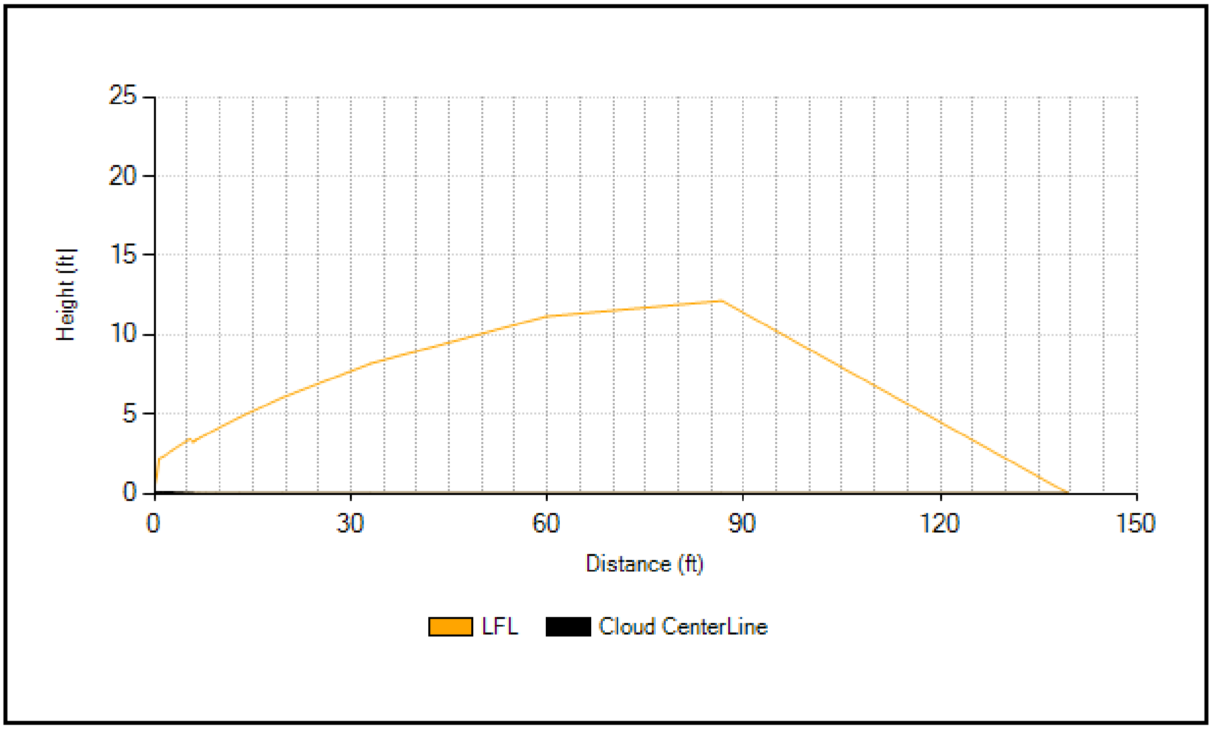

Figure D- 17. 17-PIPE-UG-6:F2.0 - Side View

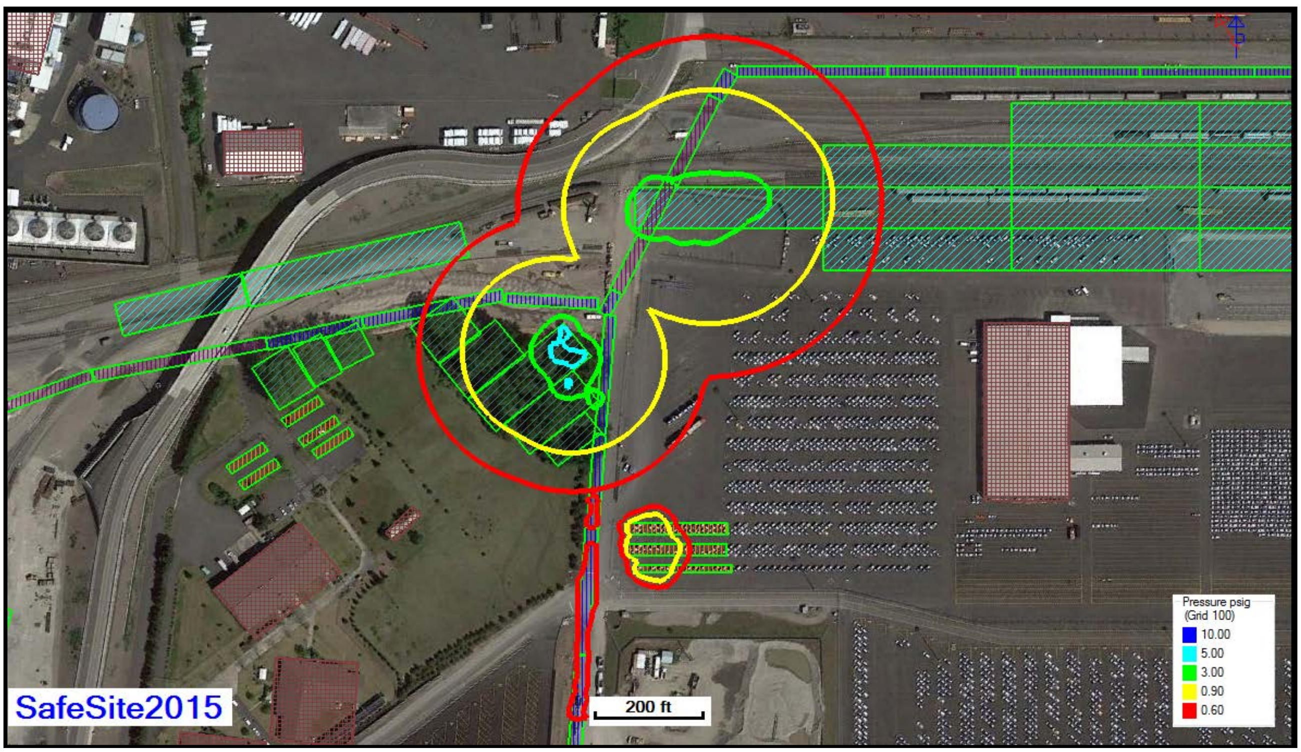

Figure D- 18. 17-PIPE-UG-6:F2.0 - Pressure Contours

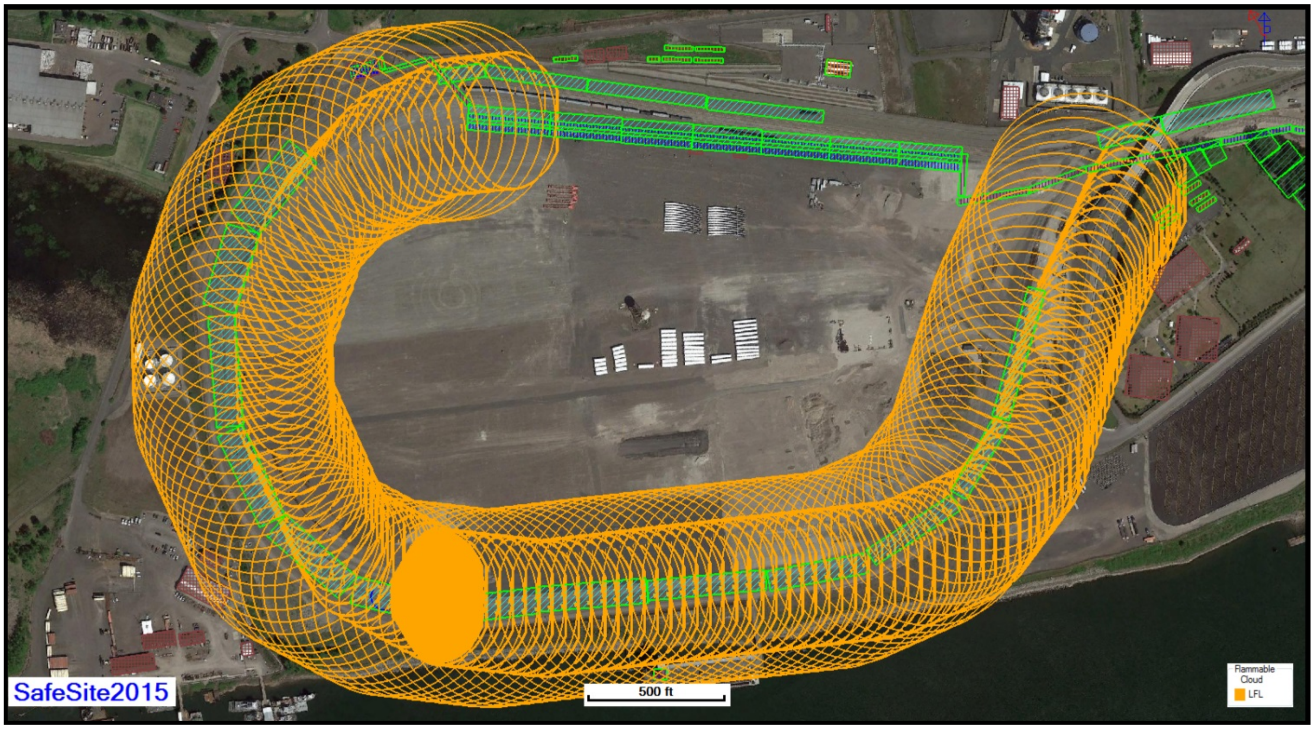

Figure D- 19. 22-Railcar-6:F2.0 - Plan View

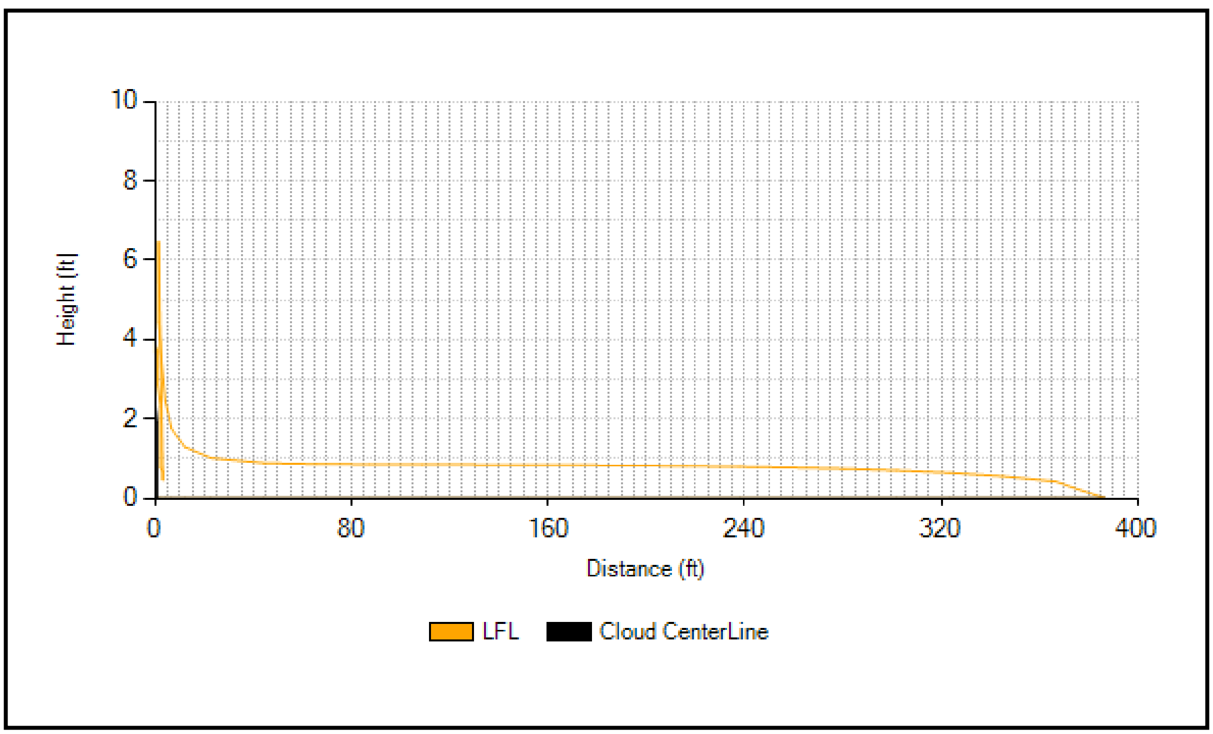

Figure D- 20. 22-Railcar-6:F2.0 - Side View

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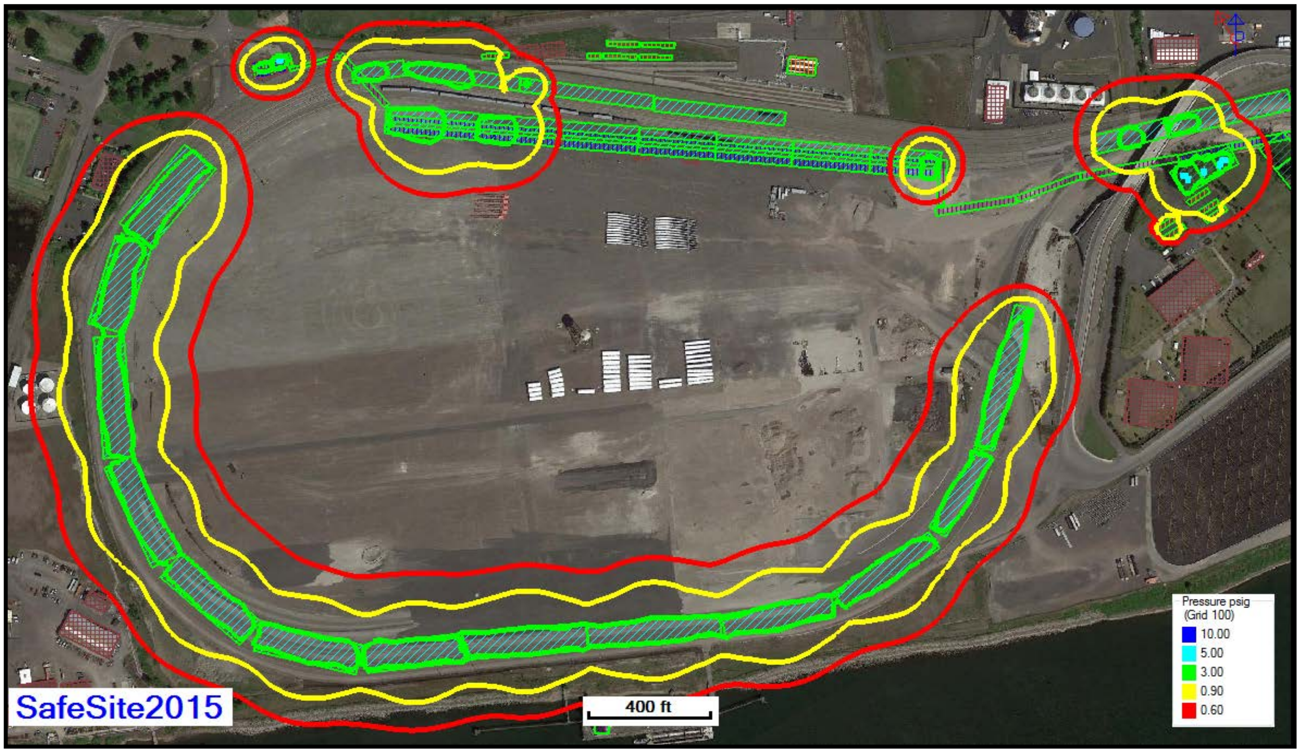

Figure D- 21. 22-Railcar-6:F2.0 - Pressure Contours

APPENDIX E.
FACILITY SITING STUDY RESULTS

This appendix provides documentation of results that are voluminous. Rather than generating large tables, results are preserved in electronic form (spreadsheet ***Vancouver Energy FSS Results Spreadsheet 05692-002-16.xlsx***) to allow sorting, searching, and use of results. The spreadsheet also includes summary tables that are provided in the report, and the formulae used to gather the data are included so the source of the data can be determined. This may be helpful in further understanding results. The following table summarizes the information provided in the spreadsheet.

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Tab	Description	Notes
Summary	Maximum BDLs, flammability concentration, and thermal OVs for each building assessed for each size category	Blank cells indicate that BDL is less than 2.5 (blast), concentration is less than 1/2 LFL (flammable), toxic concentrations are less than the 1% fatality concentration or thermal OV is less than 0.5% vulnerable.
Max Loads	Maximum reflected blast loads for each building surface	Multiple sources are shown if the maximum pressure is caused by a different source than the maximum impulse.
BDL	BDL for each building for each blast scenario assessed	Only scenarios predicted to cause BDL 2.5 or higher or scenarios predicted to cause the maximum pressure or impulse on a building are included. Upon request, BakerRisk will provide complete results for any building assessed.
Pressure	Roof center pressure for each building for each blast scenario assessed	
Impulse	Roof center impulse for each building for each blast scenario assessed	
OV	Occupant vulnerability for each building for each blast scenario assessed	
Rad-Dist	Distance to 3 heat flux values for each jet / pool fire scenario assessed	Blank cells indicate negligible thermal radiation.
Fire-Building	Heat flux at each building for each jet / pool fire scenario assessed	Blank cells indicate negligible heat flux at closest wall of the building.
Fire OV	Building occupant vulnerability due to thermal radiation	Blank cells indicate negligible vulnerability.
LFL	Lower Flammability Level - Flammable concentration categories at buildings for each source	Blank cells indicate concentration is < 1/2 LFL.
Flam-Dist	Dispersion distances to flammability values for each dispersion case assessed	Threshold values of UFL, LFL, and 1/2 LFL are reported.
Tox-Dist	Toxic dispersion distances to probit values.	Concentrations for >Conc1 (1% fatality concentration), >Conc 2 (10% fatality concentration), or > Conc 3(90% fatality concentration) are reported.
Tox-Conc	Toxic concentrations at buildings for each source.	Concentrations for >Conc1 (1% fatality concentration), >Conc 2 (10% fatality concentration), or > Conc 3(90% fatality concentration) are reported. If concentration is below Conc1, the cell is left blank.
Toxic OV	Building occupant vulnerability due to toxins.	Blank cells indicate negligible vulnerability.
Discharge	Discharge rates for each release case	
Fill	Fill case scenarios	
Sources	Release cases assessed	Material, pressure, temperature, and max hole size are listed each source.

Tab	Description	Notes
Mixtures	Mixture names and compositions assessed.	Values are molar percent of each component.
Materials	Materials and fuel reactivity values	Only chemicals used as sources are listed.
Buildings	List of buildings and the types of structures	
Zones	List of zones of confinement and congestion	Congestion and confinement details to support blast analysis calculations
Pipelines	Pipelines and release cases associated with them	Spacing between release cases is also presented for each pipeline modeled.

APPENDIX F: QUANTITATIVE RISK ASSESSMENT RESULTS

This appendix provides documentation of results that are voluminous. Instead of generating large tables, results are preserved in electronic form (spreadsheet ***Vancouver Energy QRA Results Spreadsheet_05692-002-15.xlsx***) to allow sorting, searching, and use of results. The following table summarizes the information provided in the spreadsheet.

Tab	Description
Summary- Overall	Overall source individual contribution to societal risk, building and outdoor area societal risk, LIR, WIR, and FN curves
Summary-Onsite	Source individual contribution to societal risk, onsite building and outdoor area societal risk, LIR, WIR, and FN curves
Summary-Offsite	Offsite building and outdoor area societal risk, LIR, WIR, and FN curves
Bldg Risk	Details on building and outdoor area societal risk
FN Results	Table for plotting FN curve in summary worksheet
Source Risk	Source individual contribution to societal risk based on consequence type
Ind Risk	Location individual risk and work group individual risk
Source Report	Details on sources with material, description, temperature, pressure, and hole sizes
Occupancy	Site occupancy data for buildings and process areas
Mitigation	Building mitigation information
F Release	Scenario frequency summary. Scenario equipment count.
Ignition Probabilities	Scenario and probability of ignition.
F Blast	Frequency and probability of ignition for blast hazards
F Flash Fire	Frequency and probability of ignition for flash fire hazards
F Jet Pool Fire	Frequency and probability of ignition for thermal hazards
F Fill Cases	Frequency estimates for indoor fill cases
Pipes	Pipeline spacing summary

APPENDIX G:
STATISTICAL METEOROLOGICAL DATA

STAR format meteorological data for the Pearson Field Airport near Port of Vancouver, Washington, USA, for the years 2008 to 2012 was supplied to BakerRisk®. STAR format meteorological data is generated from hourly wind speed, wind direction, cloud height and total cloud cover data and consists of the number of occurrences within each of 6 wind speeds, 16 wind directions and 6 stability categories (Pasquill - Gifford: A through F). The stability classes are defined as follows:

A Extremely unstable
B Unstable
C Slightly unstable
D Neutral
E Slightly stable
F Stable

Note: Wind direction in this document references “Wind From” direction.

Table G- 1. Wind Direction Probability by Wind Speed

Wind from Direction	**SPEED(MPH)**						
	1 - 3	**4 - 7**	**8 - 12**	**13 - 18**	**19 - 24**	**>24**	**TOTAL**
N	0.00857	0.01501	0.00117	0.00000	0.00000	0.00000	0.02474
NNE	0.00278	0.00310	0.00036	0.00000	0.00000	0.00000	0.00624
NE	0.00245	0.00165	0.00008	0.00008	0.00000	0.00000	0.00426
ENE	0.00370	0.00338	0.00189	0.00189	0.00004	0.00000	0.01090
E	0.00793	0.01730	0.00905	0.00929	0.00076	0.00000	0.04433
ESE	0.01855	0.08545	0.03516	0.01308	0.00052	0.00004	0.15279
SE	0.02144	0.07326	0.01629	0.00342	0.00000	0.00000	0.11441
SSE	0.01239	0.03508	0.00720	0.00121	0.00000	0.00000	0.05588
S	0.00877	0.03810	0.01034	0.00475	0.00028	0.00000	0.06224
SSW	0.00937	0.03303	0.01440	0.00431	0.00004	0.00000	0.06115
SW	0.00998	0.02655	0.00543	0.00141	0.00000	0.00000	0.04337
WSW	0.00853	0.02901	0.00652	0.00149	0.00012	0.00000	0.04566
W	0.00929	0.03029	0.00849	0.00326	0.00020	0.00000	0.05154
WNW	0.01320	0.04506	0.01501	0.00447	0.00008	0.00000	0.07781
NW	0.02840	0.09627	0.02893	0.00559	0.00004	0.00000	0.15923
NNW	0.01895	0.05616	0.00962	0.00072	0.00000	0.00000	0.08545
TOTAL	0.18429	0.58869	0.16993	0.05495	0.00209	0.00004	**1.00000**

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Table G- 2. Stability Category Probability by Wind Speed

WIND SPEED (m/s)							
Range:	**0.5 - 1.3**	**1.8 - 3.1**	**3.6 - 5.4**	**5.8 - 8.0**	**8.5 - 10.7**	**>10.7**	**TOTAL**
Average	**0.9**	**2.5**	**4.5**	**6.9**	**9.6**		
A	0.00	0.01	0.00	0.00	0.00	0.00	0.01
B	0.03	0.08	0.02	0.00	0.00	0.00	0.13
C	0.04	0.10	0.05	0.01	0.00	0.00	0.20
D	0.03	0.33	0.10	0.05	0.00	0.00	0.51
E	0.06	0.06	0.00	0.00	0.00	0.00	0.13
F	0.02	0.00	0.00	0.00	0.00	0.00	0.02
Total	0.18	0.59	0.17	0.05	0.00	0.00	**1.00**

Table G- 3. Stability Category/Wind Speed CombinationsUused

Stability	Wind Speed (m/s)	Probability
B	1.7	0.156
D	2.3	0.548
D	7.0	0.036
F	1.2	0.260
Total:		1.00

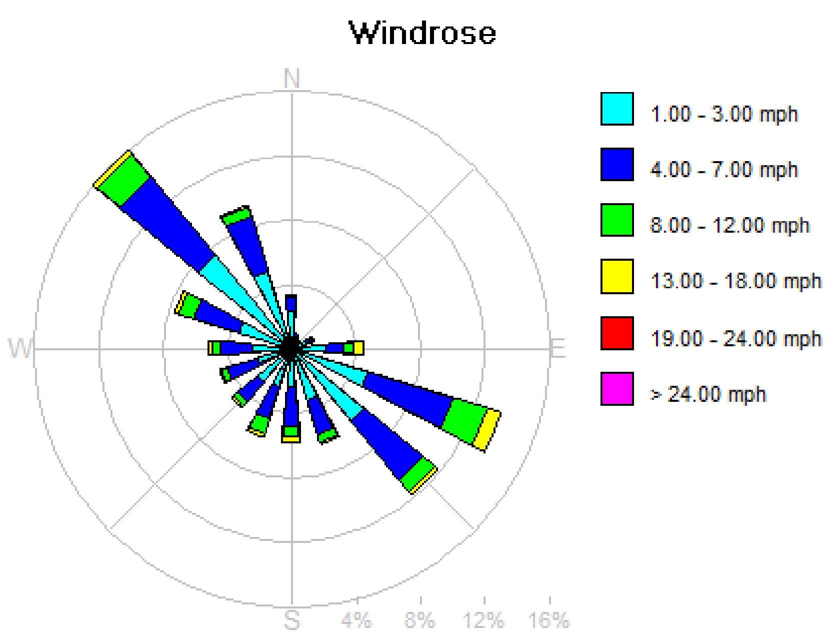

Figure G- 1. Windrose for Pearson Field Airport in Port of Vancouver, Washington

APPENDIX H: TANK DEFLAGRATION DEBRIS THROW AND EXTERNAL BLAST LOADS

A. TANK ANALYSIS

In addition to the overall facility siting requested, BakerRisk® was asked to perform a detailed analysis of an internal explosion within the atmospheric crude storage tanks. The explosion analysis conservatively assumes the entire volume of one tank (i.e., 2.4×10^6 ft^3) was free to fill with flammable vapors and ignite, which would cause an internal tank explosion, resulting in blast waves propagating from the tank and the tank roof being detached and thrown. Based on the analysis described below, the roof debris is predicted to be thrown at a maximum distance of 230 ft. from the tank (i.e., approximately one tank diameter away), which is still within the Terminal boundary.

A.1 Tank Explosion Simulation

BakerRisk modeled the potential deflagration inside one of the atmospheric crude oil storage tanks using the FLame ACceleration Simulator (FLACS) computational fluid dynamics (CFD) software. FLACS is the industry standard CFD code used for the evaluation of vapor cloud explosions for both on-shore and off-shore facilities and is routinely used by BakerRisk for project work. The use of the FLACS allowed both the transient internal tank overpressure and external blast wave propagation to be modeled.

The proposed Vancouver Terminal has six atmospheric storage tanks planned for construction in Area 300 (Northwest section of the Terminal). The atmospheric crude oil storage tanks will have a shell height of 50 ft, have a diameter of 240 ft and a pitched tank roof made of A36 steel which was modeled as 0.1875 inches thick (approximately 7.7 lb/ft^2). BakerRisk estimated that the roof would begin to yield at 0.6 psig and fail at 1.2 psig. The walls of the storage tank were conservatively modeled as rigid and unyielding.

The vapor space inside the tank was modeled as a stoichiometric propane/air mixture. Propane was selected as a representative fuel since it has a laminar burning velocity (LBV) similar to both the light crude oil and lower API crude oil compositions considered in this study, as summarized in Table H- 1. The mixture was assumed to be ignited at the tank center near the tank bottom, which maximizes the internal tank explosion pressure.

Table H- 1. LBV for Tank Mixtures and Propane

Mixture	LBV (cm/s)
Lower API Crude	44
Light Crude	45
Propane	46

The FLACS model treated the tank roof as an explosion vent with a relief pressure equal to the roof failure pressure (i.e., 1.2 psig). Monitor points were located at discreet locations inside and outside the tank to record the tank internal pressure history and external blast wave. Two different modeling approaches were used to represent the venting:

1) The tank roof was assumed to instantly be removed when the failure pressure was reached, as illustrated in Figure H- 1. This is the standard approach to modeling an explosion relief vent.

2) A solid plate with the same dimensions as the roof was placed above the roof at a specified height to capture the blast pressure on the displaced roof as it lifts away from the tank and the associated restriction in venting, as illustrated in Figure H- 2. Two different gap heights (i.e., the distance between the tank roof and solid plate) were examined: 6 feet and 12 feet.

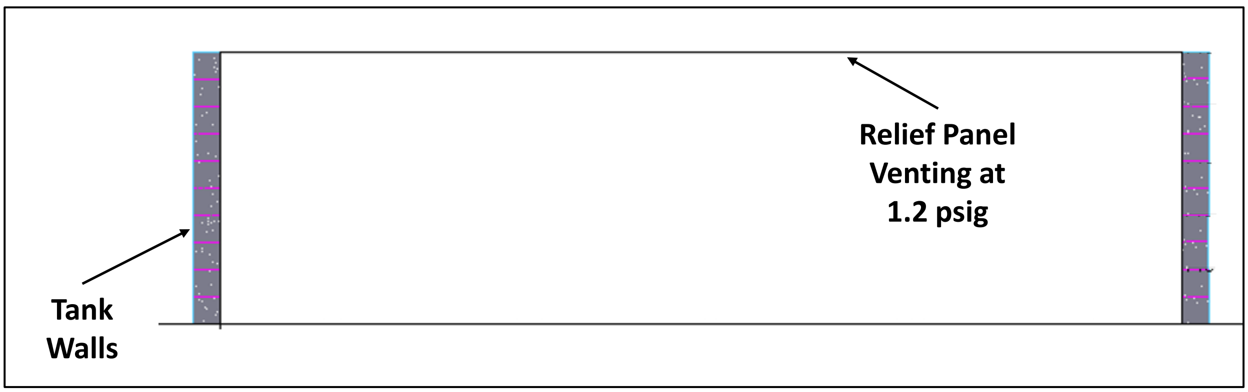

Figure H- 1. Roof Venting without Restriction (Model 1)

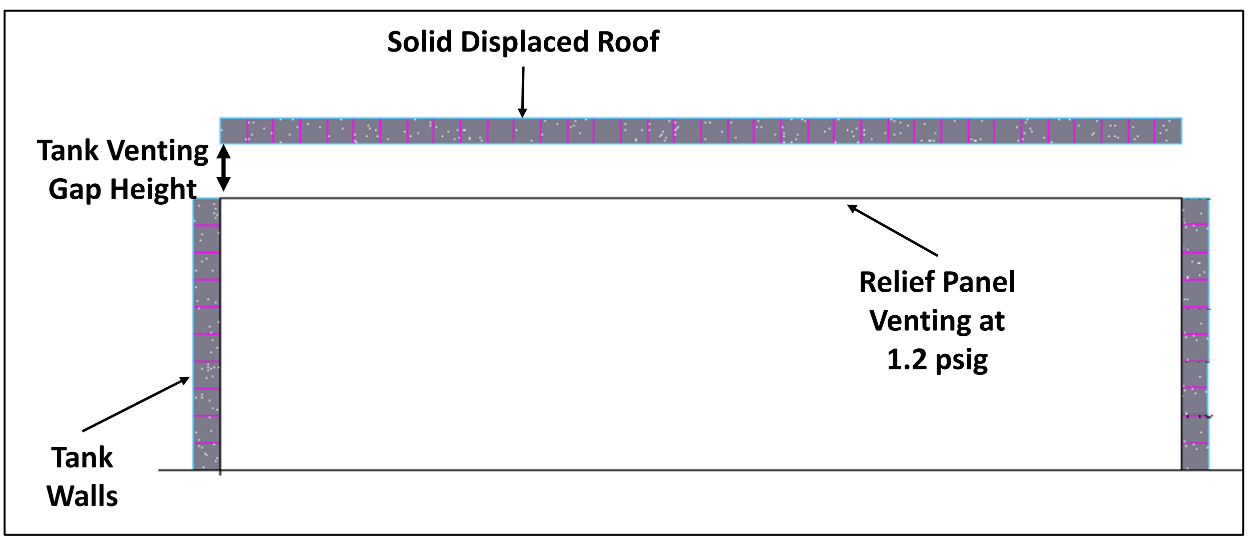

Figure H- 2. Roof Venting with Displaced Roof (Model 2)

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The pressure vs time plot for first approach (i.e. tank roof instantly removed once failure pressure is reached) and second approach (gap between tank roof and solid plate above the tank) with gap heights of 6 ft. and 12 ft. are shown in Figure H- 3. As would be expected, the internal tank pressure is slightly higher and remains longer for the smaller vent gap (i.e., 6 ft.) because the displaced roof with a smaller gap restricts the expanding blast wave to a greater degree.

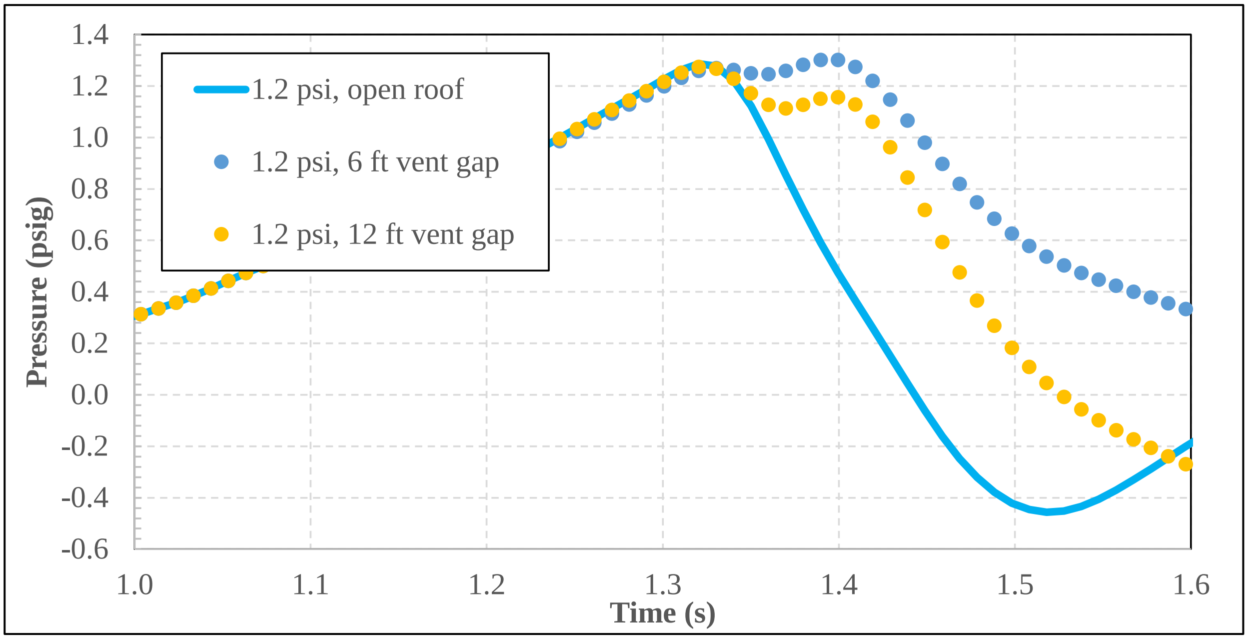

Figure H- 3. Summary of Pressure vs Time plots

A.2 Debris Throw Calculations

The roof motion based on the predicted pressures was modeled using a finite-difference time stepping routine based on the standard equations of motion. The roof velocity was predicted for both vent model approaches. The maximum roof throw distances were estimated assuming a 45 degree launch angle, which maximizes throw distance, and neglecting lift and drag. The results are summarized in Table H- 2. The predicted roof displacement is most consistent with the second vent model approach (gap between tank roof and solid plate above the tank) and a 12 ft. vent gap. Based on this approach, roof debris is predicted to be thrown at a velocity of 79 fps and impact at a maximum distance of 230 ft. from the tank (i.e., approximately one tank diameter away), which is still within the Terminal boundary. The predicted roof displacement for this case is shown in Figure H- 4.

Table H- 2. Estimated Range of Roof Debris from Tank Deflagration

Tank Venting Model		Maximum Roof Velocity (fps)	Roof Debris Throw Distance (ft)
No.	Description		
1	Unrestricted Venting	62	160
2	Restricted Venting, 6 ft. gap	120	470

	Restricted Venting, 12 ft. gap	79	230

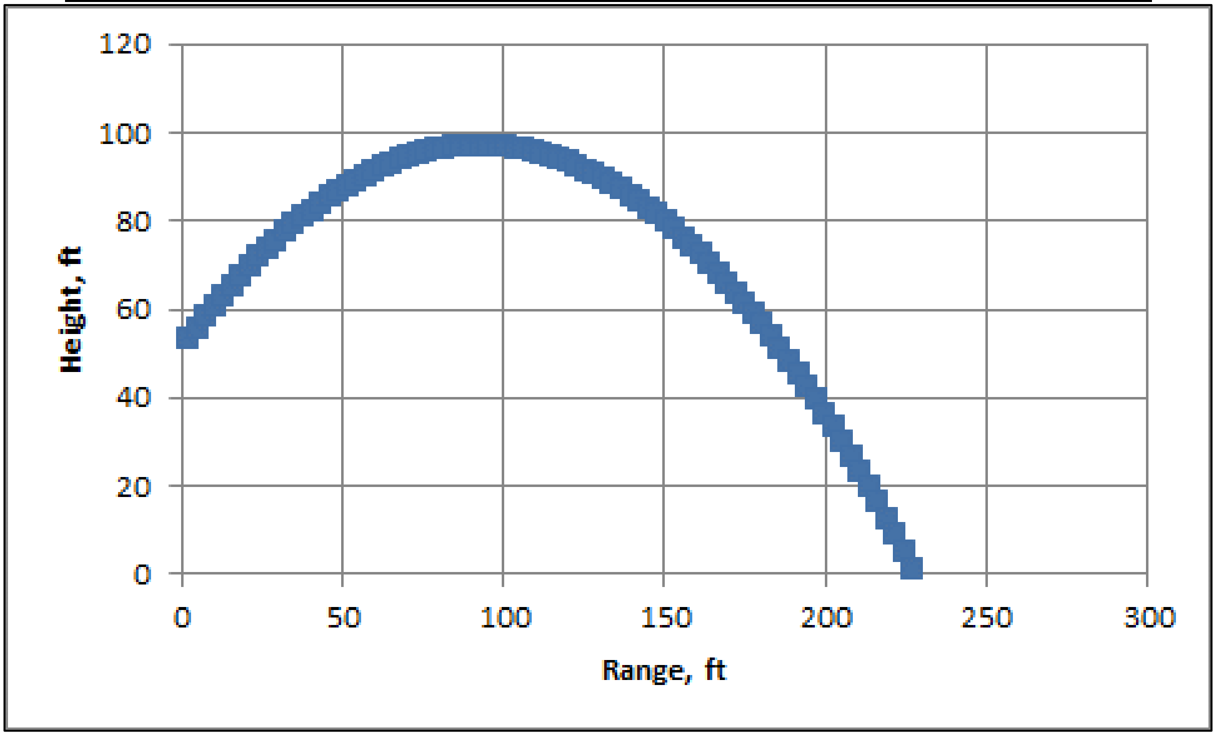

Figure H- 4. Predicted Roof Panel Trajectory

A.3 External Blast Loads

The maximum overpressure and impulse at various distances from the tank wall are shown in Figure H- 5 and Figure H- **6** for the most realistic case (i.e., vent gap of 12 ft.). Fill cases were created for all six atmospheric storage tanks in the SafeSite$_{3G}$© blast model that bound the external loads shown in Figure H- 5 and Figure H- **6**.

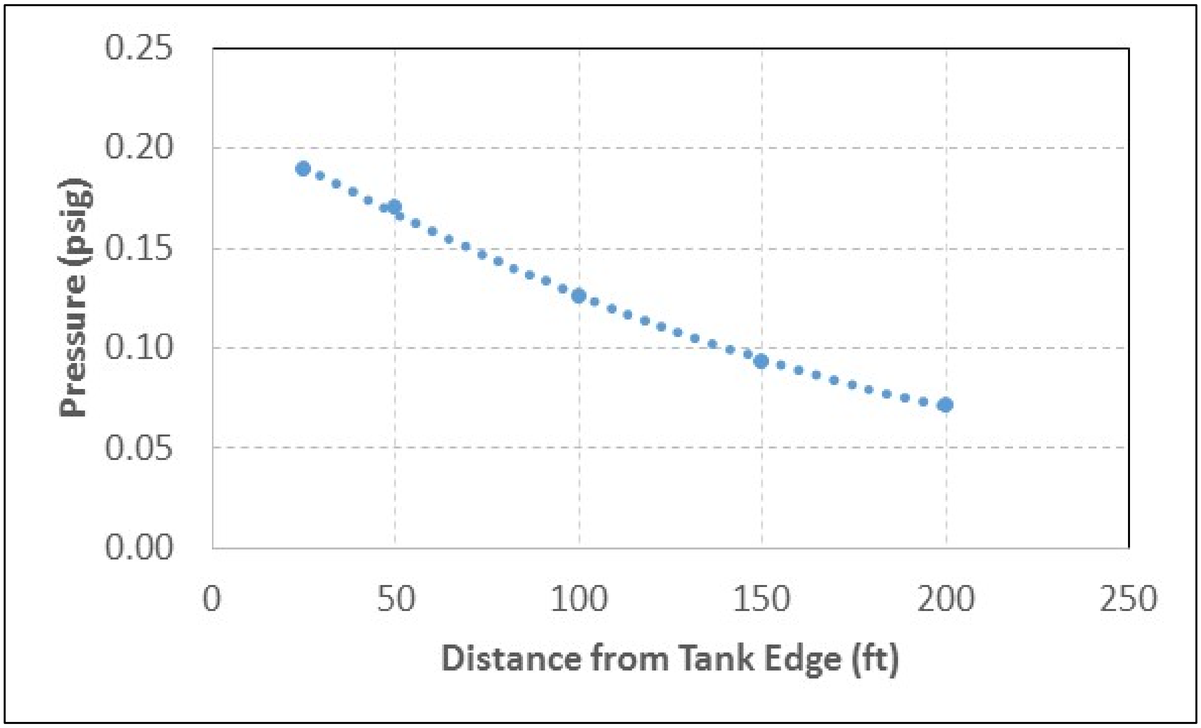

Figure H- 5. Pressure vs Distance

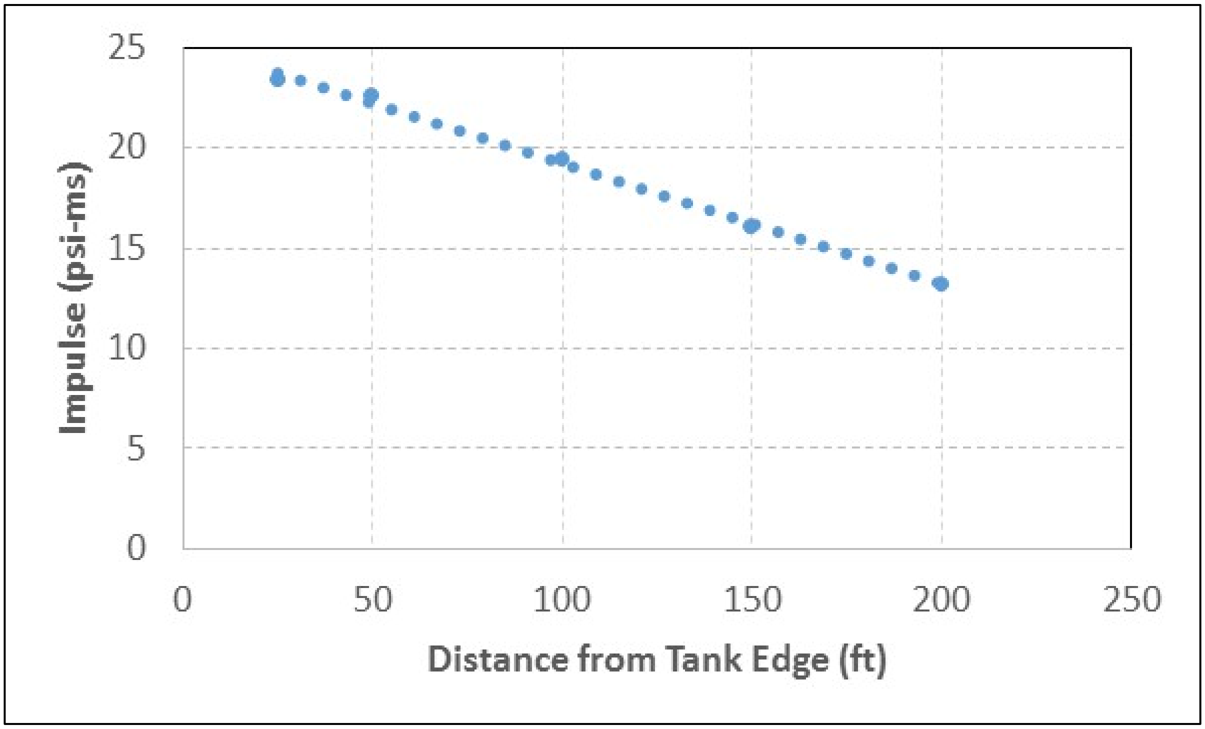

Figure H- 6. Impulse vs Distance