PEMBINA

April 2, 2015

André Baugh, Chair
Planning and Sustainability Commission
City of Portland
1900 SW 4th Avenue, Suite 7100
Portland, OR 97201-5380

RE: Terminal 6 Environmental Overlay Zone Text and Map Amendment
Final Quantitative Risk Assessment (QRA) Report

Dear Chairman Baugh and Commissioners:

Please find enclosed DNV's final "Pembina Propane Export Terminal Facility QRA Report". This report updates the draft QRA report filed with the Planning and Sustainability Commission (PSC) on March 16, 2015. This final report incorporates changes and additional analysis as a result of feedback received at the QRA technical workshop held on March 10, 2015 as well as questions received during and following the Planning and Sustainability Commission's Work Session/ Hearing on March 17, 2015.

DNV added a number of updates to the model run from the Draft QRA report recommendations and March 10th QRA Workshop outcomes/suggestions:

- On-site railcar release and derailment scenarios have been defined and added to the risk assessment once failure frequency data was finalized
- Jetty area onsite populations have been decreased to reflect the expected reduced outdoor population during marine loading after workshop discussions
- Detailed offsite population sub-areas were defined for areas immediately surrounding facility (to account for example, for the absence of population in the Smyth and Bybee Lakes natural area). The QRA draft assumed even population distribution
- across all zip codes but for several this was not accurate enough so more granularity was used to obtain more accurate results.
- City forecast 2035 population growth evaluated for sensitivity study as per your suggestions at the QRA Workshop
- Additional offsite ignition areas were defined
- Additional obstructed regions were defined for railcar locations
- Bunding to limit pool spread was included based on existing and proposed railroad tracks
- Injury endpoint criteria were defined as requested at the QRA Workshop
- Earthquake frequency and scenarios were updated to reflect the seismic design of the facility which will exceed 2014 Oregon Seismic codes
- BLEVE fragment analysis was added to the QRA as suggested at the QRA workshop

The net result of the modifications is an overall reduction in risk for the facility. Most of the risk contours have tightened up or shrunk and some of the specific results that have improved include the following:

- The total Potential Loss of Life(PLL) is **now equivalent to 1 statistical fatality every 180 years**. This is a reduction from 1 statistical fatality every 38 years as presented in the March 16th QRA Draft Report.

Pembina Marine Terminals Inc.
4000, 585 – 8th Avenue S.W., Calgary, Alberta Canada T2P 1G1
Telephone: (403) 231-7500 Fax: (403) 237-0254

- To provide even more granularity we had DNV do a PLL for onsite workers and the offsite population with the results being, 1 statistical fatality every 240 years for onsite workers and 1 statistical fatality every 670 years for offsite population. **A significant result**.
- The total PLL for a forecasted Portland population growth sensitivity case to 2035 is 1 statistical fatality every 160 years.
- The highest risk level offsite has been reduced from 1 in 1,000 years to 1 in 10,000 years in the Final Report which is also significant and reflects the "tightening/shrinking" of the risk contours.
- The societal risk, the FN Curve, has dropped further and completely below the UK HSE tolerability criteria and doesn't touch the criteria line at any point in the Final Report.
- DNV modeled a shrapnel zone impact due to an unlikely event and results show that "a fragment(not all fragments) could travel up to 0.7 miles from site", which is well short of any local residential communities.

Regards,

Eric Dyck
Vice President, Marine Terminals

PEMBINA FACILITY QRA

Pembina Propane Export Terminal Facility QRA Report

Pembina Marine Terminals Inc.

Report No.: PP124992, Rev. 3
Document No.: PP124992-1MICKCR-1
Date: April 2, 2015

Project name:	Pembina Facility QRA
Report title:	Pembina Propane Export Terminal Facility QRA Report
Customer:	Pembina Marine Terminals Inc.
Date of issue:	April 2, 2015
Project Number.:	PP124992
Organisation unit:	Environmental and Navigational Risk
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Det Norske Veritas (U.S.A.), Inc.
DNV GL Oil & Gas
Risk Advisory Services
1400 Ravello Dr
Katy, TX 77449
United States
Tel: +1 281 396 1000

Task and objective:

The objective of this study is to identify and quantify all potential credible failure modes that may lead to a major hazardous event, assess the associated risk to personnel, and make recommendations to ensure tolerable risk.

Prepared by:	Verified by:	Approved by:
Hong Wu Consultant	Cynthia Spitzenberger Principal Consultant	Tone Rice Head of Section

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☐ Secret

Keywords:
Propane, Pembina, Consequence Modeling, Risk, QRA

Reference to part of this report which may lead to misinterpretation is not permissible.

Revision	Date	Reason for Issue	Prepared by	Verified by	Approved by
0	2015-03-13	Draft Report	WHON, HCHEN	LLAT, CSPI	CSTAHL
1	2015-03-16	Updated based on Client Comments	WHON, HCHEN	LLAT, CSPI	CSTAHL
2	2015-04-01	Updated Analysis	WHON	LLAT, CSPI	TRICE
3	2015-04-02	Updated based on Client Comments	WHON	LLAT, CSPI	TRICE

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Revision Log

Revision	
1	• Text updates
2	• Railcar release and derailment scenarios defined and added to assessment • Jetty area onsite populations revised • Detailed offsite population sub-areas defined for areas surrounding facility • 2035 populations evaluated for sensitivity study • Additional offsite ignition areas defined • Additional obstructed regions defined for railcar locations • Bunding to limit pool spread considered based on railroad tracks • Injury endpoint criteria defined • Earthquake frequency and scenarios updated • BLEVE fragment analysis added
3	• Text updates

Abbreviations and Units

Abbreviations	
ACDS	UK Advisory Committee on Dangerous Substances
ALARP	As Low As Reasonably Practicable
BLEVE	Boiling Liquid Expanding Vapor Explosion
BOG	Boil-off Gas
CFD	Computational Fluid Dynamics
CLE	Contingency Level Earthquake
DOT	U.S. Department of Transportation
EC	European Commission
ESD	Emergency Shutdown
FN Curve	Cumulative Frequency (F) of Various Accidents against Number (N) of Fatalities Curve
FRA	Federal Railroad Administration
HAZID	Hazard Identification
HCRD	Hydrocarbon Release Database
IR	Individual Risk
LFL	Lower Flammable Limit
LSIR	Location Specific Individual Risk
ME	Multi-Energy
Phast	Process Hazard Analysis Software Tool
PLL	Potential Loss of Life
QRA	Quantitative Risk Assessment
SMEDIS	Scientific Model Evaluation of Dense Gas Dispersion Models
UK HSE	UK Health Safety Executive
VCE	Vapor Cloud Explosion
VLGC	Very Large Gas Carrier

UNITS	
bbl	Barrels
ft	Feet
gal	Gallons
in	Inches
kg	Kilograms
lb	Pounds
lb/hr	Pounds per hour
m	Meters
mi	Miles
min	Minutes
mm	Millimeters
psi	Pounds per square inch
sec	Seconds

Definitions

DEFINITIONS	
Hazard	Hazard is the physical situation which has the potential to cause harm. For example, a refinery is regarded as a hazardous operation, due to the toxicity of hydrogen sulfide and flammability of gases and liquids in the process. The word hazard does not express a view on how likely it is that harm will actually occur.
Risk	Risk is the combination of likelihood and consequence of accidents. More scientifically, it is defined as the probability of a specific adverse event occurring in a specific period or under specified circumstances. Although *risk* and *hazard* are colloquially used as synonyms, risk is distinct from hazard.
Incident	An unintentional unwanted event, not a near miss, which might or might not result in a release event.
Accident	An accident is an incident that results in the release of propane, which is the actual realization of a hazard.
Probit	A unit of measurement of statistical probability based on deviations from the mean of a normal distribution
Thermal Probit Equation	An equation that relates the intensity, duration, and thermal radiation exposure to the probability of a resulting fatality

1 EXECUTIVE SUMMARY

Pembina Marine Terminals Inc. and its affiliates (hereinafter referred to as "Pembina") propose to construct and operate a liquid propane export terminal in Portland, Oregon, the Pembina Portland Propane Terminal. The facility will be located at Terminal 6 in the Port of Portland. DNV GL was requested by Pembina to perform a Quantitative Risk Assessment (QRA) of the facility.

This report documents the results and findings by assessing the risk from the Pembina Propane Export Terminal during normal operation.

This study estimates the risk from flammable releases, such as jet fires, pool fire, flash fire, vapor cloud explosions, fireball and Boiling Liquid Expanding Vapor Explosion (BLEVE). The risk is presented as individual risk in the form of location specific individual risk (LSIR) contours, and as societal risk in the form of Potential Loss of Life (PLL) and FN (Cumulative Frequency (F) of Various Accidents against Number (N) of Fatalities) curves.

LSIR is a measure of the average annual risk (of fatality in this case) an individual would see (from the realization of specific hazards such as flammable releases) if one were to continuously remain at a specified location.

The societal risk for a hazardous activity is defined as the probability that a group of one or more persons would become fatalities due to an accident from the hazardous activity. PLL is the average number of fatalities per year. It is calculated by summing the products of impact frequency and the number of fatalities. The societal risk can be represented by FN curves, which are plots of the cumulative frequency (F) of various accidents against the number (N) of the fatalities.

Since there are not requirements for individual and societal risk criteria in the US, the UK HSE risk tolerability criteria for individual and societal risk are presented for the project. The estimated risk levels on the facility are evaluated against the risk tolerability criteria.

The study input data and assumptions applied in this analysis are fundamental to the validity of risk results and are provided in Appendices I-IV.

Results

The overall outdoor LSIR contours are presented in Figure 1. The outdoor LSIR contours are shown in decades of risk starting from a risk level of 1E-08 per year (1 in 100,000,000 years of operation) up to a level of 1E-03 per year (1 in 1,000 years of operation). The iso-risk contour is a line of equal risk. For example, an individual standing in the open on the 1E-06 per year risk contour line for one entire year (24 hours per day for 7 days per week for 365 days) will have a risk of one in a million of being a fatality. This risk value does not take into account the potential exposure time for the individual.

The maximum outdoor LSIR onsite is about 1E-03 per year (1 in 1,000 years) at the pressurized propane storage bullets and propane compression/refrigeration area.

The total PLL is 5.6E-03 per year, which is equivalent to 1 statistical fatality every 180 years.

The FN curve for the total population (onsite and offsite) is presented in Figure 2. The figure shows the total societal risk FN curve result for the Pembina propane terminal, which is below the risk tolerability criteria adopted by the UK HSE.

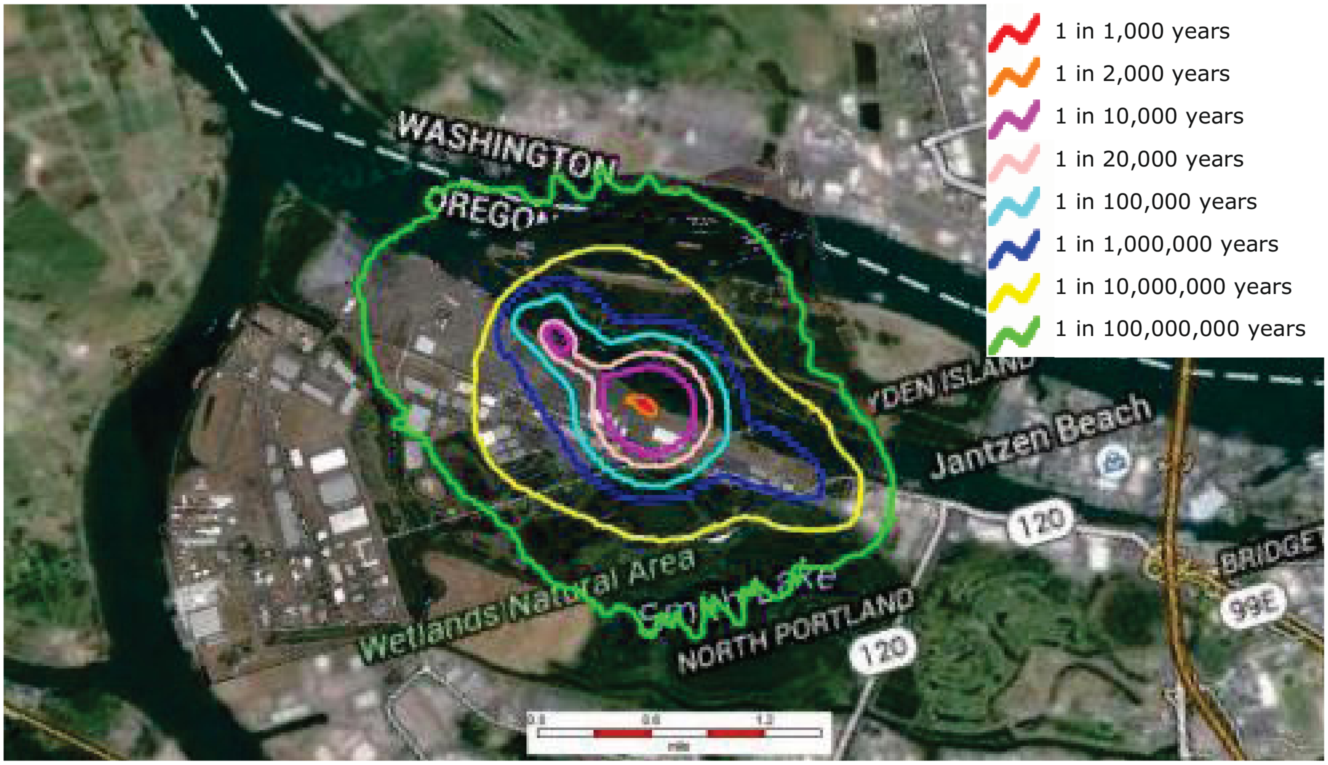

Figure 1: Overall Site Outdoor Location Specific Individual Risk (LSIR) Contours

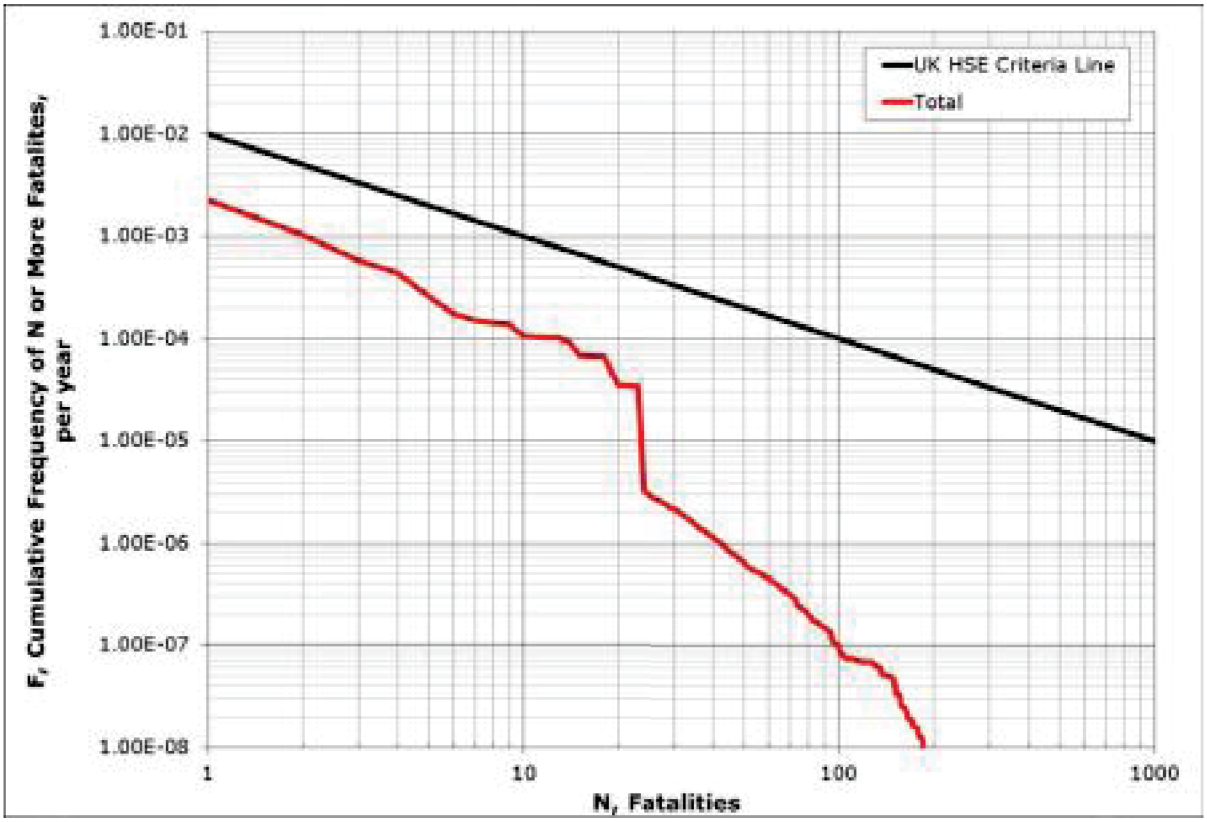

Figure 2: Overall FN Curve Compared to UK HSE Risk Criteria

Conclusions

Individual Risk

- A few locations have risk levels of 1E-03 per year (1 in 1,000 years) onsite: pressurized propane storage bullets and propane compression/refrigeration area.
- The outdoor LSIR for the control room is 1.7E-04 per year (1 in 5,770 years) and the indoor LSIR is 1.8E-04 per year (1 in 5,460 years), which are in the As Low As Reasonably Practicable (ALARP) region according to the UK HSE tolerability criteria.
- The highest risk level offsite is 1E-04 per year (1 in 10,000 years) in the channel area and to the south of the facility.
- The offsite point locations evaluated are either in the ALARP or broadly acceptable region according to the UK HSE tolerability criteria widely accepted by the marine industry.

Societal Risk

Base Case:

- The total PLL is 5.6E-03 per year, which is equivalent to 1 statistical fatality every 180 years.
- The societal risk result is below the UK HSE tolerability criteria on the FN curve.
- The liquid loading arm is the largest risk contributor to PLL, contributing 15.4% of the PLL. A majority of the risk comes from fatal impact at the jetty location. The pressure storage tank groups 3, 1, and 2 contribute 13.8%, 12.7% and 12.6% to the risk, respectively. In total, the groups of bullets contribute 39% to the risk.
- The key release scenarios contributing to the overall risk levels are: Marine Liquid Loading Arm, Propane Unloading Storage Bullets, Refrigerated Propane Tanks and Jetty Loading Pipe.
- The Propane Unloading Storage Bullets and Loading arms are the significant contributors to N < 20. The Refrigerated Storage and Railcar Transit are the significant contributors to N > 20, as seen from the FN curve result breakdown.
- Onsite PLL is 4.1E-03 per year (1 in 240 years), contributing 73% to the total risk. Offsite PLL is 1.5E-03 per year (1 in 670 years), 27% of the total PLL. The sub-area #345, where the Pembina facility is located, contributes the most to the offsite PLL, 8.3E-04 per year (1 in 1,200 years).

Sensitivity Case:

- The total PLL for the 2035 sensitivity is 6.3E-03 per year, which is equivalent to 1 statistical fatality every 160 years. This is a 13% increase from the base case result.
- The societal risk result is below the UK HSE tolerability criteria on the FN curve.
- The pressure propane storage bullet group 3 – is the largest risk contributor to PLL, contributing 14.8% of the PLL.
- Note that the sensitivity assumes no change to the terminal operation between today and 2035. If activity were to increase or decrease at the terminal by 2035, then the risk result may be higher or lower than presented here.

Recommendations

The following recommendations may be considered in developing the facility design and siting:

1. **Minimize the potential for BLEVE scenarios**. Given the number of pressurized propane bullets at the site, there is the potential for escalation scenarios and BLEVEs. Although a number of

mitigations have been input to the design to minimize these impacts, the site should further minimize this potential by focusing on the grading and drainage in the vicinity of the bullets to ensure flammable liquids will not collect in the area in the event of a release.

2. **Focus on Key Contributors**. Consider further reducing the risk posed by the high risk contributors, in particular, aim risk mitigation efforts toward the pressurized storage vessel bullets, refrigerated propane tanks, and marine loading.

3. **Impoundment Areas.** Bunding, curbing and secondary containment is recommended to limit the potential pool sizes. Bunding resulting from the existing and proposed rail lines has been roughly accounted for in the modeling of potential pool fire scenarios to limit the pool spread to more realistic distances. However, the model does not account for any other topography elements of the site. To better contain the potential pool hazards and spread of the pool fires to other areas of the facility or to offsite, bunding or other containment measures should be considered.

4. **Detection and Isolation**. Leak detection and isolation are key control measures accounted for in the model. Their primary influence is to limit the potential for escalation, the more rapidly that isolation occurs the greater the benefit in terms of risks to personnel, potential for escalation, and reduction in overall duration of event. Focus should be placed on the installation and maintenance of the systems to further optimize their reliability and effectiveness.

2 INTRODUCTION

Pembina Marine Terminals Inc. and its affiliates (hereinafter referred to as "Pembina") propose to construct and operate a liquid propane export terminal in Portland, Oregon, the Pembina Portland Propane Terminal. The facility will be located at Terminal 6 in the Port of Portland.

The facility will receive approximately 3.2 million gallons of liquid propane from rail tracks every two days. There are two rail tracks each capable of accommodating one 7,000 ft unit train (one track to receive a loaded train and one track to contain an empty train for departure). A third track is anticipated to move the locomotives from one end of the train to the other. The facility rail offloading racks have 13 double-side racks planned, for a total of 26 unloading stations.

The liquid propane will be cooled at a rate of up to 1.7 million gal per day and stored in two refrigerated double-walled storage tanks with the capacity of 550,000 bbl (23.1 million gal) and 250,000 bbl (10.5 million gal). A Very Large Gas Carrier (VLGC) up to approximately 23 million gal capacity will load at the facility approximately two to three times per month for transit down the Columbia River to foreign markets.

A simplified schematic of the operation diagram of the Pembina Portland Propane Terminal is shown in Figure 2-1.

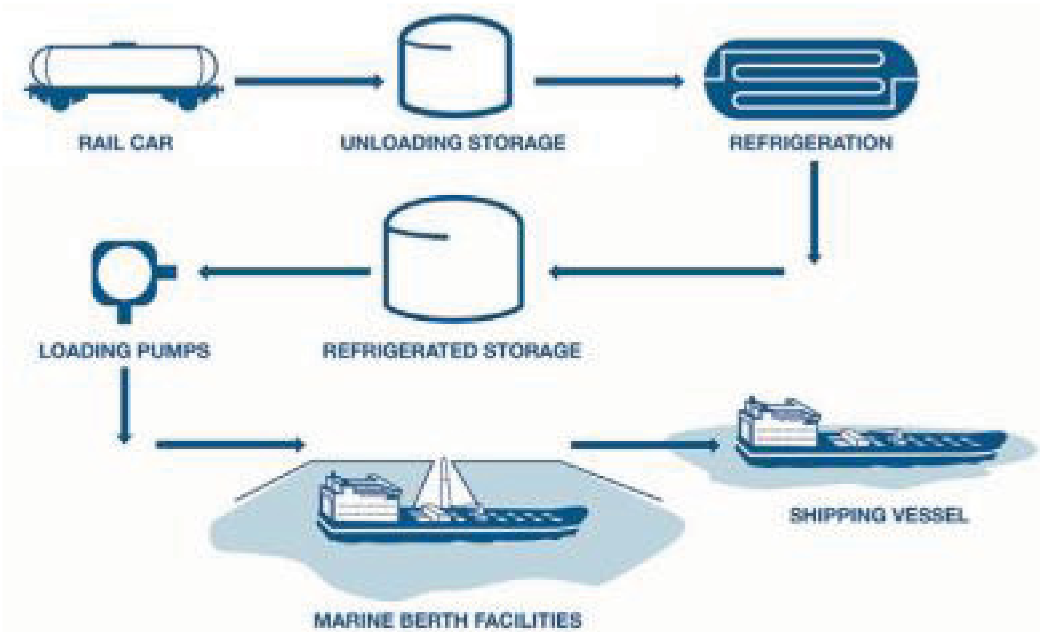

Figure 2-1: Facility Transportation, Refrigeration, Storage and Loading (Ref. /1/)

2.1 Study Objectives

The objectives of the Quantitative Risk Assessment (QRA) are to:

- Identify and quantify all potential credible failure modes that may lead to a hazardous event
- Evaluate the frequencies and consequences of the identified hazardous events, and assess the associated risk to personnel
- Based on the risk results; make recommendations to ensure that risks are tolerable

2.2 Scope of Work

The following main activities are completed to meet the above objectives of the QRA:

- Data collection and review
- Risk assessment
    - System definition
    - Identification of scenarios
    - Frequency and consequence analysis
    - Impact assessment
    - Risk calculation
    - Risk evaluation
- Identification of risk reduction measures and critical issues and challenges

The boundaries of this risk study are from the railcar entering the terminal yard, railcar unloading arms to the marine loading arms, including the loading pipe to dock for normal terminal operation (i.e., facility equipment, storage tank.).

Risk related to railcar transit outside the terminal, carrier transit, and the collisions to a carrier or the dock are not part of the current QRA scope. Note that these excluded hazards are evaluated in separate studies.

The following units and systems are identified in this QRA as possible sources for hazardous releases:

- Propane Railcar Release and Derailment
- Propane Railcar Unloading: Unit 1001
- Propane Refrigeration: Unit 1002
- Propane Ship Loading: Unit 1003
- Propane Refrigerated Storage Tanks: Unit 1004

2.3 Report Structure

The report consists of a main report body (this document) and four appendices. The main report provides a general description of facilities and presents the key risk results and risk drivers for the facility. The report documentation is organized as follows:

Section 1	**Executive Summary**	Summary of the study, risk results, and conclusions and recommendations
Section 2	**Introduction**	Describes the scope and objectives of the study
Section 3	**Methodology**	Outlines the methodology used in the study, as well as an explanation of the risk terms and measurement
Section 4	**Risk Results**	Describes the risk results of the study, comparing them to the tolerability risk criteria adopted by UK HSE
Section 5	**Conclusion and Recommendation**	Discusses the conclusions to the study and recommendations based on the risk results
Section 6	**References**	Contains references cited in the report

Appendix I	**Study Basis**	Detailed study basis and assumption sheets defined for the study
Appendix II	**Scenario Development**	Describes the hazards and scenarios defined for the analysis based upon review of the facility design documents
Appendix III	**Frequency Analysis**	Presents detailed frequency results for the scenarios modeled in the analysis
Appendix IV	**Consequence Analysis**	Presents detailed consequence results for the scenarios modeled in the analysis

3 METHODOLOGY

This section presents an overview of the QRA methodology applied in this study. Key modeling assumptions are briefly summarized.

3.1 Overview of QRA Approach

The QRA is conducted in five steps:

1. Data Gathering
2. Hazard / failure case identification and selection of events for modeling
3. Consequence analysis
4. Failure frequency analysis (based on facility design combined with generic accident data)
5. Risk assessment and evaluation of results.

Figure 3-1 presents the interrelationship of each step in the QRA process. It also shows how, once the risks have been estimated, risk assessment and management are used to identify and evaluate risk reduction measures. Risk criteria are used to determine if the estimated risks are tolerable. A more detailed description of the tasks performed in the QRA is provided in subsequent sections.

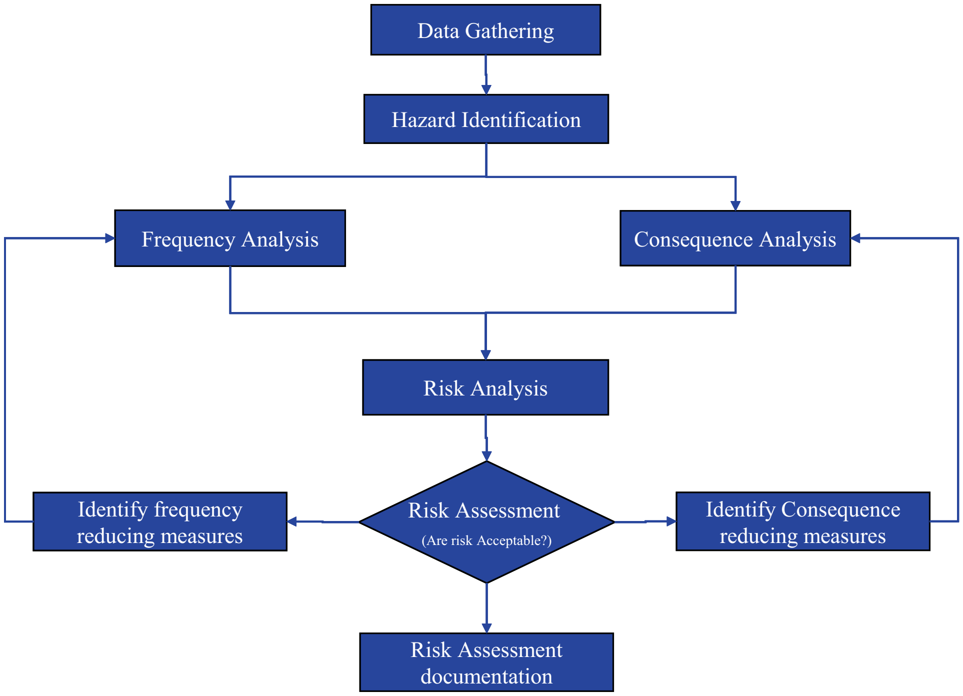

Figure 3-1: Risk Assessment Flowchart

3.1.1 Data Gathering

Prior to significant effort to identify and analyze scenarios, a study basis was drafted to guide the analysis and to document key assumptions that are common for all scenarios (also called background data). The study basis is documented in Appendix I.

3.1.2 Hazard Identification

Hazards are identified for units and piping segments, classifying the risk by hazardous material and operating conditions. The development of potential release scenarios ranging from small leaks to more catastrophic leaks is necessary to fully understand the overall risks. The approach taken in this QRA is to systematically identify the hazards and quantify leak scenario parameters based on operation conditions. The assumptions used to define the hazardous scenarios are documented in Appendix I; the outline of the defined scenarios is presented in Appendix II.

3.1.3 Consequence Analysis

The potential leak scenarios are processed through consequence models in Phast to evaluate the potential hazard zones to the levels of concern. For this study, both flammable and explosive outcome consequence zones are calculated for a specified endpoint (*e.g.*, flammable concentration, thermal radiation, or overpressure).

3.1.4 Frequency Analysis

Once the hazards are known, the likelihood of their potential occurrence is estimated using historical leak frequency data. For this study, DNV GLs analysis of the Hydrocarbon Release Database (HCRD) is utilized (Ref. /2/), complemented by the frequency data from the UK Advisory Committee on Dangerous Substances (ACDS) (Ref. /3/) specifically for loading arms and hoses. The failure rates of pressurized propane bullets and refrigerated storage tanks are obtained from UK HSE historic data for UK facilities (Ref. /4/). The railcar release frequencies are obtained from a recent 10-year railroad accident history (2005-2014) published by the Federal Railroad Administration (FRA) Office of Safety Analysis (Ref. /5/).

3.1.5 Risk Analysis

The risk is estimated using Phast Risk v.6.7 (Ref. /6/), which compiles the consequences, the likelihood of each event occurring (based on the frequency analysis and the background data) and the resulting impacts (vulnerability) to estimate risk. The risk is presented as Individual Risk in the form of Location Specific Individual Risk (LSIR) and Societal Risk in the form of Potential Loss of Life (PLL) and FN (cumulative Frequency versus Number of fatalities) curve.

3.2 Brief of Study Basis

The study basis (Appendix I) documents the background data and assumptions applied in this study in detail. Refer to Appendix I regarding specific information applied in the analysis for meteorology, population data, ignition sources, definition of source terms, and definition of receptors for reporting risk results, and similar detailed information.

3.3 Scenario Development

Detailed information about scenario development is documented in Appendix II. The following sections aim to provide a summary of the general approach and key assumptions relevant to all the releases covered within the scope of this study.

3.3.1 Scenario Identification

The analysis is conducted on a sectional basis. Failure cases (i.e., specific release scenarios to be modeled in the QRA) are defined by dividing the facility and systems into sections with similar characteristics using the following process:

1. The first level of sectionalizing is achieved by identifying the equipment within an isolatable section. An isolatable section is defined as all equipment and piping between Emergency Shutdown Valves (ESDs). In doing so, the maximum inventory available for release is defined, assuming that shutdown will be initiated within a specified time after a release occurs.

2. Further sectionalizing of the facility is then performed on the basis of location. Equipment items in the same section with significantly different geographical locations are identified and different failure cases applied to each. However, the inventory available for release may be the same for both pieces of equipment.

3. Having divided the facility according to isolatable sections and location, the next step is to further sectionalize according to the material or operating conditions handled by each equipment item. This process involves identifying the physical nature (i.e. phase, pressure, and temperature) of the material within each subsection and deciding if the subsections present significantly different characteristics that are worth differentiating because they could materially contribute to a difference in the modeled consequences.

To summarize, the key factors in the selection of these representative sections are:

- Isolation (consideration is given to whether the inventory that may be released can be isolated by ESD, noting that the time taken for such isolation to occur will be a key factor)
- Release location (the area in which the release occurs, including the height)
- Material / phase released (gas, pressurized liquid, cryogenic liquid, etc.)
- Operation conditions (temperature and pressure)

3.3.2 Definition of Scenario Inputs for Modeling

The representative release scenarios applied to the model are detailed in Appendix II. The following process systems and corresponding unit numbers are included in the analysis:

- Propane Railcar Release
- Propane Railcar Unloading: Unit 1001
- Propane Refrigeration: Unit 1002
- Propane Ship Loading: Unit 1003
- Propane Refrigerated Storage Tanks: Unit 1004

Model input for each selected scenario is defined for each of the below parameters:

- Release material and phase
- Operation pressure and temperature
- Release frequency concerning detection and isolation status
- Release inventory corresponding to detection and isolation status
- Release location and direction
- Release hole size
- Release rate

For each of the release scenarios from facility equipment or piping, four representative release sizes are considered as listed in Table 3-1. Other hole and release sizes are applied to specific equipment, such as loading and unloading arms, storage tanks, and railcars.

Table 3-1: Hole Size Categories – Releases

Size Category	Equivalent Round Diameter Hole Size Range	Modeled Representative Hole Size	
	(mm)	(mm)	(in)
Small	3 - 25	10	0.4
Moderate	25 - 75	50	2
Large	75 - 125	100	4
Full Bore Rupture	125 – Line Diameter	Line Diameter (if applicable)	

3.3.3 Release Detection and Isolation Duration

The isolation time is the estimated duration to detect a leak and initiate isolation, including isolation valve closure time. The detection and isolation time has key influences on the release duration and the total release inventory from the representative release hole size. The response time (detection and isolation) is affected by many factors including release size, release conditions, and release material. In general, the larger release rate (either caused by large hole size or high operation pressure), the shorter response time (i.e., the worse consequence, the shorter response time). The assumed response times for the various releases are documented in Appendix I, Study Basis.

3.3.4 Earthquake Scenario

The 2014 Oregon Structural Code requires that every structure shall be designed and constructed to resist the effect of earthquake motions (Ref. /7/). The Contingency Level Earthquake (CLE) event (1 in 475 years) is the minimum design seismic criterion for this facility. Note that a design in accordance with the CLE frequency represents a design performance level of controlled and repairable structural damage. The propane storage tank in this facility is to be designed to a 1 in 2,475 year event. Two models representing the releases due to the potential earthquake hazards are represented in the QRA model.

- A small release (10% of the 300mm release rate) from the larger propane storage tank is selected to reflect the designed tank frequency (1 in 2,475 years).
- A large release event (300mm hole) from the propane storage tank is modeled with a 10 times lower frequency (1 in 24,750 years).

3.4 Consequence Assessment

A detailed method description for the consequence assessment is documented in Appendix IV. The following sections summarize the general methods adopted in deriving the consequences associated with the defined release scenarios.

3.4.1 QRA Consequence Modeling

Consequence modeling is conducted in Phast version 6.7. Phast is a comprehensive hazard analysis tool applicable to all stages of design and operation across a wide range of process industries. Its theory and performance have been independently reviewed as part of the European Commission (EC) funded project – Scientific Model Evaluation of Dense Gas Dispersion Models (SMEDIS), and it has excelled in both areas.

Appendix I (Study Basis) summarizes the methods used to estimate the scenario consequence endpoints of concern. All releases are modeled to either the Lower Flammable Limit (LFL) or ½ LFL. The hazards reviewed in this study include jet fire, flash fire, pool fire, fireball (applicable only if the release duration is less than 20 seconds), and vapor cloud explosion (VCE). Boiling Liquid Expanding Vapor Explosion (BLEVE) scenarios are also considered for the pressurized propane storage bullets. Acute toxic hazards are not considered relevant to this study.

Jet fires and pool fires are modeled as relevant depending on the release phase. If the release is a pressurized vapor or two-phase release, a horizontal jet fire is modeled. A pool fire is modeled for flammable liquid and two-phase releases with rainout. The pool fires are modeled as circular pools and will spread until the pool reaches a bund or reaches a steady state condition. Jet and pool fires are modeled for their thermal radiation impact endpoints. Flash fires are modeled for flammable cloud dispersion.

Congested areas provide the potential for Vapor Cloud Explosions (VCE) to occur under certain conditions. For the QRA, the TNO Multi-Energy (ME) model was used to predict explosion effects in terms of peak overpressure in the vicinity around an explosion center within a congested region. The congested regions are defined in terms of location, geometry, and the degree of congestion/confinement. Each congested region is given a corresponding ME curve number (Ref. /8/) to reflect the level of congestion and confinement within the region. Details regarding the definition of the congested volumes can be found in Appendix I, Study Basis. The predicted overpressure caused by a VCE is associated with the volume (mass) of the flammable cloud confined within the obstructed region(s), which needs to be differentiated from the entire volume of the vapor cloud or the total released inventory. In this study, all of a flammable cloud confined within the congested region(s) with a hydrocarbon concentration between LFL and UFL is used for the overpressure calculation.

BLEVE refers to any sudden loss of containment of a fluid above its normal boiling point at the moment of vessel failure. A common cause of BLEVE event is fire engulfment of a vessel, which contains liquid under pressure, where the heating both raises the pressure in the vessel and lowers the yield strength of the equipment material. DNV GL assessed the frequency of thermal loads to the pressurized storage tank area first, to determine the potential failure rate of vessels for the occurrence of BLEVE event. The BLEVE event can give rise to a blast wave, to fragment projection, and to a fireball, a flash fire or a vapor cloud explosion with propane involved. Note that BLEVEs require a period of time to form, and thus, onsite personnel should not be exposed given time to escape. The BLEVE scenarios were included in the risk model in the current study to reflect the potential escalation hazard. A BLEVE was modeled for the pressurized propane storage bullets. To ensure the safety of the personnel under the modeled BLEVE events, appropriate emergency response plans need to be developed by the project.

The potential hazard zone for BLEVE fragments was also analyzed.

3.4.2 Consequence Analysis

This study includes a detailed analysis on the following hazards: jet fire, flash fire, pool fire, fireball, VCE and BLEVE. Consequence tables are presented in Appendix IV, and comprise a detailed consequence analysis of all the defined scenarios.

Six weather conditions were considered to represent the range of wind speeds and atmospheric stabilities that are present at the site location. The six weather conditions were modeled separately for winter and summer conditions, reflecting differences in the average atmospheric temperature and humidity.

This may be used by the Pembina facility project as decision support in developing the facility, for example as input for design specifications for and location of buildings and equipment, storage tank spacing, and location of escape routes. Additionally, the hazard zone distances can be used to assist in planning for emergency response. Table 3-2 presents the worst downwind distances predicted from various scenarios included in the risk assessment. Note that as these are large and extreme scenarios, although the potential impact distance is great, the likelihood of occurrence for these scenarios is low.

Table 3-2: Major Hazard Consequence Zones

Scenario	Hazard	Flame Thermal Radiation			Flammable Dispersion		Weather
		5 kW/m^2	12.5 kW/m^2	35 kW/m^2	1/2 LFL	LFL	
Derailment 14 railcars	Jet Fire*	1,079 m (3,538 ft)	874 m (2,867 ft)	724 m (2,374 ft)			B 1.8 m/s (4.0 mph) Winter
Refrigerated Storage Tank 1, Rupture 1000mm (40 in) hole	Jet Fire	530 m (1,730 ft)	430 m (1,410 ft)	350 m (1,160 ft)			F 1.8 m/s (4.0 mph) Winter
Refrigerated Storage Tank 1, Rupture 1000mm (40 in) hole	Pool Fire	400 m (1,310 ft)	280 m (930 ft)	190 m (630 ft)			D 7.2 m/s (16.1 mph) Winter
Refrigerated Storage Tank 1, Catastrophic Rupture	Flammable Dispersion				2,390 m (7,830 ft / 1.5 mi)	1,910 m (6,270 ft / 1.2 mi)	F1.8 m/s (4.0 mph) Summer

*: This particular event is a theoretical event with an assumed large release rate (the release rate for the scenario is defined as the total inventory of 14 railcars released in 10 min). A jet fire would likely result from the derailment but may be several individual jets from the different rail cars in addition to pool fire; and this is meant to be represented by the assumed large release rate.

Table 3-3 presents the downwind distances predicted consequence hazard zones for the top risk contributors. Note although the potential impact distances for these scenarios are not as great as the large and extreme scenarios shown in Table 3-2, these scenarios are more important from a risk perspective as these are the key contributors to the societal risk results.

Table 3-3: Hazard Consequence Zones for Risk Contributors

Scenario	Hazard	Fire Thermal Radiation				Flammable Dispersion		
		Weather	5 kW/m²	12.5 kW/m²	35 kW/m²	Weather	1/2 LFL	LFL
Liquid Loading Arm Rupture	Jet Fire	B 1.8m/s (4.0 mph) Summer	460 m (1,500 ft)	370 m (1,228 ft)	310 m (1,020 ft)	F 1.8m/s (4.0 mph) Summer	850 m (2,780 ft)	610 m (1,990 ft)
	Pool Fire	D 7.2m/s (16.1 mph) Winter	241 m (790 ft)	181 m (592 ft)	133 m (437 ft)			
Pressure Storage Bullets (connections) – Liquid Large Release	Jet Fire	D 7.2m/s (16.1 mph) Winter	24 m (790 ft)	200 m (650 ft)	170m (550 ft)	D 2.9m/s (6.5 mph) Summer Night	490 m (1,590 ft)	270 m (870 ft)
Pressure Storage Bullets Fireball	Fireball	Winter	1,080 m (3,540 ft)	660 m (2,150 ft)	300 m (990 ft)			

Based on the assessment calculations, conservatively 2 miles is the potential distance for fragment missiles from a BLEVE scenario of the pressurized storage tanks; and the majority of the fragments would be expected to be within 0.7 miles. Refer to Appendix IV for greater detail regarding the fragment calculation.

3.5 Frequency Assessment

Appendix III details the estimation of the event release frequencies. The frequencies are estimated using best available data.

For the typical facility and mechanical equipment failures, application of data from historical databases was used to estimate release frequencies. The UK HSE Hydrocarbon Release Database (HCRD) (Ref. /2/), provides the base frequency data for most scenarios, complemented by the frequency data from ACDS (Ref. /3/) specifically for loading arms and hoses. The failure rates of pressurized propane bullets and refrigerated storage tanks are obtained from UK HSE historical facility data (Ref. /4/).

Railcar release frequencies are estimated based on the railroad accidental database published by the Federal Railroad Administration (FRA) Office (Ref. /5/), which is one of the ten agencies within the U.S. Department of Transportation (DOT) concerned with intermodal transportation. Table 3-4 presents the total release frequency estimates by facility area or operation. Propane Refrigeration has the highest contribution to the overall frequency with 40% of the total. Small leaks (less than 1 inch hole) contribute approximately 83% to the overall release frequency.

Table 3-4: Summary of Estimated Leak Frequency by Facility Area / Operation

Facility Area / Operation	Small (3mm~ 25mm)	Medium (25mm~ 75mm)	Large (75mm~ 125mm)	Full Bore Rupture (>125mm)	BLEVE/ Tank Rupture / Derailment	Total (per year)	%
Railcar Unloading	5.1E-02	5.1E-03	1.7E-04	1.8E-05	5.6E-05	5.7E-02	27.1
Propane Bullets	4.2E-02	3.6E-03	5.9E-03	6.7E-04	1.2E-04	5.2E-02	24.8
Propane Refrigeration	6.6E-02	7.3E-03	8.6E-03	9.5E-04	-	8.3E-02	39.7
Propane Ship Loading	4.8E-03	9.3E-04	3.5E-04	4.3E-04	-	6.5E-03	3.1
Propane Storage Tank	9.0E-03	9.6E-04	8.2E-04	1.5E-04	2.1E-05	1.1E-02	5.2
Total (per year)	1.7E-01	1.8E-02	1.6E-02	2.2E-03	2.0E-04	2.1E-01	**100**
%	**82.7%**	**8.6%**	**7.6%**	**1.1%**	**0.1%**	**100%**	

3.6 Risk Evaluation

The risk is estimated using PhastRisk version 6.7, which compiles the consequences, the likelihood of each event (based on the frequency analysis and the background data) and the resulting impacts on populations (vulnerability). The key assumptions related to risk modeling are presented in Appendix I.

An additional model input, *vulnerability*, relates the scenario consequences (thermal radiation / overpressure) to the number of fatalities for a given population. A vulnerability value is assigned to each hazard type (e.g., jet fire, VCE), which is used by the model to estimate the number of fatalities. An input vulnerability of “1” would result in a risk estimate based on 100% fatalities within the (calculated) lethally exposed area. An input vulnerability of 0.1 would result in a risk estimate based on 10% fatalities among the population within the (calculated) lethally exposed area. The vulnerability assumptions for all relevant types of flammable impacts are presented in Appendix I.

Risk Criteria

Location-Specific Individual Risk Criteria

The following risk criteria are used by the UK Health & Safety Executive (HSE) to assess the location-specific individual risk exposed to employees, contractors as well as public people (Ref. /9/):

- Maximum tolerable risk for workers 1E-03 per year (1 in 1,000 years)
- Maximum tolerable risk for the public 1E-04 per year (1 in 10,000 years)
- Broadly acceptable risk 1E-06 per year (1 in 1,000,000 years)
- As Low As Reasonably Practicable (ALARP): 1E-03 - 1E-06 per year for workers
  1E-04 - 1E-06 per year for the public

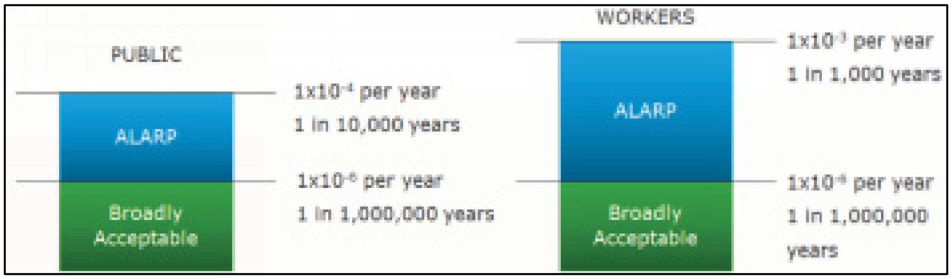

Figure 3-2: UK HSE LSIR Criteria

Societal Risk Criteria

In 2001, HSE published "Reducing Risks, Protecting People" (known as "R2P2"), with the purpose of informing external stakeholders about HSEs approach to regulatory decision-making (Ref. /10/). R2P2 gives limited guidance on criterion values for societal risks. R2P2 defines one point, (N=50, F(N)=1/5000 per year), and if this point is placed on an FN curve, and a line is drawn through it with a slope of -1, it can provide a criteria comparison line. To use this, a calculated curve for a site can be superimposed, and if any point of this curve lies above the criteria line at any point, then this could indicate unacceptability. This begs the question whether the actual curve must be below the criterion line at all points, or can some excursions above the line be allowed, if these are balanced by points where the curve is below the criterion line. There is no technical widespread agreement on this issue (Figure 3-3).

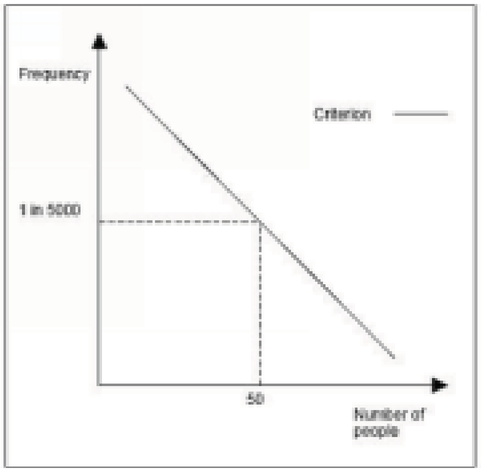

Figure 3-3: UK HSE R2P2 Criterion point (Ref. /11/)

4 RISK RESULTS

The risk of each event is estimated by combining the frequency and the consequence of the event. This section summarizes the estimated risk levels posed by the Pembina Propane Export Terminal.

4.1 Individual Risk

Individual Risk (IR) is the annual probability of fatality for an individual person. This QRA analysis reports IR in the form of Location Specific Individual Risk (LSIR) contours, and point location risk values.

4.1.1 Location Specific Individual Risk Contours

LSIR gives the frequency of fatality over a year period for personnel at a certain location, when permanently exposed. LSIR is commonly presented as iso-risk contours on a map by drawing lines that connect locations with the same value of risk. The contour maps (Figure 4-1 to Figure 4-3) present the LSIR contours for the Pembina facility and surrounding areas, accounting for all scenarios within the scope of the QRA. These contours reflect the outdoor LSIR to onsite workers, and any potential public populations, assuming continuous presence outdoors, at each point.

The LSIR contours show that:

- The red 1E-03 per year (1 in 1,000 years) LSIR contour (onsite individual risk (LSIR) criterion adopted by UK HSE) is confined within the Pembina propane terminal. Only the pressurized propane storage bullets (1001-V-01, 1001-V-02, 1001-V-03 and 1001-V-04) and the propane compression/refrigeration area are exposed to this LSIR level.
- The purple 1E-04 per year (1 in 10,000 years) LSIR contour (elevated public individual risk (LSIR) criterion adopted by UK HSE) exceeds the facility boundary at the channel area and the area south of the facility but is confined within the boundary at the jetty area (the boundary is the thin blue line shown in Figure 4-3). The onsite control room is located between the 1E-04 per year (1 in 10,000 years) and 5E-03 per year (1 in 2,000 years) LSIR contour.

Figure 4-1: Outdoor LSIR Contours (Zoom 1)

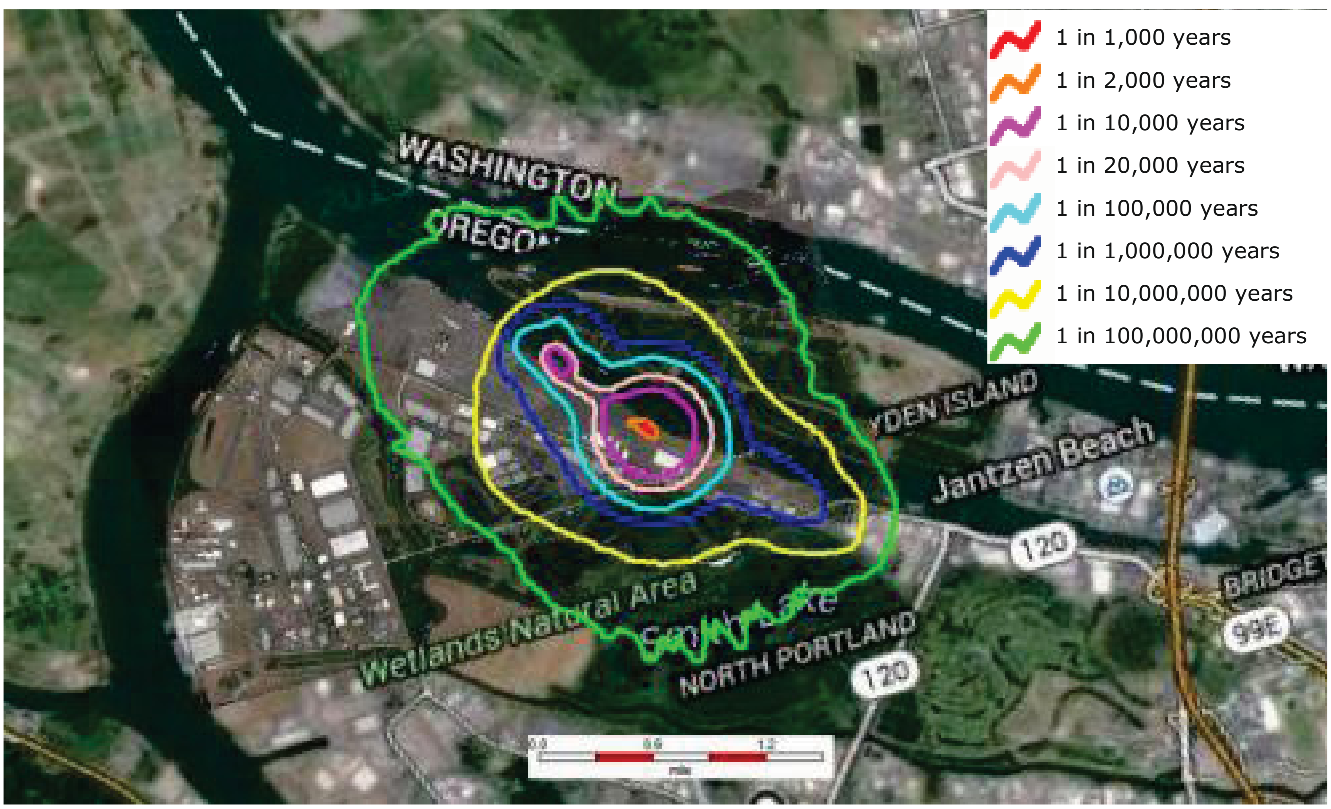

Figure 4-2: Outdoor LSIR Contours (Zoom 2)

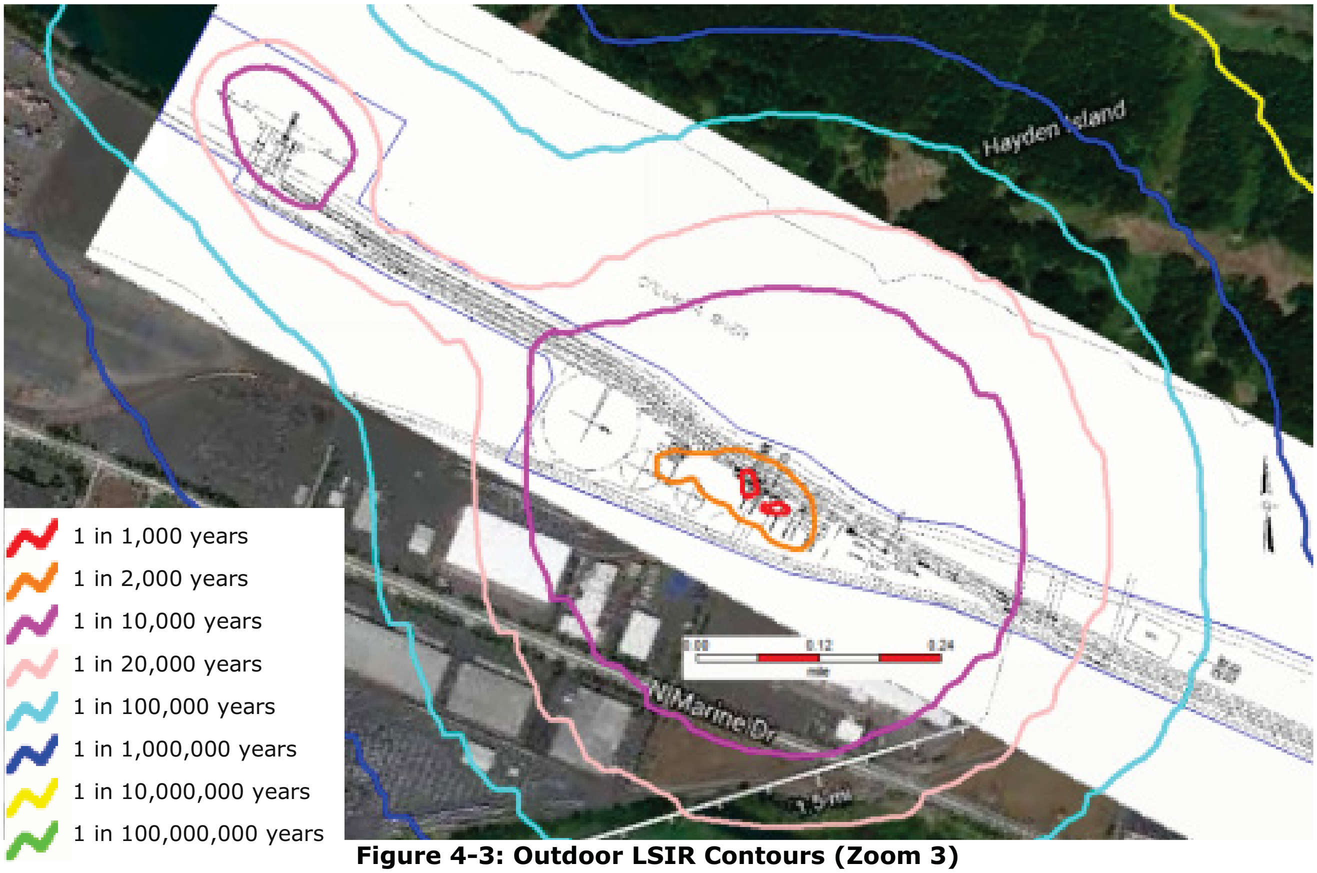

Figure 4-3: Outdoor LSIR Contours (Zoom 3)

4.1.2 Location Specific Individual Risk Ranking Points

Twenty-four onsite and offsite receptor points were set up in the risk model to estimate the value of the outdoor/indoor LSIR at each point (as shown in Figure 4-4 and Figure 4-5). The estimated overall LSIR at each point assumes the risk target is permanently present at the receptor location. Table 4-1 and Table 4-2 presents the outdoor and indoor (building specific) LSIR results at each onsite and offsite receptor location. A buildings specific indoor LSIR accounts for the fire and blast rating assumed for the building.

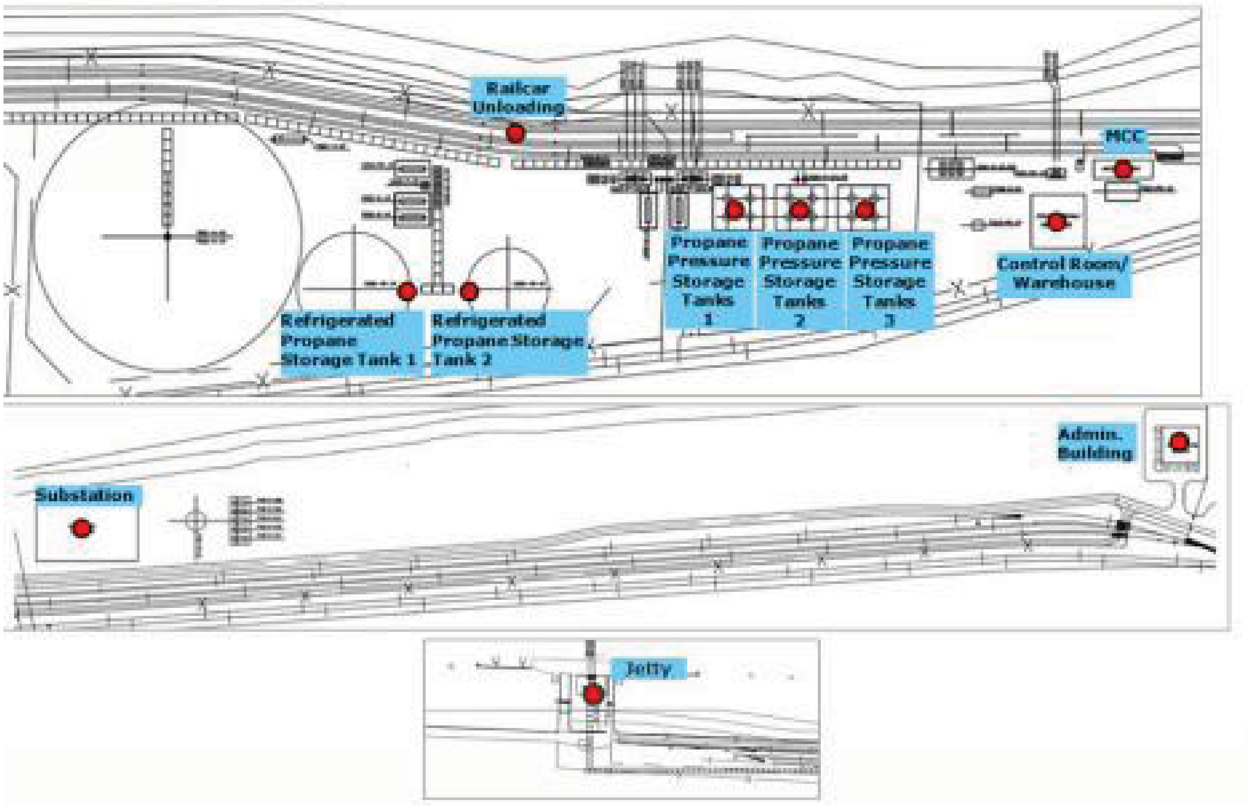

Figure 4-4: Receptor Locations – Onsite

Figure 4-5: Receptor Locations – Offsite

Table 4-1: LSIR at Onsite Receptor Locations – Outdoor and Indoor

Receptor Description	Outdoor IR per year	Outdoor Average Recurrence Interval [years] (Given 100% Exposure)	Indoor IR per year	Indoor Average Recurrence Interval [years] (Given 100% Exposure)
Pressure Propane Storage Bullets 1	1.4E-03	730		
Pressure Propane Storage Bullets 2	1.2E-03	860		
Pressure Propane Storage Bullets 3	6.6E-04	1,530		
Refrigerated Propane Storage Tank 1	5.2E-04	1,920		
Refrigerated Propane Storage Tank 2	4.9E-04	2,050		
Railcar Unloading	4.4E-04	2,270		
Jetty	3.5E-04	2,830		
Control Room / Warehouse	1.7E-04	5,770	1.8E-04	5,460
MCC Building	1.5E-04	6,780	1.4E-04	6,930
Substation	2.4E-05	41,690		
Admin. Building	2.5E-06	400,790	1.5E-06	660,270

Green – Broadly Acceptable, Blue – ALARP, Black – Exceeds Criteria

Table 4-2: LSIR at Offsite Receptor Locations – Outdoor and Indoor

Receptor Description	Outdoor IR per year	Outdoor Average Recurrence Interval [years] (Given 100% Exposure)	Indoor IR per year	Indoor Average Recurrence Interval [years] (Given 100% Exposure)
Neighboring Point 3 (NP3)	2.7E-07	3.7 million		
Neighboring Point 1 (NP1)	1.7E-07	5.8 million		
Neighboring Point 2 (NP2)	1.1E-07	8.9 million	1.1E-08	91 million
Smith Natural Area (SNA)	9.8E-08	10 million	2.3E-10	4.3 billion
Hayden Island West Point (HIWP)	2.5E-08	40 million		
Floating Home (FH)	4.0E-09	251 million		
Neighboring Point 4 (NP4)	3.3E-09	302 million		

Green – Broadly Acceptable, Blue – ALARP, Black – Exceeds Criteria

The following general conclusions may be drawn:

- The Pressurized Propane Storage Bullets 1 location has the greatest estimated outdoor LSIR, 1.4E-03 (1 in 730 years) followed by the other two Pressurized Propane Storage Bullets with LSIR of 1.2E-03 per year (1 in 860 years) and 6.6E-04 per year (1 in 1,530 years). Note that these risk results include the escalation hazard impact from BLEVE scenarios of the bullets.
- All of the onsite buildings (Control Room/Warehouse, MCC building and Admin. building) are exposed to LSIR no greater than 1E-03 per year; falling in the ALARP region according to the UK HSE tolerability criteria.

- Neighboring Point 3, which is at the south of the facility, has the highest offsite LSIR of 2.7E-07 per year (1 in 3.7 million years). There is no evaluated offsite point location that is exposed to LSIR exceeding 1E-06 per year (1 in 1 million years). All the selected offsite receptor locations are exposed to LSIR in the broadly acceptable region according to the UK HSE tolerability criteria.
- Note that offsite receptor locations not reported in Table 4-2 received negligible risk levels.

The top ten contributing release events to risk ranking points (Pressurized Propane Storage Bullets 1, Refrigerated Propane Storage Tank 1, Neighboring Point 3, Floating Home, and Control Room) are presented in Table 4-3. In general, release scenarios from the following systems are the main risk contributors:

- Propane Unloading Storage Group (connections) - Liquid
- Propane Unloading Storage Group - Bullets
- Refrigerated Propane Storage Tanks
- MP Suction Drum - Liquid

Table 4-3: Top Contributing Events for Risk Ranking Point Locations

IR Ranking point	Top Contributing Event			
	Event	**Event Description**	**Risk (per year)**	**%**
Pressure Propane Storage Bullets 1 (Outdoor)	B01-06A	Propane Unloading Storage Group1 (connections) - Liquid	7.0E-04	51.0
	B01-07A	Propane Unloading Storage Group2 (connections) - Liquid	1.4E-04	10.1
	F02-03A	MP Suction Drum - Liquid	7.2E-05	5.2
	B01-06C	Propane Unloading Storage Group1 - Bullets	6.8E-05	5.0
	B01-07C	Propane Unloading Storage Group2 - Bullets	6.5E-05	4.7
	B01-08C	Propane Unloading Storage Group3 - Bullets	6.3E-05	4.6
	F02-01A	Propane Feed Pumps	5.9E-05	4.3
	F02-04A	LP Suction Drum - Liquid	4.3E-05	3.2
	B01-08A	Propane Unloading Storage Group3 (connections) - Liquid	3.6E-05	2.6
	F02-06B	Propane Rundown Pipe to Storage Tank	3.3E-05	2.4
	Total for Top Contributors		**1.3E-03**	**93.1**
	Total for Other Events		**9.4E-05**	**6.9**
Refrigerated Propane Storage Tank 1 (Outdoor)	EQ-L	Storage Tank 1 95mm Release due to Earthquake	2.2E-04	42.3
	B01-06C	Propane Unloading Storage Group1 - Bullets	4.2E-05	8.1
	B01-07C	Propane Unloading Storage Group2 - Bullets	4.1E-05	8.0
	EQ-R	Storage Tank 1 300mm Release due to Earthquake	3.9E-05	7.6
	B01-08C	Propane Unloading Storage Group3 - Bullets	3.9E-05	7.4
	S04-02C	Storage Tank 2	3.7E-05	7.2
	S04-01C	Storage Tank 1	3.4E-05	6.6
	F02-06B	Propane Rundown Pipe to Storage Tank	2.3E-05	4.4
	M03-01H	Marine Propane Loading Line - Holding Mode	1.8E-05	3.5
	B01-06A	Propane Unloading Storage Group1 (connections) - Liquid	5.7E-06	1.1
	Total for Top Contributors		**5.0E-04**	**96.0**
	Total for Other Events		**2.1E-05**	**4.0**
Neighboring Point 3 (NP3) (Outdoor)	S04-01C	Storage Tank 1	2.0E-07	75.7
	S04-02C	Storage Tank 2	6.5E-08	24.3
	R00-01Z	Railcar Release	3.2E-11	0.01
	M03-01L	Marine Propane Loading Line - Loading Mode	1.7E-16	<0.01
	Total		**2.7E-07**	**100.0**

IR Ranking point	Top Contributing Event			
	Event	**Event Description**	**Risk (per year)**	**%**
Floating Home (Outdoor)	S04-01C	Storage Tank 1	3.6E-09	91.4
	R00-01Z	Railcar Release	3.4E-10	8.6
	Total		**4.0E-09**	**100.0**
Control Room / Warehouse (Indoor)	B01-08C	Propane Unloading Storage Group3 - Bullets	4.8E-05	26.0
	B01-07C	Propane Unloading Storage Group2 - Bullets	4.8E-05	26.0
	B01-06C	Propane Unloading Storage Group1 - Bullets	4.8E-05	26.0
	B01-08A	Propane Unloading Storage Group3 (connections) - Liquid	2.3E-05	12.4
	B01-07A	Propane Unloading Storage Group2 (connections) - Liquid	9.6E-06	5.3
	B01-06A	Propane Unloading Storage Group1 (connections) - Liquid	4.4E-06	2.4
	R00-01Z	Railcar Release	2.4E-06	1.3
	F02-03A	MP Suction Drum - Liquid	9.2E-07	0.5
	S04-02C	Storage Tank 2	2.0E-07	0.1
	R01-05Z	Propane Unloading Pipe	1.3E-07	0.1
	Total for Top Contributors		**1.8E-04**	**99.9**
	Total for Other Events		**1.1E-07**	**0.1**

4.2 Societal Risk

4.2.1 Potential Loss of Lives (PLL)

The PLL is dependent on the likelihood of an event resulting in fatalities, the frequency of that event occurring and the number of persons present in the hazard zone at the time the situation materializes. Therefore, events that can affect areas with a large population are likely to contribute more to the PLL than those that affect areas with a small or infrequent population. The total PLL across onsite and offsite populations is 5.6E-03 per year, which equates to 1 statistical fatality every 180 years. Table 4-4 summarizes the top 10 contributors to the total PLL. The liquid loading arm is the largest risk contributor to PLL, contributing 15.4% of the PLL. A majority of the risk comes from fatal impact at the jetty location. The outdoor population at the jetty is estimated to have a 100% chance of fatality if exposed to a radiation level greater than 35kW/m^2 (Ref. /12/), which results from the liquid loading arm pool fire, given ignition of a release. The leakage rate from potential failures of the liquid loading arms is significant, imposing severe consequences to any nearby personnel. Since the loading arm release is at the jetty, as detailed in Appendix IV – Consequence Assessment, the model shows the entire jetty area to be inside the 35 kW/m^2 thermal radiation zone in the loading arm rupture release case. Therefore, all the jetty population contributes to the PLL in this scenario.

The other top risk contribution is from the propane pressure storage bullets, contributing 13.8%, 12.7% and 12.6% of the PLL, respectively for the different bullet groups; however altogether they contribute 39% of the PLL result. The drivers for this contribution include the associated initial release frequency plus the assumed BLEVE escalation potential resulting from releases in the bullet area, and then the large resulting consequence zone.

Table 4-4: Top 10 Contributors to PLL

Event Description	PLL (/yr)	1 Statistical Fatality Every # Years	Contribution to PLL (%)
Liquid Loading Arm	8.6E-04	1,170	15.4
Propane Unloading Storage Group3 - Bullets	7.7E-04	1,300	13.8
Propane Unloading Storage Group1 - Bullets	7.1E-04	1,410	12.7
Propane Unloading Storage Group2 - Bullets	7.0E-04	1,430	12.6
Propane Unloading Storage Group1 (connections) - Liquid	2.8E-04	3,520	5.1
Storage Tank 1	2.2E-04	4,490	4.0
Storage Tank 2	2.0E-04	5,000	3.6
LP Suction Drum - Liquid	1.8E-04	5,630	3.2
MP Suction Drum - Liquid	1.7E-04	5,810	3.1
Railcar Release	1.7E-04	5,880	3.0
Total for Top 10 Contributors	**4.3E-03**	**240**	**76.4**
Total for Other Events	**1.3E-03**	**760**	**23.6**
Total PLL	**5.6E-03**	**180**	**100.0**

Table 4-5 presents the distribution of the PLL results among the assessed population areas. Figure 4-6 illustrates the distribution of the PLLs among the offsite sub-areas. The railcar unloading population contributes the most to the PLL (25.3 %) since 4 railcar unloading personnel are conservatively assumed to be at the unloading area 24 hours a day, 7 days a week for 365 days. The railcar unloading area is near the pressure propane storage bullets and propane compression/refrigeration areas, which have the highest onsite LSIR of 1E-03 per year (1 in 1,000 years). The total onsite population PLL is 4.1E-03 per year (1 in 240 years), contributing 73% to the total risk.

The total offsite population PLL is 1.5E-03 per year (1 in 670 years), 26.7% of the total PLL. For offsite population, not all the sub-areas defined in the model contribute to the risk. Only the sub-areas presented in Table 4-5 contribute to the risk result; all other areas receive negligible risk levels and do not contribute. The sub-area ID numbers are shown in blue in Figure 4-6. The sub-areas that are nearest the Pembina propane export terminal have relatively larger PLLs than the far-a-way sub-areas as these are the areas that would most often be impacted by potential releases. The sub-area #345, where the Pembina facility is located, contributes the most to the PLL, 8.3E-04 per year (1 in 1,200 years). Sub-area #342 and 344 are where the residential areas are located. Sub-area #344 is near the site, thus the PLL is 1.7E-07 per year (1 in 6 million years); Sub-area #342 is further away than #344 and has less population (1486 in #342 vs. 3512 in #244), so the PLL is 3.5E-11 per year (1 in 28.8 billion years)

Table 4-5: Contribution from Different Population Areas to PLL

Location	Population Area	PLL (per year)	1 Statistical Fatality Every # Years	Contribution to PLL	Total PLL (per year)	1 Statistical Fatality Every # Years	Total Contribution to PLL
Onsite	Railcar Unloading	1.4E-03	710	25.3%	4.1E-03	240	73.3%
	Facility Area	1.4E-03	720	24.8%			
	Jetty	5.9E-04	1,700	10.6%			
	Carrier	3.8E-04	2,660	6.7%			
	Control Room and Warehouse	3.3E-04	3,020	5.9%			
	Admin Building	1.5E-06	670,100	0.03%			
Offsite	345	8.3E-04	1,200	14.9%	1.5E-03	670	26.7%
	349	4.9E-04	2,040	8.8%			
	67	1.6E-04	6,140	2.9%			
	73	3.0E-07	3.3 million	0.01%			
	350	2.1E-07	4.8 million	<0.01%			
	344	1.7E-07	6.0 million	< 0.01%			
	98660	1.6E-07	6.2 million	< 0.01%			
	75	1.5E-08	65 million	< 0.01%			
	346	1.5E-09	674 million	< 0.01%			
	58	3.2E-10	3.1 billion	< 0.01%			
	342	3.5E-11	28.8 billion	< 0.01%			
Total		**5.6E-03**	**180**	**100%**			

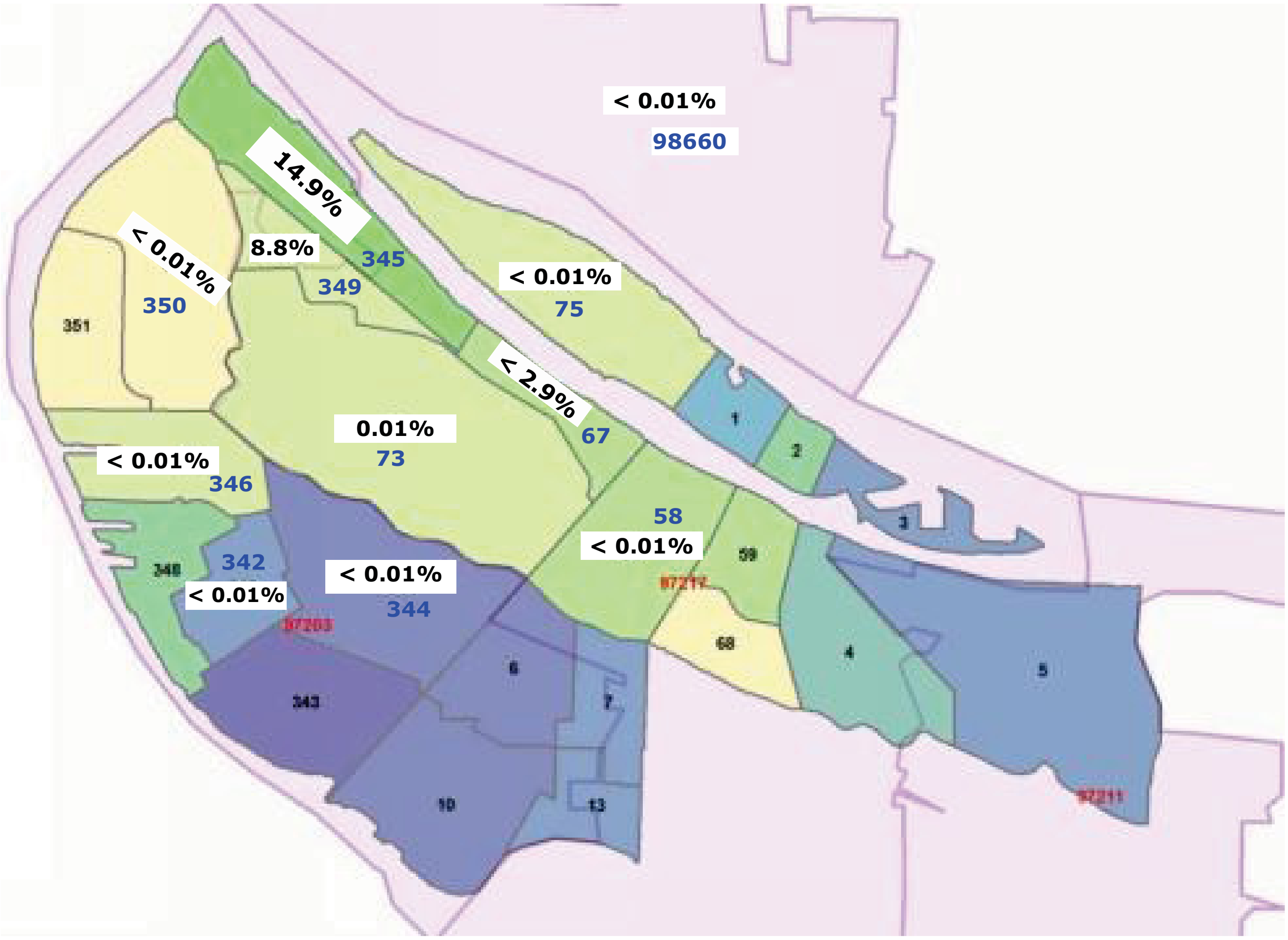

Figure 4-6: PLL Contributions from Offsite Sub-Areas

4.2.2 FN Curves

The societal risk is presented as an FN curve. An FN curve is used to identify the frequency associated with a given number of fatalities (or more). These curves are graphed as cumulative frequency (F) versus the number of fatalities (N). As there is no US societal risk criteria requirement, the UK HSE criteria are applied. The FN curve in this project counts for all the onsite and offsite populations.

Figure 4-7 shows the societal risk FN curve for the Pembina propane terminal during normal operations. As indicated by the figures, the societal risk is below the risk tolerability criteria line adopted by UK HSE. The cut-off on the FN curve shown in the figure is 1E-08 per year since it is a quite low frequency (1 in 100 million years). The actual maximum estimated N is 293 fatalities at a frequency of 4.0E-14 per year (1 in 25 trillion years). The activities in the period when no ships are present dominates the contribution to the higher N part of the FN curve, as these activities are more frequent.

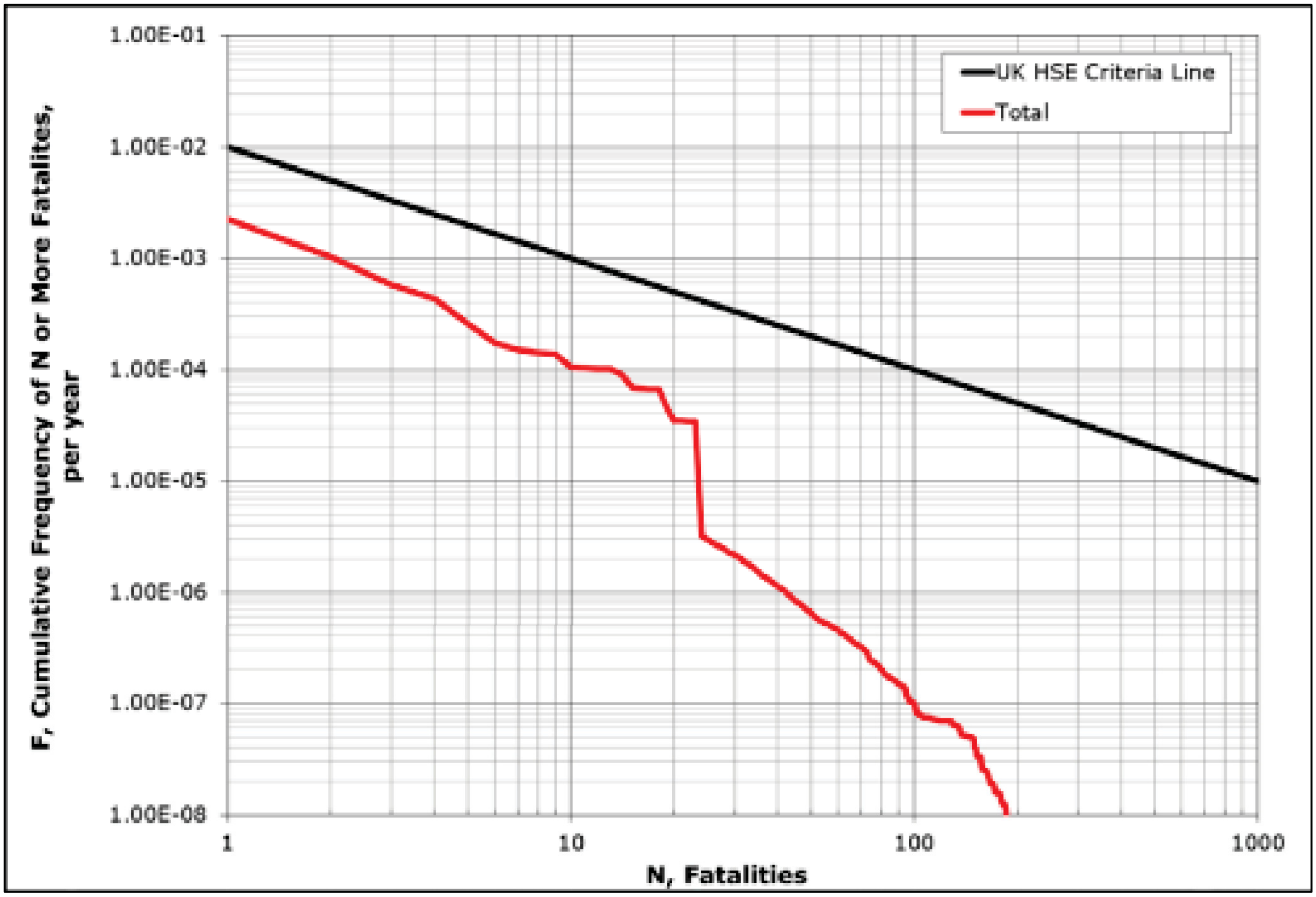

Figure 4-7: Overall FN Curve Compared to UK HSE Criteria

Figure 4-8 shows the FN curves by ship presence. No ship presence and ship presence contribute comparably to the total risk for the following reasons:

- During the majority (85%) of the time, the ship is not present at the Pembina propane terminal (details can be found in Appendix I), leading to the significant contribution to the total risk from no ship presence.

- When ship is present, the liquid loading arm is the key contributor to the total risk.
- Additionally there are differences in risk between Day and Night as more people are present at the terminal during the Day than at Night. Therefore the Day risk results are higher than the Night results.

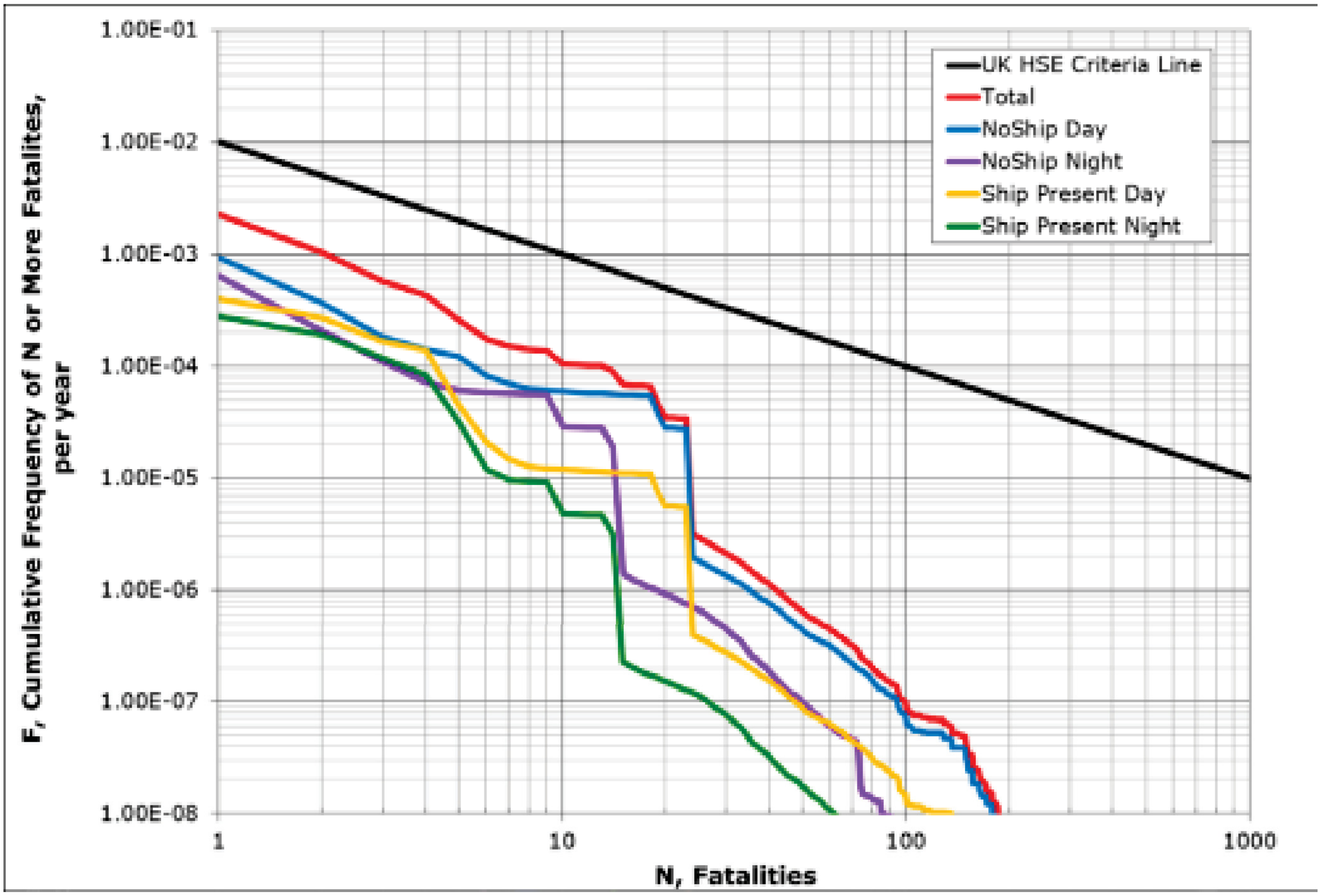

Figure 4-8: FN Curves by Ship Presence Compared to UK HSE Criteria

Figure 4-9 presents the contributions to the overall FN curve from the different events. At lower end of N (N <20), the pressurized (purple curve) and refrigerated (dark purple curve) storage tanks, and main facility equipment (brown curve) – are the dominant contributors to the overall risk given the fact they are in continuous operations. Although the Loading arm is not in operation all the time, loading arm (pink curve) is another big contributor to the overall risk due to the great impact on the nearby population as stated in section 4.2.1 The Refrigerated Storage and Railcar Transit are the significant contributors to N > 20. For N > 100, the estimated fatalities are mainly from refrigerated storage tanks due to the large consequence zone associated with the storage tank releases. Railcar Transit scenarios (railcar releases and derailments) are also a key contributor to results for N > 20. Events associated with the recirculation activity (green curve) contribute minimal risk because recirculation only occurs for 24 hours before ship loading (a minimal time in comparison to the other operations).

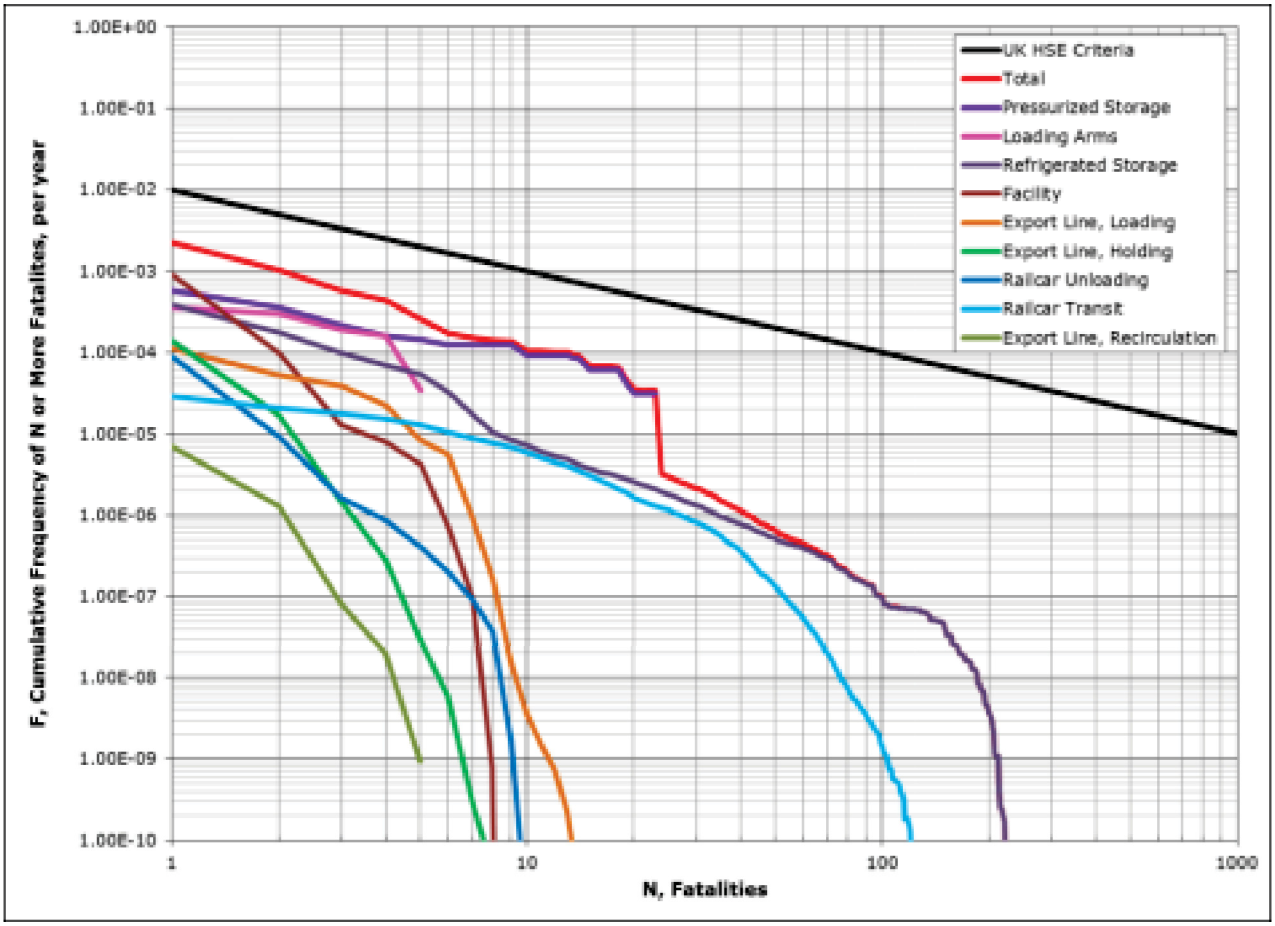

Figure 4-9: FN Curves by Event Compared to UK HSE Criteria

4.3 2035 Sensitivity Study

A sensitivity study with projected future (year 2035) offsite populations was performed. Refer to Appendix I: Study basis for detailed population information for year 2035. With the projected future offsite population, the PLL and FN curves are summarized.

4.3.1 Potential Loss of Lives (PLL)

Due to the increasing offsite population, the total PLL is increased from 5.6E-03 per year for the current study to 6.3E-03 per year for the 2035 sensitivity, which equates to 1 statistical fatality every 160 years. Table 4-6 summarizes the total PLLs for current year and year 2035. In comparison to the base study, the PLL for the sensitivity study increases by 13%. Note that the sensitivity assumes no change to the terminal operation between today and 2035. If activity were to increase or decrease at the terminal by 2035, then the risk result may be higher or lower than presented here.

Table 4-6: Top 10 Contributors to PLL

Period	PLL (per year)	1 Statistical Fatality Every # Years	Change from Base Result
Base Case	5.6E-03	180	13%
Sensitivity, 2035	6.3E-03	160	

4.3.2 FN Curves

Figure 4-10 presents the FN curve for the sensitivity case (red curve) compared to the base case (green curve). There are only slight differences for N at the lower end (N < 10), while larger differences are observed for N at the higher end. This result is driven by the assumption that no activity changes for the operation of the terminal (meaning the onsite population remains the same) and only the offsite populations were adjusted to reflect the projected 2035 population. The FN curve for the 2035 population is below the criteria line.

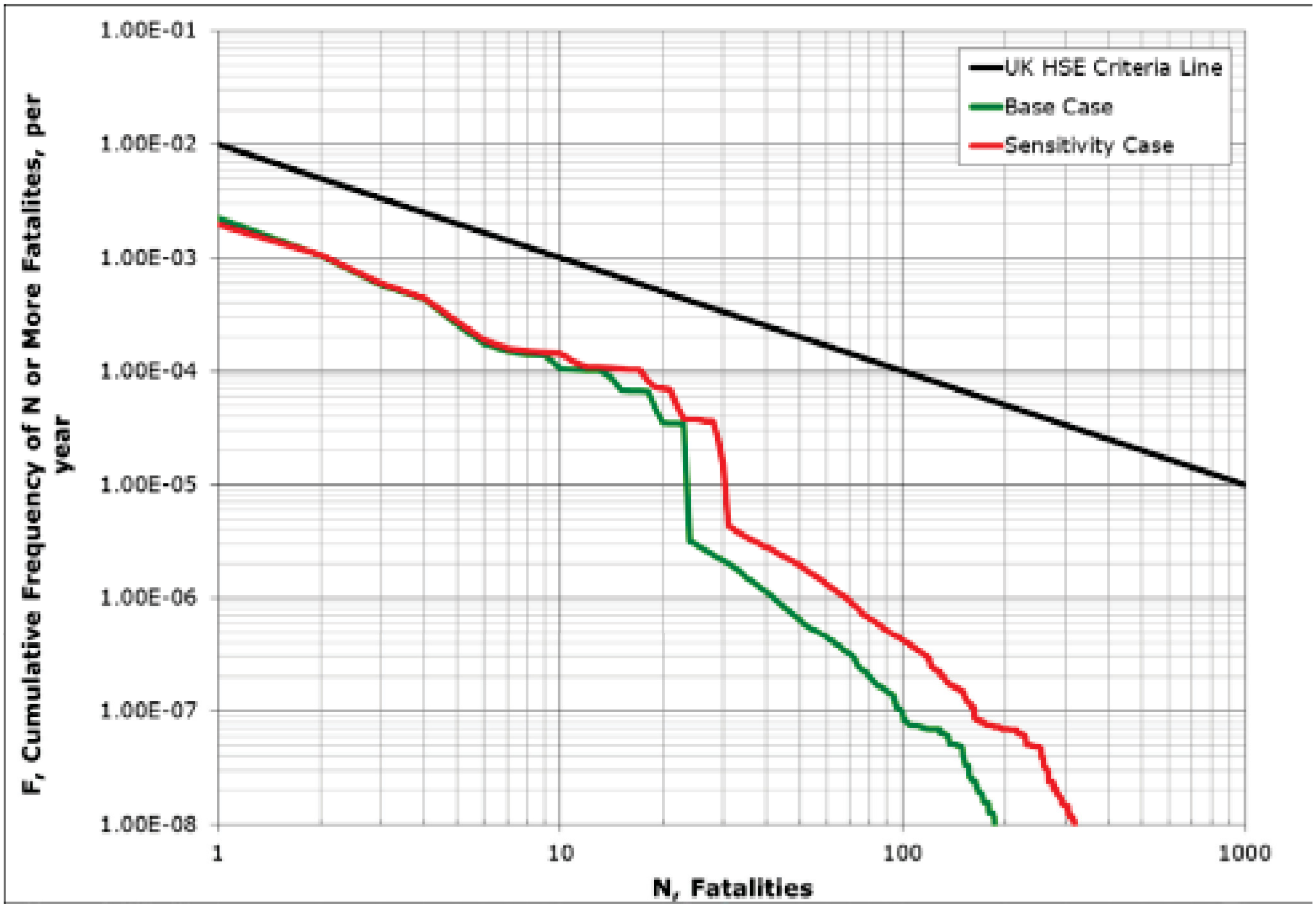

Figure 4-10: FN Curves for the Base Case and Sensitivity Case Compared to UK HSE Criteria

4.4 Accidental Loads

The risk model focuses on estimation of the potential fatal risk to personnel. Additionally, it is possible to extract the frequency of impact and impairment to key receptor locations to assess the frequency of hazardous loads to a structure, specifically the frequency of side-on overpressure and thermal radiation. A summary of the impairment frequency results are presented in this section.

4.4.1 Overpressure-Frequency Contours

Figure 4-11 to Figure 4-13 show the frequency contours of impact from different overpressure levels (1 psi, 3 psi and 5 psi), taking into account all possible explosion hazards from the identified scenarios. Overpressure of 1 psi will cause partial damage of a house, e.g. window breakage; overpressure of 3 psi will cause a steel frame building to distort and pull away from its foundation and 5 psi overpressure will cause a wooden utility pole to snap and nearly completely destroy a house. The 5 psi overpressure-frequency contour centers on the pressurized propane storage bullets. The control room/warehouse is located outside of the 5E-05 per year (1 in 20,000 years) zone for overpressure level of 5 psi.

Note that the 1 psi overpressure contour has a small "bubble" of low risk (1E-07 per year, 1 in 10 million) to the east side of the facility. Rail cars may be staged along the rail tracks in this area and a level of congestion has been assumed for the rail tracks with cars present. The congestion level is expected to be low, but still a 1 psi overpressure is predicted from potential explosions in the area.

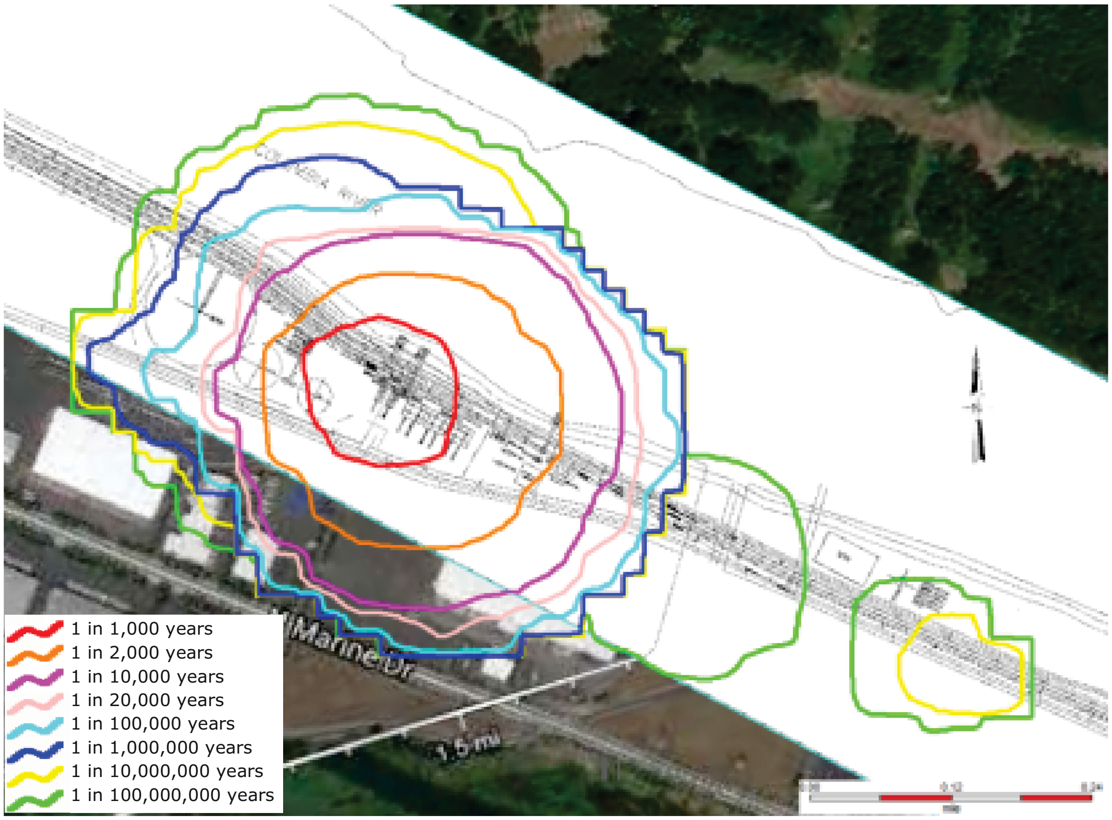

Figure 4-11: 1 psi Overpressure Risk Contours

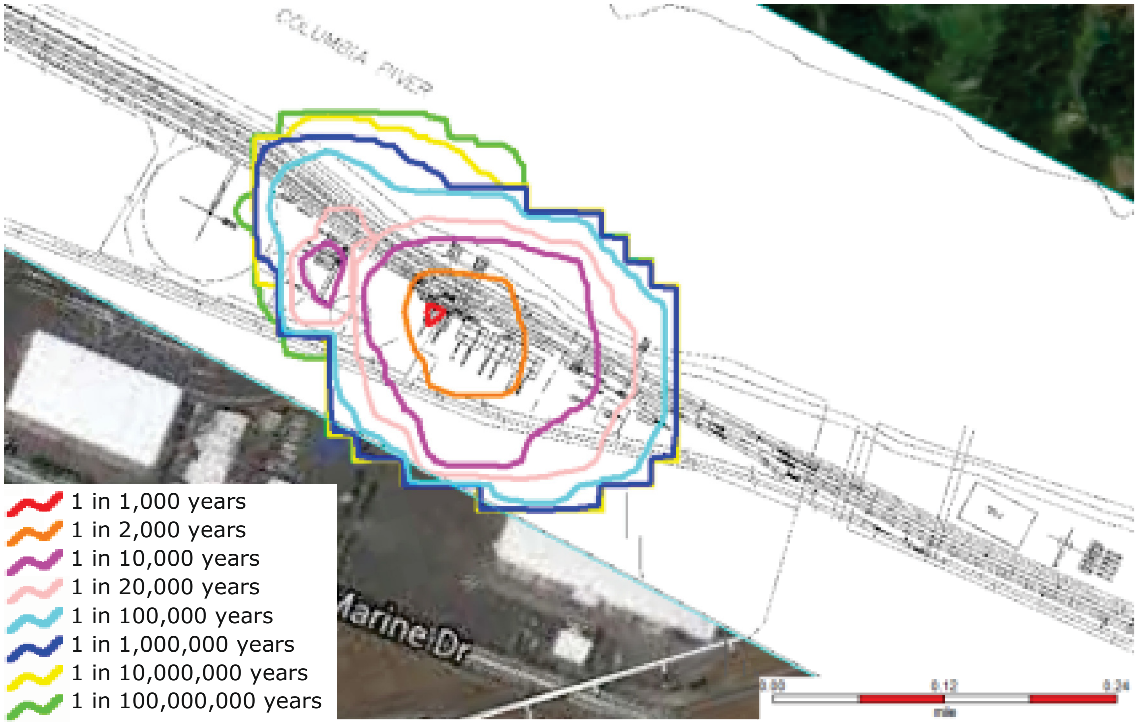

Figure 4-12: 3 psi Overpressure Risk Contours

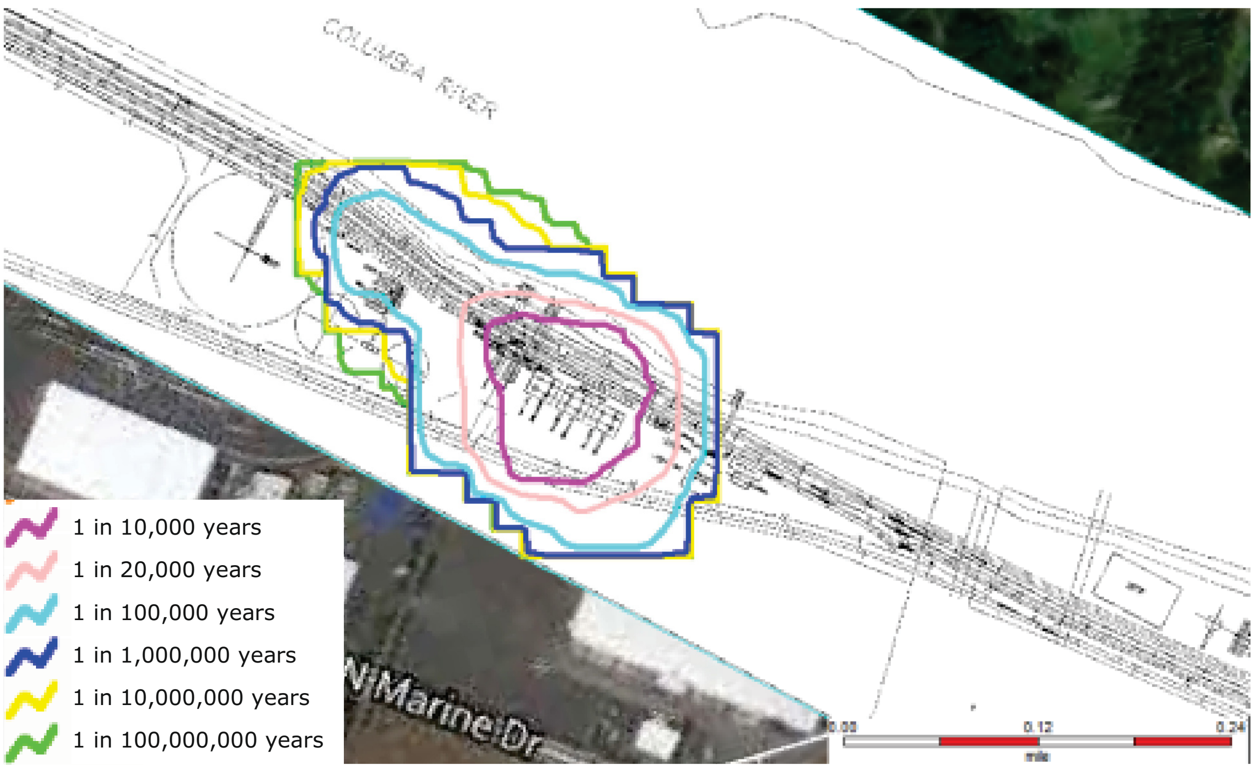

Figure 4-13: 5 psi Overpressure Risk Contours

4.4.2 Radiation-Frequency Contours

Figure 4-14 and Figure 4-15 show the radiation-frequency contours at radiation levels of 5 kW/m^2 and 35 kW/m^2 respectively, accounting for all the potential fire hazards: jet fire, pool fire and fireball. All of the contours are plotted based on 1 second exposure, which means the radiation - frequency contours take into account the total leak frequency for all release events that result in a fire hazard (since all fires will last at least 1 second).

A thermal radiation of 5 kW/m^2 will cause pain in 15-20 seconds and injury after 30 seconds exposure. The outer zones for thermal radiation of 5 kW/m^2 are driven by the fireball and BLEVE hazard of pressure storage bullets as the radiation-frequency contours at radiation level of 5 kW/m^2 are perfectly rounded in Figure 4-14.

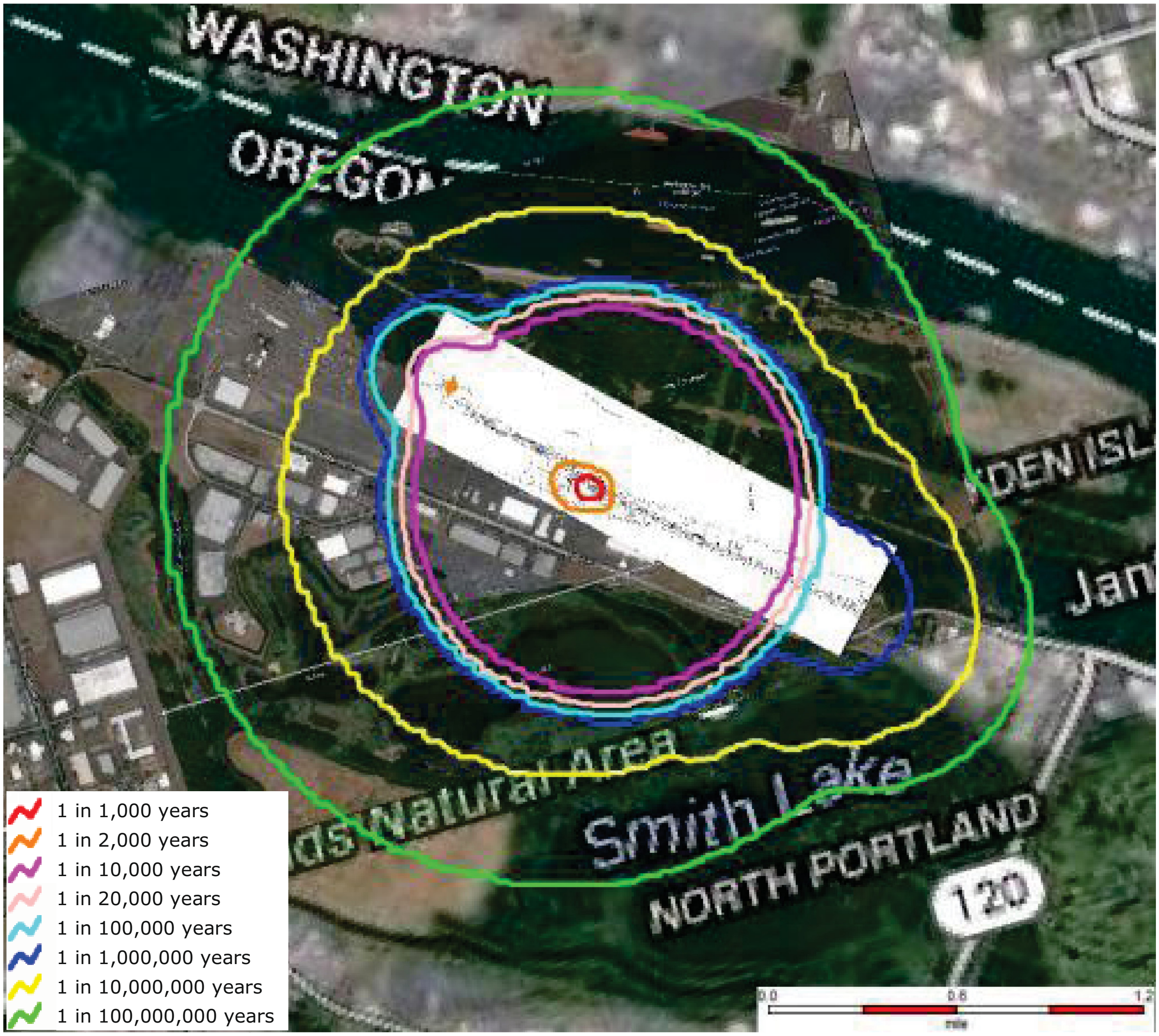

Figure 4-14: Fire Radiation – Frequency Contours for 5 kW/m^2 (all fire hazards)

A thermal radiation of 35 kW/m^2 will pose significant fatality risk to people. The contour centers are around the facility area and the loading area, where the relatively higher frequency release events are located.

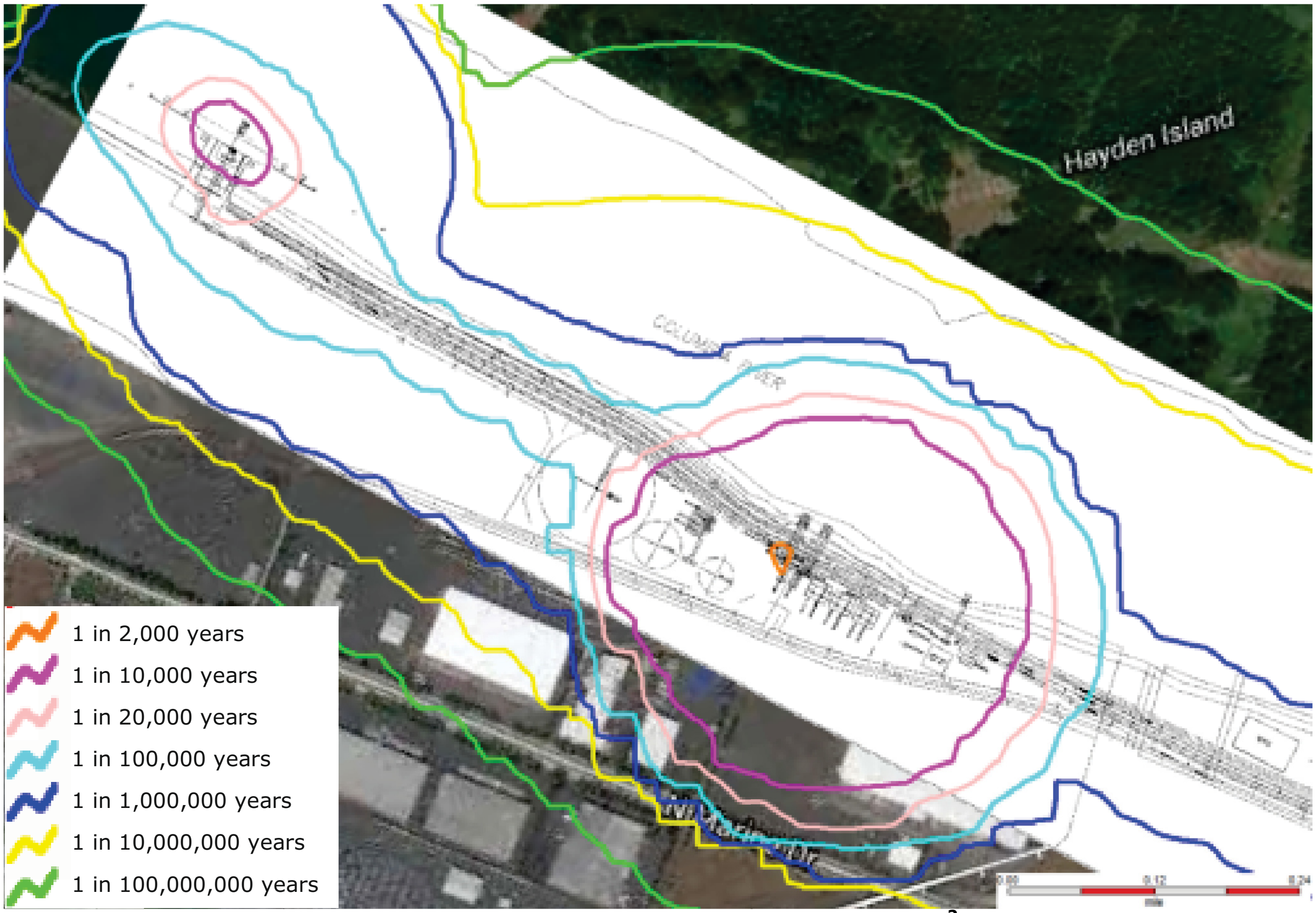

Figure 4-15: Fire Radiation – Frequency Contours for 35 kW/m^2 (all fire hazards)

4.4.3 Flash Fire-Frequency Contours

Figure 4-16 shows the frequency contours for flash fire with the ignition concentration at LFL, taking into account all possible flash fire hazards from the identified scenarios.

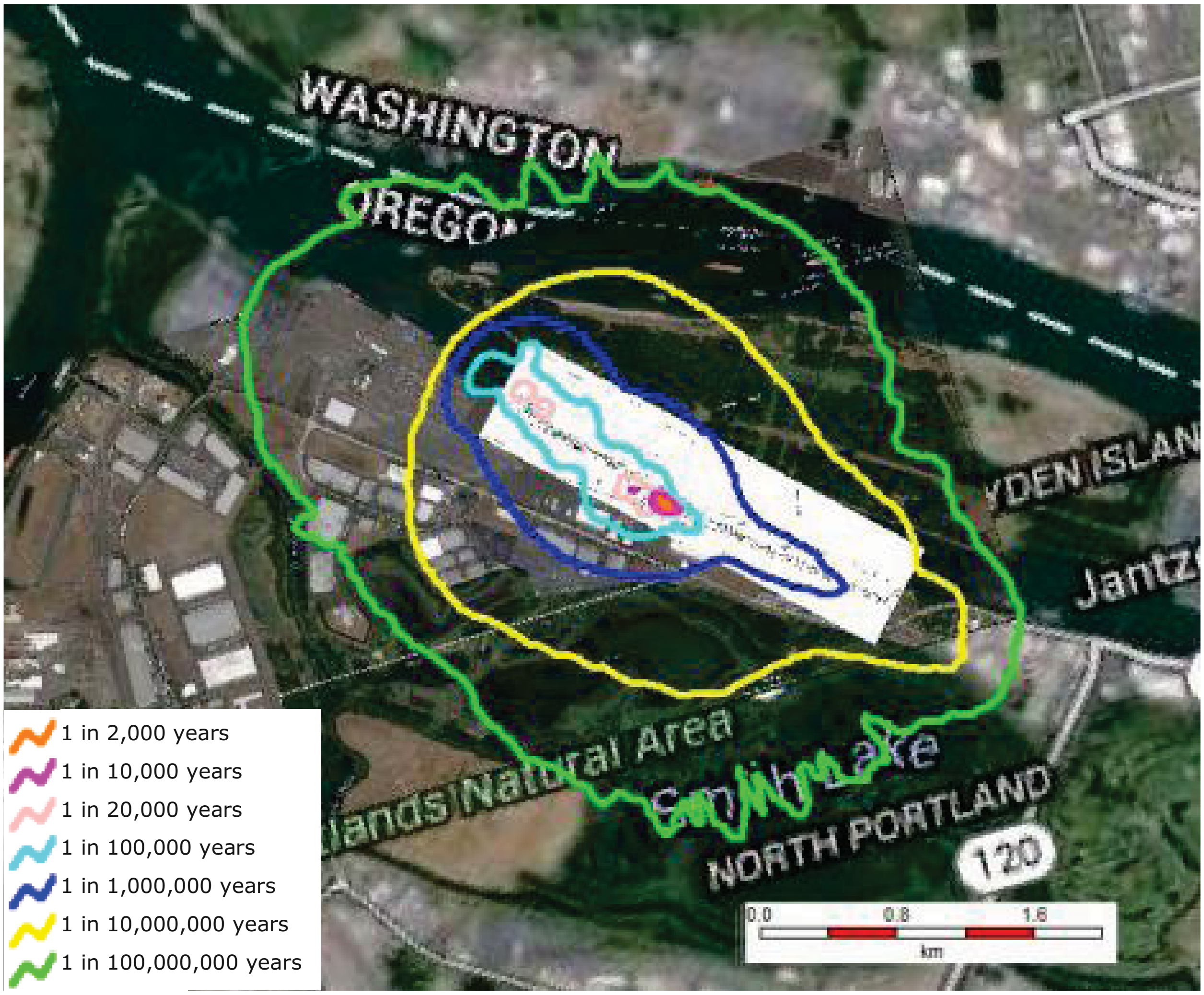

Figure 4-16: LFL Flash Fire Risk Contours

4.4.4 Injury Frequency Contours

Injury frequency contours are also presented in Figure 4-17. Previously the fatal outdoor risk contours have been presented. Injury risk contours have also been evaluated. The outdoor injury risk contours are meant to present the potential frequency of being injured by location. The outdoor injury risk used the following endpoint criteria to evaluate the potential for injury:

- 0.15 barg / 2.2 psig overpressure (Personnel outdoors are expected to survive overpressures of 0.17 barg or lower. Missiles may travel and cause lacerations with overpressures between 0.07-0.15 barg. Ref. /13/)
- 2 kW/m^2 thermal radiation (minimum value to cause pain after 1 minute of exposure, Ref. /13/)

Since this study does not include any risk related to the occupational hazards, the injury risk for onsite personnel may be underestimated. For areas that are outside the facility boundary (contours starting from 1 in 10,000 years), compared to the fatal level contours (Figure 4-2), the injury level contours are greatly expanded. For example, the 1 in 10,000 years injury level contour (purple contour) covers a large part of Hayden Island, while the 1 in 10,000 years fatal level contour only reaches the south boundary of the island.

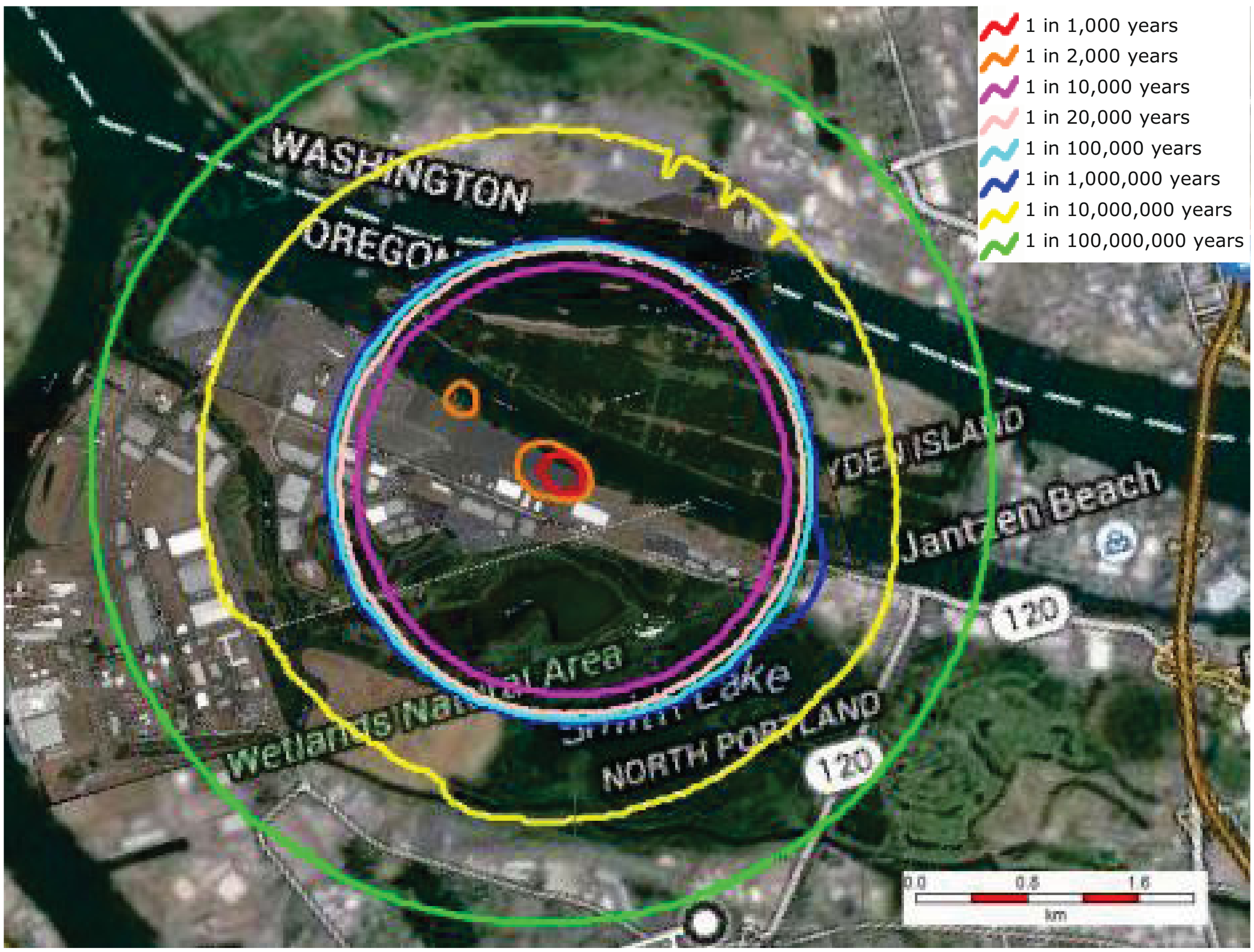

Figure 4-17: Injury Risk Contours

4.5 Uncertainties

All quantitative risk analyses are subject to uncertainty. A QRA can, for instance, be compared to a weather forecast; based on models and available data it attempts to predict what can be expected. The quality and accuracy of the "weather forecast" is dependent on knowledge, available calculation models, data quality, and degree of detail.

All risk assessments are, in general, aiming to give a "best estimate". A QRA is therefore generally not based on a systematic conservatism. However, this QRA errs on the conservative side for several of the scenarios that have been modeled, in order to extend the area of applicability.

Uncertainty can be divided into five categories:

Assumptions regarding design and operation of the facility: These assumptions are diverse, ranging from inventory volume for the segments and manning distribution.

Statistical uncertainty in data sources: The risks at the facility have been calculated using industry generic event frequency or leak frequency data as a basis. The databases reflect the experience of the offshore and onshore industry over a large number of exposure years. The failure data is deemed to be the best available source to apply in the analysis; however the data is not specific to propane export terminal operations and thus introduces a degree of uncertainty.

Applicability of the data sources and models to Pembina: The data sources for the assessment were selected from both offshore and onshore facility experience. In general, the hazards identified for Pembina propane export terminal are common to other facilities intended for similar service and the use of existing databases representing good practice is considered appropriate for assessing such hazards.

Limitations of the tools and methods used: For consequence and frequency modeling, a number of tools are used. All modeling of physical events have their limitations, related to, for example, the number of parameters that are taken into account. No consequence modeling, no matter how good the final graphics look, is precise. All risk assessment based on such consequence modeling must take this into consideration. Simplified free-field, obstacle dispersion and radiation modeling is applied in the analysis, and thus introduces conservatism and uncertainties in the hazard zone estimation.

Engineering judgment is applied to a number of areas and evaluations within the risk assessment model. In areas where engineering judgment is applied, there is always a large degree of uncertainty. In general, systematic conservatism is not intentionally built into models. However, where uncertainty exists it has been approached from the conservative side. Subsequently, this has an influence on the risk results.

For all practical purposes, it is not possible to eliminate or to quantify the uncertainty of a risk analysis. It is, however, important to identify and discuss parameters being both uncertain and with large influence on the risk results. This report strives to illustrate the uncertainty either quantitatively through sensitivities, or by highlighting uncertain issue in the discussions.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusions

5.1.1 Individual Risk

The following are the key findings related to the individual risk results:

- A few locations have risk levels of 1E-03 per year (1 in 1,000 years) onsite: pressurized propane storage bullets and propane compression/refrigeration area.
- The outdoor LSIR for the control room is 1.7E-04 per year (1 in 5,770 years) and the indoor LSIR is 1.8E-04 per year (1 in 5,460 years), which are in the ALARP region according to the UK HSE tolerability criteria.
- The highest risk level offsite is 1E-04 per year (1 in 10,000 years) in the channel area and to the south of the facility.
- The offsite point locations evaluated are either in the ALARP or broadly acceptable region according to the UK HSE tolerability criteria widely accepted by the marine industry.

5.1.2 Societal Risk

The following are the key findings related to the societal risk results:

<u>Base Case:</u>

- The total PLL is 5.6E-03 per year, which is equivalent to 1 statistical fatality every 180 years.
- The societal risk result is below the UK HSE tolerability criteria on the FN curve.
- The liquid loading arm is the largest risk contributor to PLL, contributing 15.4% of the PLL. A majority of the risk comes from fatal impact at the jetty location. The pressure storage tank groups 3, 1, and 2 contribute 13.8%, 12.7% and 12.6% to the risk, respectively. In total, the groups of bullets contribute 39% to the risk.
- The key release scenarios contributing to the overall risk levels are: Marine Liquid Loading Arm, Propane Unloading Storage Bullets, Refrigerated Propane Tanks and Jetty Loading Pipe.
- The Propane Unloading Storage Bullets and Loading arms are the significant contributors to N < 20. The Refrigerated Storage and Railcar Transit are the significant contributors to N > 20, as seen from the FN curve result breakdown.
- Onsite PLL is 4.1E-03 per year (1 in 240 years), contributing 73% to the total risk. Offsite PLL is 1.5E-03 per year (1 in 670 years), 27% of the total PLL. The sub-area #345, where the Pembina facility is located, contributes the most to the offsite PLL, 8.3E-04 per year (1 in 1,200 years).

<u>Sensitivity Case:</u>

- The total PLL for the 2035 sensitivity is 6.3E-03 per year, which is equivalent to 1 statistical fatality every 160 years. This is a 13% increase from the base case result.
- The societal risk result is below the UK HSE tolerability criteria on the FN curve.
- The pressure propane storage bullet group 3 - is the largest risk contributor to PLL, contributing 14.8% of the PLL.
- Note that the sensitivity assumes no change to the terminal operation between today and 2035. If activity were to increase or decrease at the terminal by 2035, then the risk result may be higher or lower than presented here.

5.2 Recommendations

The following recommendations may be considered in developing the facility design and siting:

1. **Minimize the potential for BLEVE scenarios**. Given the number of pressurized propane bullets at the site, there is the potential for escalation scenarios and BLEVEs. Although a number of mitigations have been input to the design to minimize these impacts, the site should further minimize this potential by focusing on the grading and drainage in the vicinity of the bullets to ensure flammable liquids will not collect in the area in the event of a release.

2. **Focus on Key Contributors**. Consider further reducing the risk posed by the high risk contributors, in particular, aim risk mitigation efforts toward the pressurized storage vessel bullets, refrigerated propane tanks, and marine loading.

3. **Impoundment Areas.** Bunding, curbing and secondary containment is recommended to limit the potential pool sizes. Bunding resulting from the existing and proposed rail lines has been roughly accounted for in the modeling of potential pool fire scenarios to limit the pool spread to more realistic distances. However the model does not account for any other topography elements of the site. To better contain the potential pool hazards and spread of the pool fires to other areas of the facility or to offsite, bunding or other containment measures should be considered.

4. **Detection and Isolation**. Leak detection and isolation are key control measures accounted for in the model. Their primary influence is to limit the potential for escalation. The more rapidly that isolation occurs the greater the benefit in terms of risks to personnel, potential for escalation, and reduction in overall duration of event. Focus should be placed on the installation and maintenance of the systems to further optimize their reliability and effectiveness.

6 REFERENCES

/1/ Propane Export Terminal Design Overview. Portland, Oregon: Pembina Pipeline Corporation, 10-01-2014

/2/ Hydrocarbon Release Database (HCRD), UK Health and Safety Executive (HSE), October 1992 – March 2010.

/3/ DNV GL Expert Judgement based on ACDS. Major hazard Aspects of the Transport of Dangerous Substances Advisory Committee on Dangerous Substances. *HMSO Major hazard aspects of the transport of dangerous substances.* Health & Safety Commission, 1991.

/4/ Failure Rate and Event Data for Use within Risk Assessment, June 28 2012, UK HSE.

/5/ Federal Railroad Administration Office of Safety Analysis. U.S. Department of Transportation, 2015. http://safetydata.fra.dot.gov/OfficeofSafety/Default.aspx

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/7/ 2014 Oregon Structural Specialty Code. Chapter 16 Section 1613: Structural Design - Earthquake Loads

/8/ Pitblado, et al., "Facility Siting Rule Set for the TNO Multi-Energy Model for Congested Volumes (PES) and Severity Levels", 10th Global Congress on Process Safety, 2014Obstructed region explosion model (OREM) theory, DNV Software, March 2010.

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/10/ HSE, 2001. Reducing Risks, Protecting People: HSEs decision-making process, (R2P2), HSE Books. London: HSE. [Online] Available at: http://www.hse.gov.uk/risk/theory/r2p2.pdf

/11/ HSE, 2009, Societal Risk: Initial Briefing to Societal Risk Technical Advisory Group, Research Report, RR703.

/12/ VROM, Guidelines for Quantitative Risk Assessment (Purple Book), PGS 3, Ministerie van Verkeer en Waterstaat, December 2005.

/13/ HSE, "Methods of approximation and determination of human vulnerability for offshore major accident hazard assessment".

About DNV GL

APPENDIX I: STUDY BASIS

Table of Contents

I ASSUMPTIONS OVERVIEW

This study basis consists of the assumptions for conducting a quantitative risk analysis (QRA) for the Pembina Propane Export Terminal designed by Pembina Marine Terminal Inc., hereafter referred to as "Pembina". The intent of this document is to clarify the assumptions made by DNV GL related to how the key aspects of the Pembina terminal site configuration have been interpreted in the QRA study and what has been assumed when detailed information has not been available.

These assumptions form the basis for the QRA. If any of these assumptions are altered, the results presented for the study are no longer valid. Consequently, alteration of any of these assumptions may generate a need for an update of the analysis.

The following table outlines the key changes made in the Study Basis for this revision:

Assumption No.	Description
1	Railcar releases and derailments added into facility scope.
4	Jetty area onsite populations revised. Detailed offsite population sub-areas defined for areas surrounding facility. 2035 populations evaluated for sensitivity study.
9	Additional offsite ignition areas defined.
22	Additional obstructed regions defined for railcar locations.
25	Bunding to limit pool spread considered based on railroad tracks.
26	Injury endpoint criteria defined.
27	Additional risk receptor locations defined.
32	Earthquake frequency and scenarios modified.
35	Railcar release and derailment scenarios and frequencies defined.

I.1 Description and Background Data

I.1.1 Facility Description

Assumption No.:	1		
Revision:	2	**Prepared by:**	WHON 2015-03-30
Date:	30 March 2015	**Verified by:**	CSPI 2015-03-30
Relevant Analysis:	General	**Category:**	Design

Specifications:

Pembina intends to construct and operate a Propane Export Terminal in Portland, Oregon on the Columbia River capable of

- receiving propane via rail,
- storing the propane on receipt,
- refrigerating propane,
- storing 800,000 bbl in a refrigerated state,
- loading propane onto vessels to be transported down the Columbia River to Asia Pacific markets,
- supplying all of the utilities and safety systems to support the propane terminal

The proposed simplified flow diagram for the propane export terminal is shown in Figure I-1.

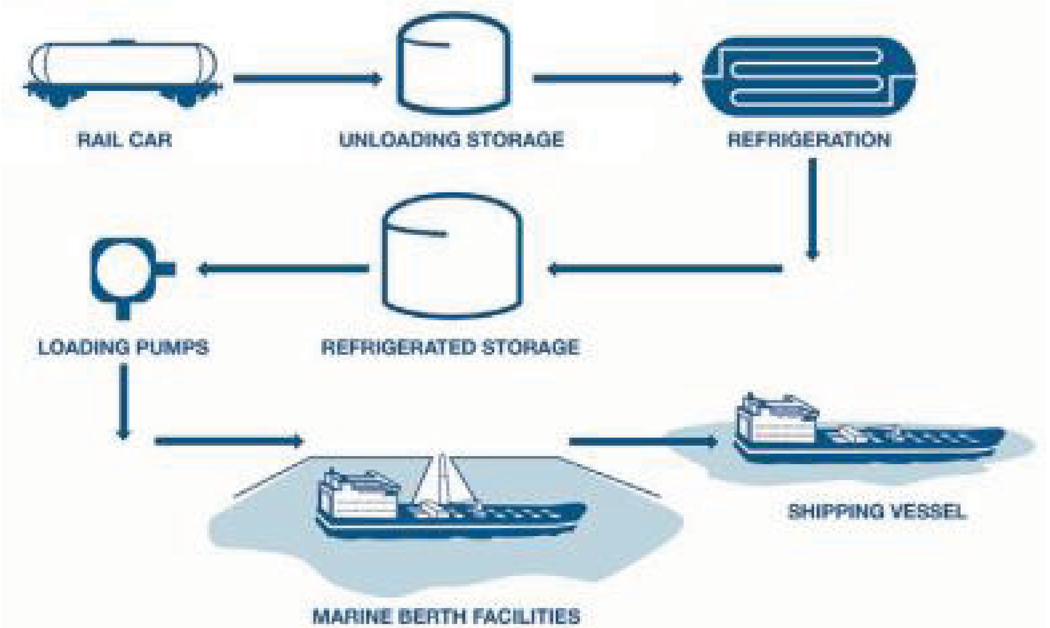


Figure I-1: Facility Transportation, Refrigeration, Storage and Loading (Ref. 1)

I.1.1 Facility Description

Assumption No.:	1

The major equipment at the terminal includes

- Rail unload racks
- Offload propane pressure storage tanks
- Refrigerated propane storage tanks
- Refrigeration compression
- Boil off compression
- Vapor compression
- Product transfer pumps
- Ship loading pumps
- Marine loading arms

All of the above equipment are included in the evaluation of the facility risk assessment. Potential releases related to the railcar and derailment within the terminal are also included in this study.

Potential releases related to the propane carrier are evaluated in a separate study.

Implication of Assumption:

Defines boundaries and scope of the analysis.

References:

1. Pembina Marine Terminal Inc.: Propane Export Terminal Design Overview. Oct 01 2014

Comments:

I.1.2 Facility Operational Philosophy

Assumption No.:	2		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA, CA	**Category:**	Design

Specifications:

The following are important operation philosophy details (Ref. 1)

- Two trains of the propane refrigeration compressor package are identified based on PFD 14088D-PR-PF-1002-001 and 002. Normal operation has only one refrigeration compression train operational. In event propane train rail cars being late, the spare refrigeration compression unit is operated to unload the train more quickly than in normal operation.
- The line (stream 43), which recirculates propane from tank to downstream of rundown pump (PFD 14088D-PR-PF-1002-001), generally remains empty during normal operation. If refrigeration compression has to be run (e.g. a rail train is late), refrigerated propane is recirculated to the lines downstream of the rundown pumps. There may be some potential use of this pump as one refrigeration compressor is brought on line, prior to dropping the running unit offline for maintenance. This depends on final design and length of piping that is needed to be cooled from the unit coming online.
- Although normal operation for propane rundown is to one tank, there is no operational reason to restrict rundown to only one tank unless the facility is loading a ship from one of the tanks. So rundown is assumed into two propane storage tanks (PFD 14008D-PR-PF-1002-003 and 004) simultaneously. (Ref. 1).
- The cool down only runs for 24 hours prior to ship arrival (probably shorter). The ship is loaded using the propane load line to dock and vapor return line from the ship to the large refrigerated storage tanks. Upon completion of loading, the marine load arms are isolated, and propane load line / vapor return lines are left open to the large refrigerated storage tanks allowing all propane to vaporize from the lines leaving only propane vapors at the pressure of the storage tanks (up to 19 psia) until the next ship arrives and cool down is needed for the lines (Ref. 2).

There are five Cases of Heat & Material Balances provided by Pembina Facility (Ref. 3). For normal operation and ship loading, the risk modelling is based on Case 1 (Base Case: Average Feed + Ship Loading + High Amb. Temp. 82F). For operation specific to propane recirculation, the risk modelling is based on Case 2 (Average Feed + Holding + Average Amb. Temp. 52F)

Implication of Assumption:

The above assumptions each have key influences on the risk results.

### I.1.2 Facility Operational Philosophy	
Assumption No.:	2
References: 1. Email from Chris Hayes "More Clarification Questions", January 27, 2015 2. Email from Chris Hayes "Additional Data Request", January 27, 2015 3. Heat & Material Balances, rev. A November 14 2014. Pembina Marine Terminal Inc.: Pembina Propane Terminal Project (14088D), Portland Oregon	
Comments:	

I.1.3 Operational Periods

Assumption No.:	3		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA	**Category:**	Operational

Specifications:

Day time and night time is split equally: 12 hours for day and 12 hours for night.

For the normal operation, the following information applies to vessel calls (Ref. 1):

- 26 ships per year for 83,000m^3 ship
- Cooling the loading equipment starts up to 24 hours prior to ship arrival.
- Loading is assumed to start within a couple of hours after the ship is berthed (assuming during the day time).
- Propane loading time is approximately 38 hours for very large propane carrier.
- The ship is assumed to be held at dock up to 12 hours after being loading waiting to sail.
- The ship port time is assumed to be 52 hrs.

Preparation for Loading	–	2 hours
Loading time	–	38 hours
Preparation for Departure	–	12 hours
Total:		**52 hours**

To simplify the risk model, it is assumed that the loading activity always starts in the beginning of the day. The data is presented according to the different scenario that occur:

1. Common Events* – ship present, Loading – day;
2. Common Events – ship present, Loading – night;
3. Common Events – ship present, no-loading – day;
4. Common Events – ship present, no-loading – night;
5. Common Events – no ship present – day;
6. Common Events – no ship present – night;
7. Recirculation – no ship present – day;
8. Recirculation – no ship present – night;
9. Recirculation – ship present – day;
10. Loading – ship present – day;
11. Loading – ship present – night;

*Common events are normal operations that exclude marine recirculation and loading events.

I.1.3 Operational Periods

Assumption No.:	3

The following are the annual time fractions that apply for the different operational phases (assuming 26 vessel shipments every year):

- 0.0178, Common Events – ship present, Loading – day;
- 0.0237, Common Events – ship present, Loading – night;
- 0.0653, Common Events – ship present, no-loading – day;
- 0.0475, Common Events – ship present, no-loading – night;
- 0.4169, Common Events – no ship present – day;
- 0.4288, Common Events – no ship present – night;
- 0.0297, Recirculation – no ship present – day;
- 0.0356, Recirculation – no ship present – night;
- 0.0059, Recirculation – ship present – day;
- 0.0653, Loading – ship present – day;
- 0.0475, Loading – ship present – night;

Implication of Assumption:

The risk level is directly influenced by the frequency of the loading operation.

References:

1. Email from Chris Hayes, January 23 2015 and January 27 2015

Comments:

I.1.4 Population / Manning

Assumption No.:	4		
Revision:	2	**Prepared by:**	WHON 2015-03-30
Date:	30 March 2015	**Verified by:**	CSPI 2015-03-30
Relevant Analysis:	QRA	**Category:**	Operational

Specifications:

The presence and locations of people within the terminal (onsite) and surrounding areas (offsite) are required to evaluate the impact of a hazardous release.

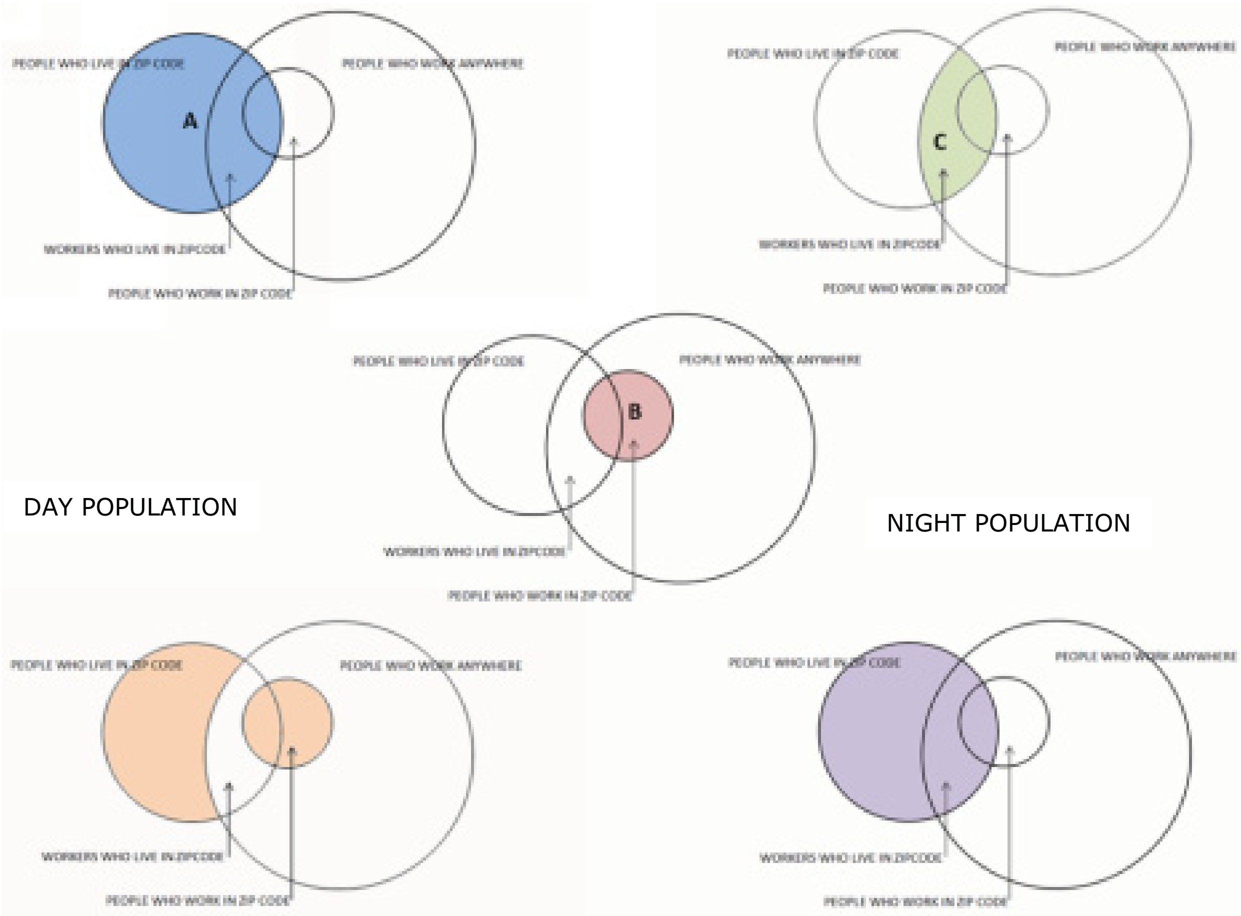
Personnel counts are categorized by day, night, ship presence and whether loading activities are being conducted. Day time and night time is split equally: 12 hours for day and 12 hours for night. The manning areas within the site area have been highlighted in Figure I-2. Table I-1 presents a summary of original onsite populations data (Ref. 1) and Table I-2 to Table I-4 present the onsite populations with different shift patterns and assumed working locations. The Jetty building is assumed to be at the dock housing mooring system controls and loading arm controls / ESD's, etc.

The population areas offsite of the facility by zip code have been highlighted with different colors in Figure I-3. Detailed sub-area population distributions for zip code 97203 (facility) and the three nearest neighboring areas, zip codes 97217, 97211, 97227, are obtained from Pembina / City of Portland (Ref. 2) and demonstrated in Table I-5 and Figure I-4. Detailed sub-areas are needed for these zip codes as the population distribution is not even across the zip code. Table I-5 presents a summary of the sub-area offsite populations that live or work near the Propane Export Terminal in zip codes 97023, 97217, 97211 and 97227. The ID Number corresponds to the numbers shows in Figure I-4 for each area. The Residential and Worker existing populations are available for each detailed sub-area. DNV GL assumes that the offsite residential population spends 90% of the time indoors and 10% of the time outdoors all the time; while the industrial population spends 70% of the time indoors and 30% of the time outdoors during the day, and 90% of the time indoors and 10% of the time outdoors at night.

Table I-6 presents a summary of the offsite populations that live or work further from the Propane Export Terminal. The “total population living in the area” (***A***) is obtained from census population data by zip code (Ref. 3). Additional census information is used to determine “total number of people who *work*” within the zip code (***B***) and “total number of *workers* who *live*” within the zip code (***C***) (Ref. 4). The day population for the area equals population ***A*** + ***B*** – ***C***, and night population is population ***A***. DNV GL assumes that the offsite population spends 70% of the time indoors and 30% of the time outdoors during the day, and 90% of the time indoors and 10% of the time outdoors at night.

I.1.4 Population / Manning

Assumption No.:	4



<u>2035 Sensitivity Study</u>

A sensitivity study with projected future (year 2035) offsite populations was performed. Table I-7 presents the detailed sub-area population information, with the current and projected population values. For the sub-areas near the facility (zip codes 97203, 97217, 97211 and 97227), the projected year 2035 population is applied directly.

The detailed sub-areas do not always align completely with the large zip code areas. For far-away areas (other zip codes), the projected population is based on the population from Table I-6 multiplied by an estimated factor to account for the population increase for each zip code based on the detailed population statistics provided. For zip codes with no detailed information provided, the projected 2035 population is based on the population from Table I-6 multiplied by an average population increase factor (1.35). Table I-8 summarizes the year 2035 population information applied for the far-away offsite areas in the sensitivity study.

I.1.4 Population / Manning

Assumption No.:	4

Implication of Assumption:

Societal risks (risks to groups of people) are directly influenced by the numbers of personnel exposed to hazardous events and hence the group risk (societal risk) results are sensitive to the manning assumptions.

References:

1. Email from Chris Hayes, January 23 2015, January 27 2015, and March 23 2015
2. Email from Chris Hayes, March 18 2015
3. Census Population Data by Zip Code http://www.census.gov/geo/www/gazetteer/files/Gaz_zcta_national.txt
4. Worker Information by Zip Code, http://onthemap.ces.census.gov/

Comments:

Table I-1: Onsite Population

Worker Group	Ship Loading		Ship Holding		No Ship Present	
	Day	Night	Day	Night	Day	Night
Foreman	2	-	2	-	2	-
Control Room Operator	1	1	1	1	1	1
On Site Operators	2	2	2	2	2	2
Train Unloading	4	4	4	4	4	4
Maintenance	6	-	6	-	6	-
Dock Staff	2	2	3*	3*	-	-
Ship Crew (outside)	3	3	4**	4**	-	-
Security	1	1	1	1	-	-
Manager + Admin.	3	-	3	-	3	-

* Number of Dock Staff changes during the total period the ship is present but not during loading; it ranges from 9 people present for approximately 3 hrs to 0 people for approximately 10 hrs. 3 people is the time-weighted average number.
** Number of Ship Crew (outside) changes during the total period the ship is present but not during loading; it ranges from 8 people present for approximately 2 hrs to 3 people for approximately 10 hrs. 4 people is the time-weighted average number.

Table I-2: Onsite Population – Summary Table (No Ship)

No Ship	Area	Indoor		Outdoor			
Worker Group	**Population**	**Admin. Building**	**Control Room and Warehouse**	**Jetty**	**Process Area**	**Railcar Unloading**	**Carrier**
DAY							
Manager + Admin.	3	3					
Foreman	2		2				
Control Room Operator	1		1				
On Site Operators	2		1		1		
Train Unloading	4					4	
Maintenance	6		1		5		
Dock Staff	-						
Ship Crew	-						
Security	-						
Total:	**18**	**3**	**5**	**-**	**6**	**4**	**-**
NIGHT							
Manager + Admin.	-						
Foreman	-						
Control Room Operator	1		1				
On Site Operators	2		1		1		
Train Unloading	4					4	
Maintenance	-						
Dock Staff	-						
Ship Crew	-						
Security	-						
Total:	**7**	**-**	**2**	**-**	**1**	**4**	**-**

Table I-3: Onsite Population – Summary Table (Ship Loading)

Ship Loading	Area	Indoor		Outdoor			
Worker Group	**Population**	**Admin. Building**	**Control Room and Warehouse**	**Jetty**	**Process Area**	**Railcar Unloading**	**Carrier**
DAY							
Manager + Admin.	3	3					
Foreman	2		2				
Control Room Operator	1		1				
On Site Operators	2		1		1		
Train Unloading	4					4	
Maintenance	6		1		5		
Dock Staff	2			2			
Ship Crew	3						3
Security	1			1			
Total:	**24**	**3**	**5**	**3**	**6**	**4**	**3**
NIGHT							
Manager + Admin.	-						
Foreman	-						
Control Room Operator	1		1				
On Site Operators	2		1		1		
Train Unloading	4					4	
Maintenance	-						
Dock Staff	2			2			
Ship Crew	3						3
Security	1			1			
Total:	**13**	**-**	**2**	**3**	**1**	**4**	**3**

Table I-4: Onsite Population – Summary Table (Ship Holding)

Ship Holding	Area	Indoor		Outdoor			
Worker Group	**Population**	**Admin. Building**	**Control Room and Warehouse**	**Jetty**	**Process Area**	**Railcar Unloading**	**Carrier**
DAY							
Manager + Admin.	3	3					
Foreman	2		2				
Control Room Operator	1		1				
On Site Operators	2		1		1		
Train Unloading	4					4	
Maintenance	6		1		5		
Dock Staff	3			3			
Ship Crew	4						4
Security	1			1			
Total:	**26**	**3**	**5**	**4**	**6**	**4**	**4**
NIGHT							
Manager + Admin.	-						
Foreman	-						
Control Room Operator	1		1				
On Site Operators	2		1		1		
Train Unloading	4					4	
Maintenance	-						
Dock Staff	3			3			
Ship Crew	4						4
Security	1			1			
Total:	**15**	**-**	**2**	**4**	**1**	**4**	**4**

Table I-5: Detailed Offsite Population – Summary Table (Nearby Areas)

ID Number	Zip Code	Residential Population	Worker Population	Total	Day Indoor Population	Day Indoor Fraction	Night Indoor Population	Night Indoor Fraction
1	97217	557	525	1,082	869	0.80	974	0.9
2	97217	163	968	1,131	824	0.73	1,018	0.9
3	97217	898	559	1,457	1,199	0.82	1,311	0.9
4	97217/97211	311	1,604	1,914	1,402	0.73	1,723	0.9
5	97211/97217	921	2,692	3,614	2,714	0.75	3,252	0.9
6	97203	2,134	344	2,478	2,161	0.87	2,230	0.9
7	97217	886	263	1,149	982	0.85	1,034	0.9
8	97217	1,050	521	1,572	1,310	0.83	1,414	0.9
9	97217	483	753	1,236	962	0.78	1,113	0.9
10	97203	2,422	1,546	3,968	3,262	0.82	3,572	0.9
11	97217	17	878	894	629	0.70	805	0.9
13	97217	950	164	1,114	969	0.87	1,002	0.9
14	97217	622	104	725	632	0.87	653	0.9
15	97217	1,352	456	1,808	1,536	0.85	1,628	0.9
16	97217	454	438	892	715	0.80	803	0.9
17	97217	181	351	532	409	0.77	479	0.9
19	97217	88	10,748	10,836	7,603	0.70	9,752	0.9
20	97211	1,254	174	1,428	1,251	0.88	1,285	0.9
22	97211	672	521	1,193	970	0.81	1,074	0.9
23	97211	763	405	1,168	970	0.83	1,051	0.9
24	97217	1,052	140	1,192	1,045	0.88	1,073	0.9
25	97217	204	318	522	406	0.78	470	0.9
26	97217	537	73	610	534	0.88	549	0.9
27	97217	336	15	351	313	0.89	316	0.9
28	97217	309	46	354	310	0.87	319	0.9
29	97217	649	65	713	629	0.88	642	0.9
30	97211	541	122	663	572	0.86	596	0.9
33	97217	771	216	987	845	0.86	889	0.9
34	97217	448	182	630	531	0.84	567	0.9
35	97217	391	101	492	423	0.86	443	0.9
36	97217	395	66	462	402	0.87	415	0.9
37	97217	338	968	1,306	982	0.75	1,176	0.9
39	97217	889	478	1,367	1,135	0.83	1,230	0.9
40	97211	657	781	1,438	1,138	0.79	1,294	0.9
41	97211	1,166	689	1,855	1,532	0.83	1,669	0.9
42	97211	918	286	1,204	1,026	0.85	1,083	0.9
43	97211	888	823	1,710	1,375	0.80	1,539	0.9
47	97217	301	19	320	284	0.89	288	0.9
48	97217	383	95	478	411	0.86	430	0.9
49	97217	417	318	735	598	0.81	661	0.9
52	97217	341	167	509	424	0.83	458	0.9
53	97217	488	221	709	594	0.84	638	0.9
54	97217	908	205	1,113	960	0.86	1,001	0.9
55	97211	1,010	217	1,227	1,061	0.86	1,104	0.9
56	97211	996	954	1,950	1,564	0.80	1,755	0.9
57	97211	943	191	1,134	982	0.87	1,021	0.9
58	97217	5	428	433	304	0.70	390	0.9
59	97217	6	93	99	71	0.71	89	0.9
61	97211/97218	1	906	907	635	0.70	816	0.9
62	97211	12	2,263	2,274	1,594	0.70	2,047	0.9
67	97217	12	570	582	410	0.70	524	0.9
68	97217	0	54	54	38	0.70	49	0.9
73	97203	1	9	10	7	0.71	9	0.9
75	97217	1	0	1	0	0.90	0	0.9
83	97211	942	200	1,142	988	0.86	1,028	0.9

ID Number	Zip Code	Residential Population	Worker Population	Total	Day Indoor Population	Day Indoor Fraction	Night Indoor Population	Night Indoor Fraction
92	97227	5	159	164	116	0.71	148	0.9
93	97227	191	20	211	186	0.88	190	0.9
94	97227	519	843	1,361	1,057	0.78	1,225	0.9
95	97227	638	337	975	810	0.83	878	0.9
109	97227	850	5,355	6,205	4,513	0.73	5,584	0.9
134	97227	1	801	802	562	0.70	722	0.9
148	97227	0	1,150	1,150	805	0.70	1,035	0.9
342	97203	1,372	117	1,489	1,317	0.88	1,340	0.9
343	97203	3,042	2,140	5,182	4,236	0.82	4,664	0.9
344	97203	2,557	956	3,512	2,970	0.85	3,161	0.9
345	97203/97217	22	200	223	160	0.72	200	0.9
346	97203	1	856	857	600	0.70	771	0.9
348	97203	187	774	961	710	0.74	865	0.9
349	97203	0	1,158	1,158	811	0.70	1,042	0.9
350	97203	0	1,896	1,896	1,327	0.70	1,707	0.9
351	97203	0	788	788	552	0.70	710	0.9
381	97227	73	1,423	1,496	1,062	0.71	1,347	0.9
382	97227	12	2,016	2,028	1,422	0.70	1,825	0.9
447	97217	711	694	1,405	1,126	0.80	1,264	0.9
448	97211	504	618	1,122	886	0.79	1,010	0.9
449	97211	33	541	574	408	0.71	516	0.9
451	97211	241	7	247	221	0.89	223	0.9
453	97211	548	188	736	625	0.85	662	0.9
456	97211	604	302	906	755	0.83	816	0.9
469	97227	229	1,105	1,334	980	0.73	1,201	0.9

Table I-6: Offsite Population – Summary Table (Far-away Areas)

Zip Code	Population A	Population B	Population C	Day Population		Night Population	
	total number of *people* who *live* within the zip code	total number of *people* who *work* within the zip code	total number of *workers* who *live* within the zip code	Indoor	Outdoor	Indoor	Outdoor
97210	10,887	20,463	5,347	18,202	7,801	9,798	1,089
97229	58,217	8,496	26,014	28,489	12,210	52,395	5,822
97231	4,280	752	1,822	2,247	963	3,852	428
98660	11,858	11,872	5,141	13,012	5,577	10,672	1,186
97209	14,950	21,394	6,405	20,957	8,982	13,455	1,495
97205	7,688	16,654	2,969	14,961	6,412	6,919	769
97204	1,036	34,361	277	24,584	10,536	932	104
97201	15,484	22,293	5,469	22,616	9,692	13,936	1,548
97212	24,126	5,839	10,669	13,507	5,789	21,713	2,413
97213	29,219	19,107	15,239	23,161	9,926	26,297	2,922
97214	23,813	19,067	11,839	21,729	9,312	21,432	2,381
97215	16,375	3,047	7,096	8,628	3,698	14,738	1,638
97218	14,561	12,503	6,344	14,504	6,216	13,105	1,456
97232	11,472	25,079	5,499	21,736	9,316	10,325	1,147
98663	14,115	3,784	5,873	8,418	3,608	12,704	1,412
98661	41,740	18,516	15,947	31,016	13,293	37,566	4,174
98665	24,057	7,536	9,732	15,303	6,558	21,651	2,406
98685	26,217	3,744	10,838	13,386	5,737	23,595	2,622
98664	21,771	6,073	8,449	13,577	5,819	19,594	2,177
98662	31,644	9,941	12,343	20,469	8,773	28,480	3,164
98686	17,385	5,092	7,605	10,410	4,462	15,647	1,739
97124	48,349	43,403	22,726	48,318	20,708	43,514	4,835

Table I-7: Projected 2035 Offsite Population (Detailed Nearby Areas)

ID Number	Zip Code	Residential Population Existing	Worker Population Existing	Current	Residential Population 2035	Worker Population 2035	Total Population 2035	Total Existing Population	Total 2035 Population	Factor Increased
6	97203	2,134	344	2,478	2,421	457	2,877	22,522	33,681	1.50
10	97203	2,422	1,546	3,968	3,064	4,912	7,976			
73	97203	1	9	10	1	9	10			
342	97203	1,372	117	1,489	1,500	224	1,724			
343	97203	3,042	2,140	5,182	5,035	2,649	7,684			
344	97203	2,557	956	3,512	2,956	1,551	4,508			
345	97203/97217	22	200	223	22	253	275			
346	97203	1	856	857	1	1,123	1,124			
348	97203	187	774	961	187	886	1,073			
349	97203	0	1,158	1,158	0	2,051	2,052			
350	97203	0	1,896	1,896	0	3,252	3,252			
351	97203	0	788	788	0	1,126	1,126			
5	97211/97217	921	2,692	3,614	1,534	6,008	7,542	26,492	38,486	1.45
20	97211	1,254	174	1,428	1,345	176	1,521			
22	97211	672	521	1,193	720	2,421	3,141			
23	97211	763	405	1,168	1,025	575	1,600			
30	97211	541	122	663	570	379	949			
40	97211	657	781	1,438	1,009	979	1,989			
41	97211	1,166	689	1,855	1,324	823	2,148			
42	97211	918	286	1,204	1,054	333	1,386			
43	97211	888	823	1,710	990	897	1,887			
55	97211	1,010	217	1,227	1,055	224	1,279			
56	97211	996	954	1,950	1,424	1,096	2,520			
57	97211	943	191	1,134	1,024	220	1,244			
61	97211/97218	1	906	907	1	2,942	2,943			
62	97211	12	2,263	2,274	12	2,421	2,432			
83	97211	942	200	1,142	1,007	277	1,284			
448	97211	504	618	1,122	627	756	1,383			
449	97211	33	541	574	33	766	799			
451	97211	241	7	247	292	14	306			
453	97211	548	188	736	768	277	1,044			
456	97211	604	302	906	723	367	1,090			
1	97217	557	525	1,082	667	671	1,338	45,603	63,077	1.38
2	97217	163	968	1,131	483	1,148	1,631			
3	97217	898	559	1,457	1,692	907	2,599			
4	97217/97211	311	1,604	1,914	379	2,536	2,915			
5	97211/97217	921	2,692	3,614	1,534	6,008	7,542			
7	97217	886	263	1,149	954	305	1,259			
8	97217	1,050	521	1,572	1,098	673	1,771			
9	97217	483	753	1,236	1,112	1,027	2,139			
11	97217	17	878	894	17	960	977			
13	97217	950	164	1,114	1,115	199	1,314			
14	97217	622	104	725	668	151	819			
15	97217	1,352	456	1,808	1,671	607	2,278			
16	97217	454	438	892	633	513	1,145			
17	97217	181	351	532	825	393	1,219			
19	97217	88	10,748	10,836	95	10,956	11,052			
24	97217	1,052	140	1,192	1,104	140	1,245			
25	97217	204	318	522	959	366	1,324			
26	97217	537	73	610	1,093	102	1,195			
27	97217	336	15	351	341	15	356			
28	97217	309	46	354	338	55	394			
29	97217	649	65	713	687	65	751			
33	97217	771	216	987	922	281	1,203			
34	97217	448	182	630	702	268	970			
35	97217	391	101	492	1,316	177	1,493			
36	97217	395	66	462	549	708	1,257			
37	97217	338	968	1,306	400	1,552	1,952			
39	97217	889	478	1,367	1,243	527	1,770			
47	97217	301	19	320	363	19	381			
48	97217	383	95	478	554	124	678			
49	97217	417	318	735	1,006	500	1,506			
52	97217	341	167	509	511	216	728			
53	97217	488	221	709	616	352	969			
54	97217	908	205	1,113	1,114	244	1,358			
58	97217	5	428	433	5	494	499			

ID Number	Zip Code	Residential Population Existing	Worker Population Existing	Current	Residential Population 2035	Worker Population 2035	Total Population 2035	Total Existing Population	Total 2035 Population	Factor Increased
59	97217	6	93	99	6	148	154			
67	97217	12	570	582	12	1,003	1,015			
68	97217	0	54	54	0	56	56			
75	97217	1	0	1	1	0	1			
345	97203/97217	22	200	223	22	253	275			
447	97217	711	694	1,405	776	773	1,549			
92	97227	5	159	164	5	193	199	15,726	19,998	1.27
93	97227	191	20	211	319	26	345			
94	97227	519	843	1,361	695	906	1,601			
95	97227	638	337	975	1,056	428	1,484			
109	97227	850	5,355	6,205	1,236	6,026	7,262			
134	97227	1	801	802	1	801	802			
148	97227	0	1,150	1,150	205	1,440	1,645			
381	97227	73	1,423	1,496	165	1,515	1,680			
382	97227	12	2,016	2,028	281	2,537	2,818			
469	97227	229	1,105	1,334	392	1,770	2,162			

Table I-8: Projected Offsite Population – Summary Table (Far-away Areas)

Zip Code	Year 2010		Factor Increased	Year 2035	
	Day	Night		Day	Night
97210	26,003	10,887	1.16	30,176	12,634
97229	40,699	58,217	1.22	49,579	70,919
97231	3,210	4,280	1.67	5,357	7,143
98660	18,589	11,858	1.35*	25,002	15,949
97209	29,939	14,950	1.33	39,785	19,867
97205	21,373	7,688	1.38	29,459	10,597
97204	35,120	1,036	1.17	41,012	1,210
97201	32,308	15,484	1.52	49,011	23,489
97212	19,296	24,126	1.17	22,564	28,212
97213	33,087	29,219	1.15	38,036	33,590
97214	31,041	23,813	1.38	42,865	32,883
97215	12,326	16,375	1.26	15,549	20,656
97218	20,720	14,561	1.19	24,639	17,315
97232	31,052	11,472	1.67	51,921	19,182
98663	12,026	14,115	1.35*	16,175	18,985
98661	44,309	41,740	1.35*	59,596	56,141
98665	21,861	24,057	1.35*	29,403	32,357
98685	19,123	26,217	1.35*	25,721	35,262
98664	19,395	21,771	1.35*	26,086	29,282
98662	29,242	31,644	1.35*	39,331	42,561
98686	14,872	17,385	1.35*	20,003	23,383
97124	69,026	48,349	1.35*	92,840	65,030

Note: *: 1.35 is the average population increase factor rate from the areas investigated.

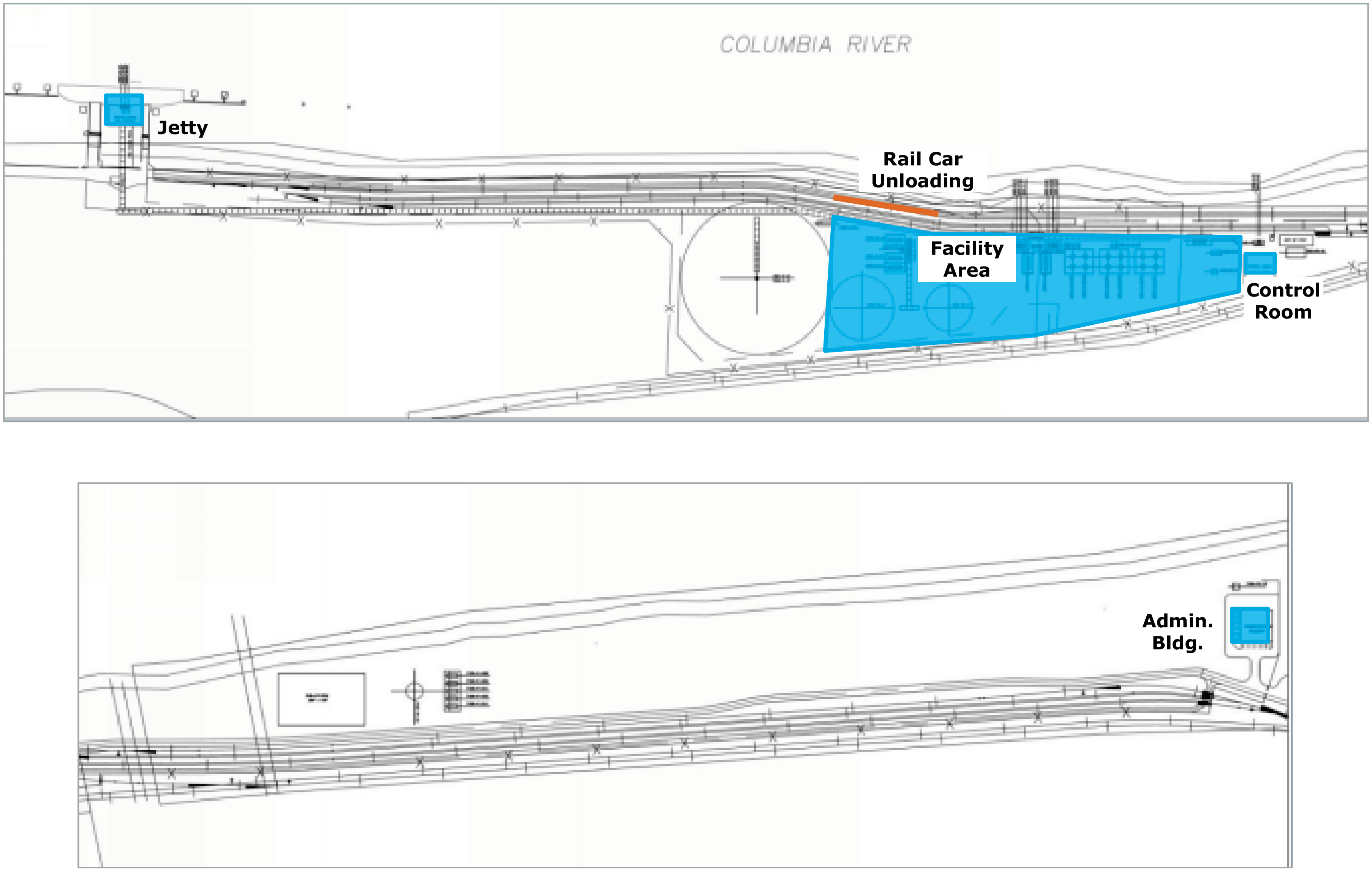


Figure I-2: Onsite Populated Areas Applied to Pembina Terminal QRA Model

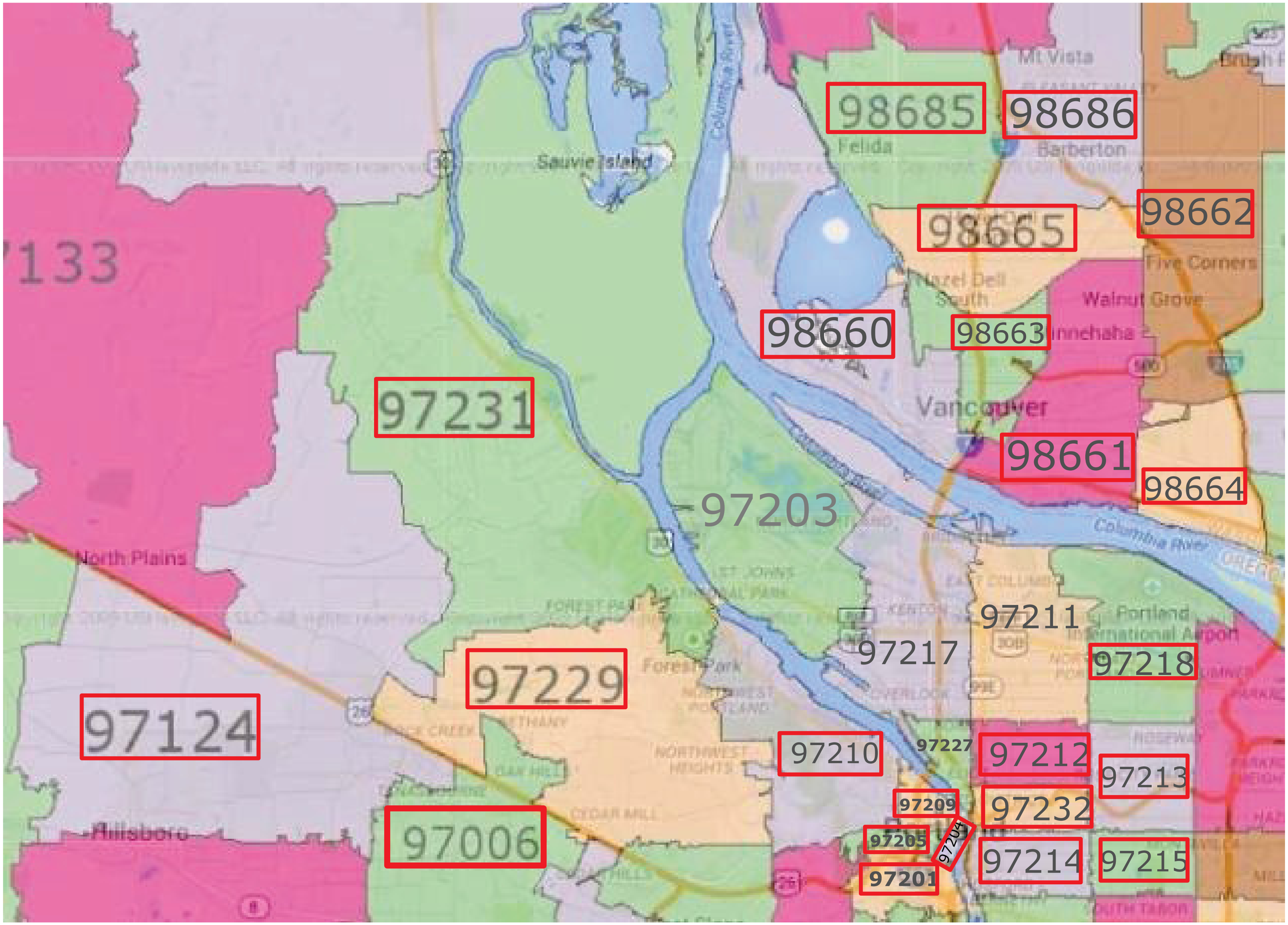


Figure I-3: Offsite Populated Areas Applied to Pembina Terminal QRA Model by Zip Code (Ref. 3)

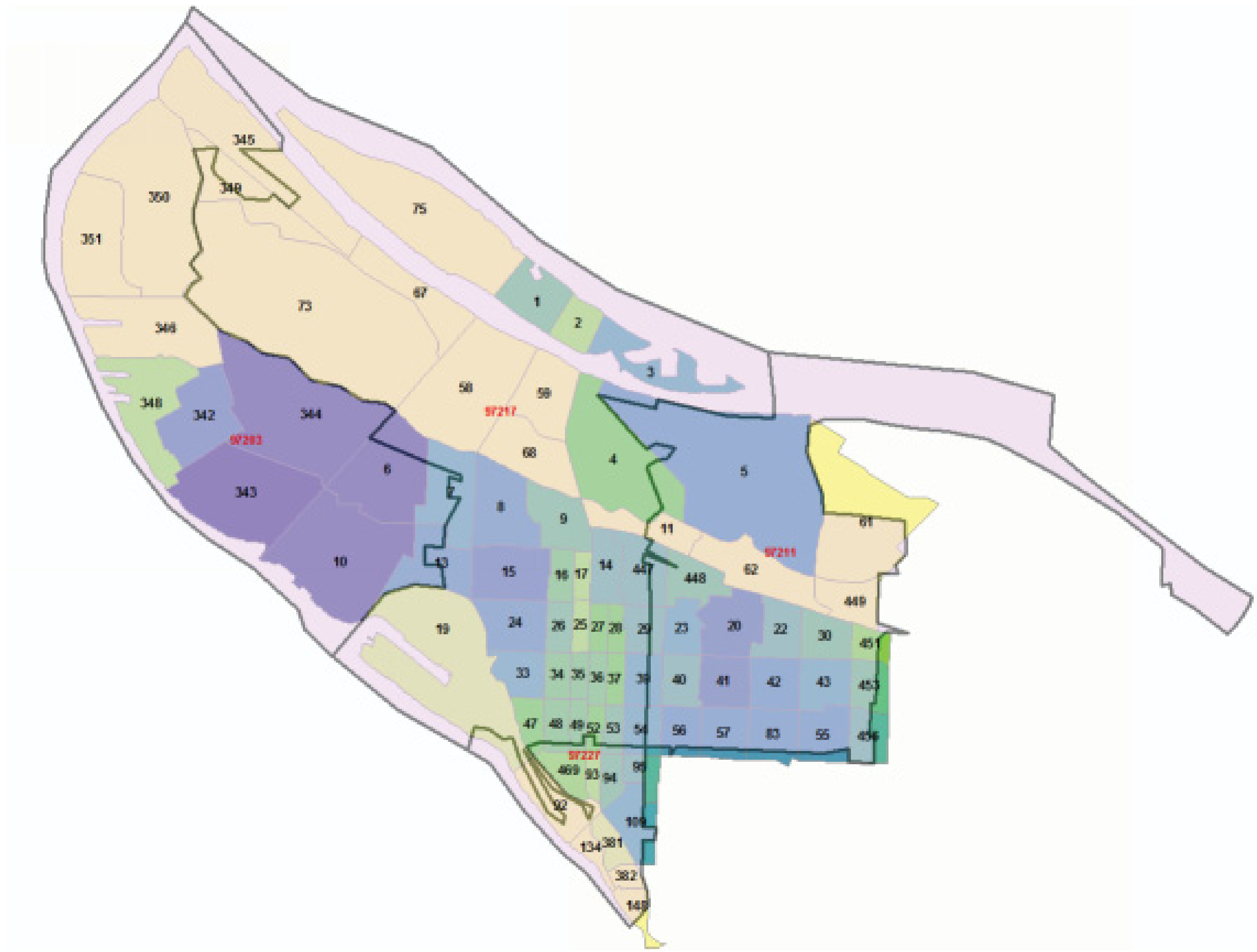


Figure I-4: Offsite Populated Areas Applied to Pembina Terminal QRA Model for Zip Codes 97203, 97217, 97211 and 97227 (Ref. 2)

I.1.5 Wind Rose

Assumption No.:	5		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA, CA	**Category:**	Design

Specifications:

Data on the wind direction, wind speed and atmospheric stability are combined to form a set of representative weather categories. The wind speed by direction is analyzed from the raw data for Pearson Airport, Vancouver WA (Ref. 1) and generates the wind rose. Pearson Airport is the closest weather station to the proposed site. The stability data is obtained for Pearson from NCDC (National Climatic Data Center) based on a 10-year average (2000-2009 (Ref. 2). Note that all calm stability weather is excluded in our wind rose and stability data processing.

- Data on distribution of wind speed and wind direction in the surroundings of Pembina terminal are presented in Table I-9, Table I-10 and Table I-11.
- The day, night, and total wind roses based on the data are presented in Figure I-5, Figure I-6 and Figure I-7. The wind roses are plotted using a freeware program WRPLOT View (Ref. 3).
- The analyzed stability class data is presented in Table I-12.
- In combining the wind rose and stability data we assume six weather categories for Pembina terminal Project. The probability of each weather category (stability and speed) is presented in Table I-13.
- The wind data input to the risk model is presented in Table I-14.

Implication of Assumption:

The weather conditions have a key influence on flammable cloud dispersion and hence the consequences associated with any release. The influence of any specific weather category and direction will vary for each and every release. Minor changes in the meteorological assumptions will have a negligible influence on the risk results.

References:

1. NOAA Weather Station: Pearson Airport, Vancouver WA (ASOS), 01/01/2005 – 12/31/2014.
2. NCDC, Stability Array, Pearson Airport, 2000 – 2009
3. WRPLOT View (freeware wind rose plots for meteorological data): http://www.weblakes.com/products/wrplot/

Comments:

Table I-9: Wind Rose Data – Day – Site Location, Normalized Probability

Direction (From)	0.5 - 2.1 m/s	2.1 - 3.6 m/s	3.6 - 5.7 m/s	5.7 - 8.8 m/s	8.8 - 11.1 m/s	>11.1 m/s	Total
N	2.54E-02	9.12E-03	4.73E-04	0.00E+00	0.00E+00	0.00E+00	**3.50E-02**
NNE	5.72E-03	1.13E-03	9.45E-05	0.00E+00	0.00E+00	0.00E+00	**6.95E-03**
NE	4.63E-03	7.56E-04	0.00E+00	9.45E-05	0.00E+00	0.00E+00	**5.48E-03**
ENE	5.95E-03	5.67E-04	9.45E-05	2.36E-04	0.00E+00	0.00E+00	**6.85E-03**
E	2.73E-02	1.61E-02	1.03E-02	7.47E-03	1.32E-03	1.89E-04	**6.27E-02**
ESE	6.03E-02	7.72E-02	4.54E-02	5.86E-03	3.31E-04	4.73E-05	**1.89E-01**
SE	5.47E-02	5.22E-02	1.69E-02	1.04E-03	0.00E+00	0.00E+00	**1.25E-01**
SSE	3.03E-02	2.31E-02	6.76E-03	4.73E-04	0.00E+00	0.00E+00	**6.07E-02**
S	3.00E-02	3.97E-02	1.98E-02	4.30E-03	3.31E-04	4.73E-05	**9.42E-02**
SSW	1.58E-02	2.12E-02	1.16E-02	1.98E-03	2.36E-04	0.00E+00	**5.09E-02**
SW	1.26E-02	1.10E-02	2.41E-03	5.67E-04	0.00E+00	0.00E+00	**2.66E-02**
WSW	1.29E-02	1.02E-02	2.13E-03	9.45E-05	0.00E+00	0.00E+00	**2.53E-02**
W	2.38E-02	1.64E-02	3.21E-03	8.51E-04	4.73E-05	0.00E+00	**4.44E-02**
WNW	3.13E-02	1.90E-02	4.54E-03	1.89E-04	0.00E+00	0.00E+00	**5.50E-02**
NW	6.74E-02	5.09E-02	7.47E-03	2.36E-04	0.00E+00	0.00E+00	**1.26E-01**
NNW	5.26E-02	3.10E-02	2.46E-03	0.00E+00	0.00E+00	0.00E+00	**8.61E-02**
Total	**4.61E-01**	**3.79E-01**	**1.34E-01**	**2.34E-02**	**2.27E-03**	**2.84E-04**	**1.00E+00**

Table I-10: Wind Rose Data – Night – Site Location, Normalized Probability

Direction (From)	0.5 - 2.1 m/s	2.1 - 3.6 m/s	3.6 - 5.7 m/s	5.7 - 8.8 m/s	8.8 - 11.1 m/s	>11.1 m/s	Total
N	1.61E-02	1.94E-02	4.51E-03	3.29E-05	0.00E+00	0.00E+00	**4.01E-02**
NNE	3.26E-03	1.61E-03	3.95E-04	0.00E+00	0.00E+00	0.00E+00	**5.27E-03**
NE	2.17E-03	6.58E-04	1.32E-04	0.00E+00	0.00E+00	0.00E+00	**2.96E-03**
ENE	4.02E-03	1.91E-03	2.07E-03	1.15E-03	0.00E+00	0.00E+00	**9.15E-03**
E	1.26E-02	1.32E-02	1.65E-02	1.39E-02	1.51E-03	4.28E-04	**5.81E-02**
ESE	2.66E-02	4.79E-02	3.54E-02	7.21E-03	3.62E-04	6.58E-05	**1.18E-01**
SE	2.81E-02	3.81E-02	1.59E-02	7.57E-04	0.00E+00	0.00E+00	**8.28E-02**
SSE	1.73E-02	2.09E-02	6.52E-03	4.28E-04	6.58E-05	0.00E+00	**4.52E-02**
S	1.83E-02	2.98E-02	1.69E-02	4.11E-03	3.29E-04	6.58E-05	**6.95E-02**
SSW	1.62E-02	2.10E-02	1.22E-02	2.17E-03	1.65E-04	0.00E+00	**5.18E-02**
SW	1.83E-02	1.63E-02	5.30E-03	7.57E-04	3.29E-05	0.00E+00	**4.07E-02**
WSW	1.73E-02	2.27E-02	6.91E-03	8.56E-04	6.58E-05	3.29E-05	**4.79E-02**
W	2.34E-02	3.69E-02	1.83E-02	4.11E-03	9.87E-05	0.00E+00	**8.28E-02**
WNW	2.15E-02	3.71E-02	2.36E-02	2.93E-03	0.00E+00	0.00E+00	**8.51E-02**
NW	3.46E-02	6.81E-02	4.78E-02	4.61E-03	3.29E-05	0.00E+00	**1.55E-01**
NNW	2.92E-02	5.29E-02	2.33E-02	5.92E-04	0.00E+00	0.00E+00	**1.06E-01**
Total	**2.89E-01**	**4.28E-01**	**2.36E-01**	**4.36E-02**	**2.67E-03**	**5.92E-04**	**1.00E+00**

Table I-11: Wind Rose Data - Total Weather Probability

Direction (From)	0.5 - 2.1 m/s	2.1 - 3.6 m/s	3.6 - 5.7 m/s	5.7 - 8.8 m/s	8.8 - 11.1 m/s	>11.1 m/s	Total
N	1.99E-02	1.52E-02	2.85E-03	1.94E-05	0.00E+00	0.00E+00	**3.80E-02**
NNE	4.27E-03	1.42E-03	2.72E-04	0.00E+00	0.00E+00	0.00E+00	**5.96E-03**
NE	3.18E-03	6.98E-04	7.76E-05	3.88E-05	0.00E+00	0.00E+00	**4.00E-03**
ENE	4.81E-03	1.36E-03	1.26E-03	7.76E-04	0.00E+00	0.00E+00	**8.21E-03**
E	1.86E-02	1.44E-02	1.40E-02	1.12E-02	1.44E-03	3.30E-04	**6.00E-02**
ESE	4.05E-02	5.99E-02	3.95E-02	6.65E-03	3.49E-04	5.82E-05	**1.47E-01**
SE	3.90E-02	4.38E-02	1.63E-02	8.73E-04	0.00E+00	0.00E+00	**1.00E-01**
SSE	2.26E-02	2.18E-02	6.62E-03	4.46E-04	3.88E-05	0.00E+00	**5.16E-02**
S	2.31E-02	3.38E-02	1.81E-02	4.19E-03	3.30E-04	5.82E-05	**7.96E-02**
SSW	1.61E-02	2.11E-02	1.20E-02	2.10E-03	1.94E-04	0.00E+00	**5.14E-02**
SW	1.60E-02	1.41E-02	4.11E-03	6.79E-04	1.94E-05	0.00E+00	**3.49E-02**
WSW	1.55E-02	1.76E-02	4.95E-03	5.43E-04	3.88E-05	1.94E-05	**3.86E-02**
W	2.36E-02	2.85E-02	1.21E-02	2.77E-03	7.76E-05	0.00E+00	**6.70E-02**
WNW	2.55E-02	2.96E-02	1.58E-02	1.80E-03	0.00E+00	0.00E+00	**7.27E-02**
NW	4.81E-02	6.11E-02	3.12E-02	2.81E-03	1.94E-05	0.00E+00	**1.43E-01**
NNW	3.88E-02	4.39E-02	1.47E-02	3.49E-04	0.00E+00	0.00E+00	**9.78E-02**
Total	**3.60E-01**	**4.08E-01**	**1.94E-01**	**3.53E-02**	**2.50E-03**	**4.66E-04**	**1.00E+00**

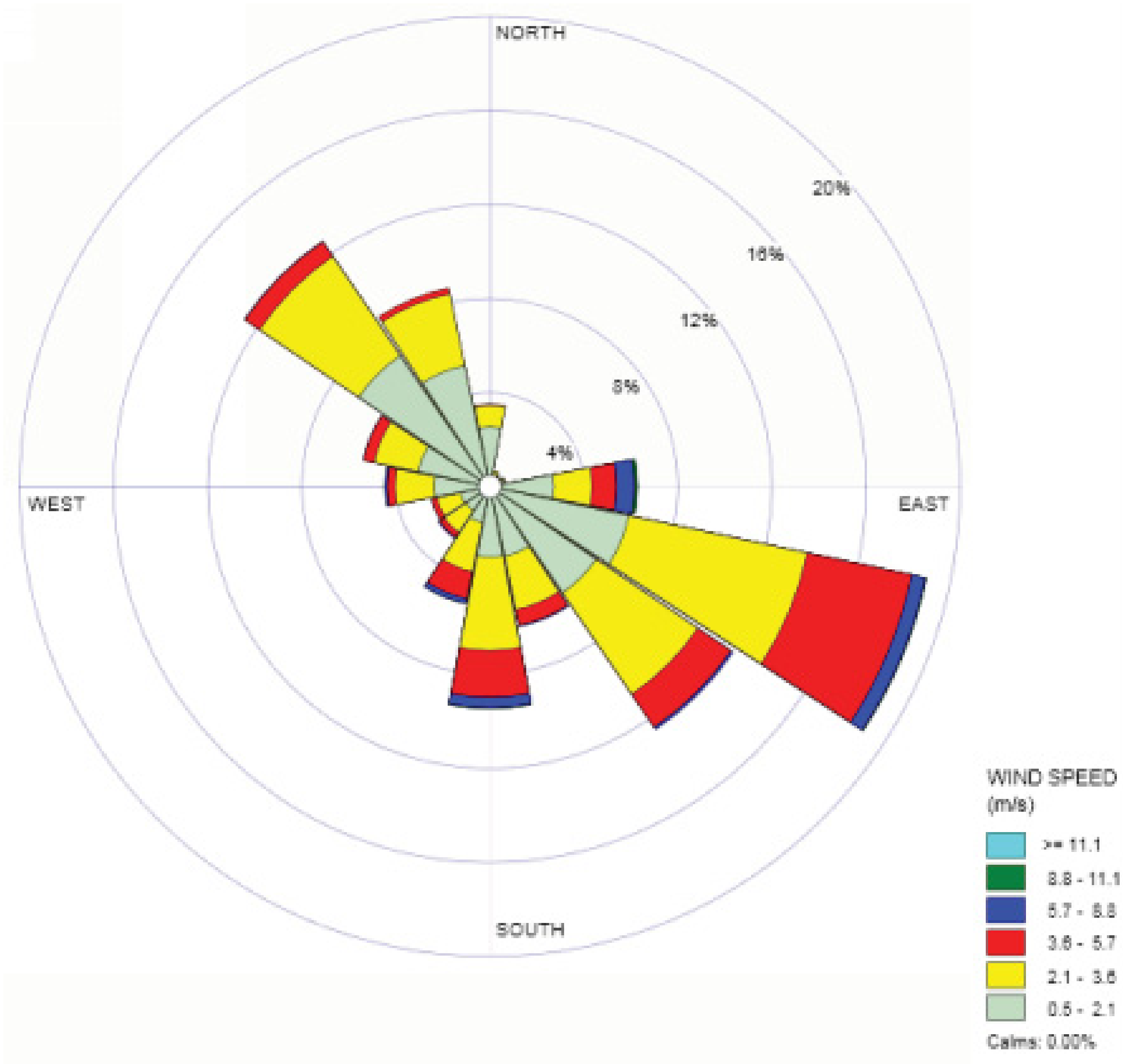


Figure I-5: Day Wind Rose, Normalized

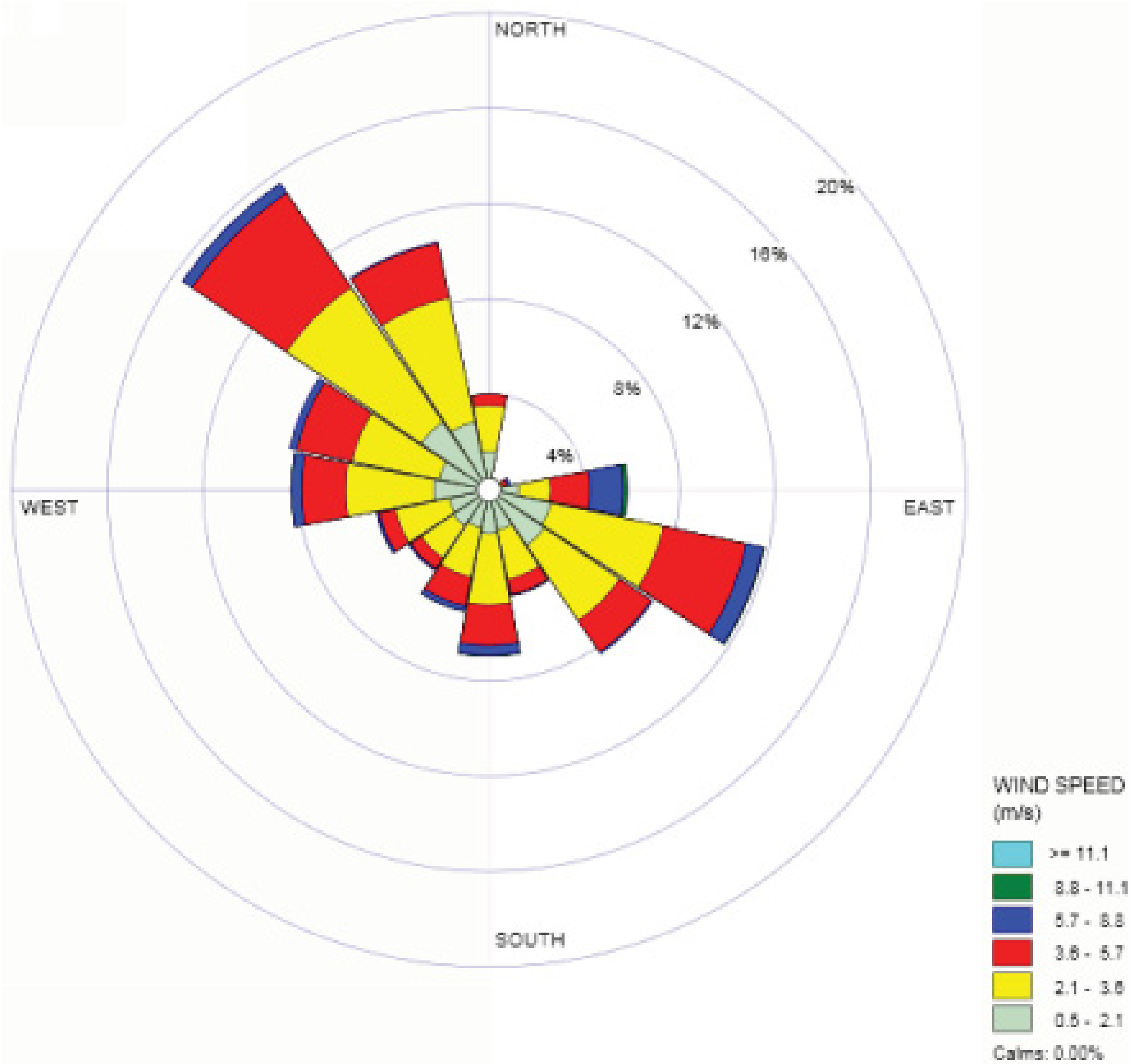


Figure I-6: Night Wind Rose, Normalized

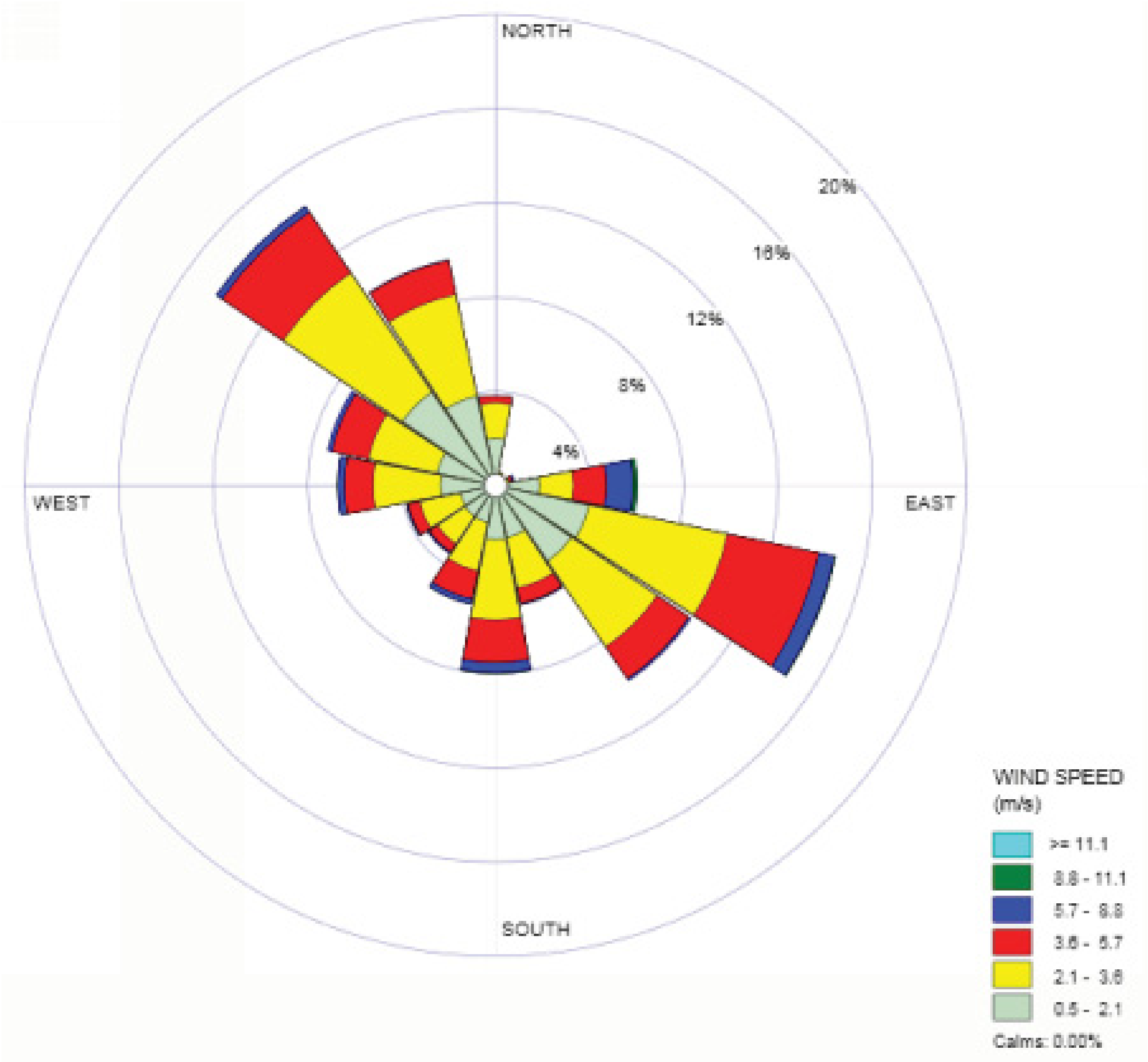


Figure I-7: **Wind Rose – Total**

Table I-12: Stability Class Distribution, Pearson Field (Ref. 2)

Wind Speed (knot)	Pasquill Stability Class								Total
	A	B	C	D-Day	D-Night	E	F	G	
0-3	6.00E-04	1.83E-02	1.02E-02	2.66E-02	4.51E-02	0.00E+00	1.58E-02	3.83E-02	0.155
4-6	4.30E-03	4.61E-02	4.78E-02	1.17E-01	1.11E-01	3.98E-02	9.19E-02	0.00E+00	0.458
7-10	0.00E+00	2.51E-02	5.77E-02	9.33E-02	9.08E-02	4.84E-02	0.00E+00	0.00E+00	0.315
11-16	0.00E+00	0.00E+00	3.80E-03	3.62E-02	2.68E-02	0.00E+00	0.00E+00	0.00E+00	0.067
17-21	0.00E+00	0.00E+00	3.91E-05	2.70E-03	2.10E-03	0.00E+00	0.00E+00	0.00E+00	0.005
21+	0.00E+00	0.00E+00	0.00E+00	3.00E-04	9.78E-05	0.00E+00	0.00E+00	0.00E+00	<0.001
Total	0.005	0.090	0.120	0.276	0.276	0.088	0.108	0.038	**1.000**

Table I-13: Representative Weather Categories for Pembina

	From Analysis			To be modeled		
	Representative Stability Class	**Average wind speed (m/s)**	**Fraction**	**Representative Stability Class**	**Average wind speed (m/s)**	**Fraction**
Day	B	1.8	0.132	B	1.8	0.132
	C/D	2.2	0.355	C/D	2.2	0.355
	D	7.2	0.013	D	7.2	0.013
Night*	D	2.7	0.241	D	2.9	0.317
	D	7.2	0.023			
	E	3.5	0.076	D	7.2	0.023
	F	2.2	0.104	F	1.8	0.160
	G	1.0	0.056			
Total			1.000	Total		1.000

* D 2.7 m/s and E 3.5 m/s weather categories are combined and represented as D stability, 2.9 m/s wind speed. F and G weather categories are combined and represented as F stability, 1.8 m/s wind speed.

Table I-14: Weather Data Input into QRA Model

Day	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
B	1.08E-02	2.22E-03	1.75E-03	2.17E-03	1.45E-02	4.50E-02	3.32E-02	1.67E-02	2.23E-02	1.20E-02	7.20E-03	7.08E-03	1.24E-02	1.57E-02	3.59E-02	2.55E-02
C/D	2.42E-02	4.73E-03	3.64E-03	4.45E-03	3.92E-02	1.38E-01	9.05E-02	4.35E-02	6.72E-02	3.66E-02	1.88E-02	1.82E-02	3.11E-02	3.91E-02	8.99E-02	6.06E-02
D	0.00E+00	0.00E+00	9.45E-05	2.36E-04	8.98E-03	6.24E-03	1.04E-03	4.73E-04	4.68E-03	2.22E-03	5.67E-04	9.45E-05	8.98E-04	1.89E-04	2.36E-04	0.00E+00
Night	**N**	**NNE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**	**S**	**SSW**	**SW**	**WSW**	**W**	**WNW**	**NW**	**NNW**
D	2.39E-02	2.88E-03	1.53E-03	5.09E-03	3.04E-02	7.73E-02	5.23E-02	2.74E-02	4.37E-02	3.26E-02	2.37E-02	2.89E-02	5.19E-02	5.64E-02	1.06E-01	6.94E-02
D	3.29E-05	0.00E+00	0.00E+00	1.15E-03	1.58E-02	7.64E-03	7.57E-04	4.94E-04	4.51E-03	2.34E-03	7.90E-04	9.55E-04	4.21E-03	2.93E-03	4.64E-03	5.92E-04
F	1.61E-02	2.39E-03	1.43E-03	2.91E-03	1.19E-02	3.27E-02	2.97E-02	1.73E-02	2.12E-02	1.68E-02	1.61E-02	1.81E-02	2.67E-02	2.58E-02	4.46E-02	3.60E-02

I.1.6 Meteorological Data

Assumption No.:	6		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA, CA	**Category:**	Design

Specifications

In addition to the weather categories, certain meteorological constants are defined as inputs to the consequence modeling. These values are summarized below and are taken from the design document (Ref. 1):

Parameter	Value	Notes and References
Atmospheric temperature	35 F (Winter) 82 F (Summer)	Based on ambient temperatures quoted in the project design data (Ref. 1). Note that this has a relatively minor influence on the dispersion characteristics (although there is some influence on the buoyancy of gas clouds).
Atmospheric pressure	1.019 bar (14.774 psia)	Based on average atmospheric pressure. Negligible influence on dispersion / consequence results.
Relative humidity	69% (Winter) 40% (Summer)	The data are taken from www.weathspark.com (Ref. 1). Based on average yearly humidity. The relative humidity typically ranges from 40% (comfortable) to 95% (very humid) over the course of the year. This has a relatively minor influence on the dispersion of buoyant gases, but can significantly affect the dispersion range of vapor generated from propane spills (which are sensitive to the heat transfer from airborne moisture).
Surface temperature	35 F (Winter) 82 F (Summer)	Same as atmospheric temperature.
Surface roughness parameter	0.1	Land value (0.3) is appropriate for open flat terrain with grass and few isolated objects. Water value (0.05) is applied for coastal waters. 0.1 is used as an average.
Solar flux	Day - 266 W/m^2 Night – 4 W/m^2	Solar radiation of 266 W/m^2 is applied for the day weather and 4 W/m^2 is applied for the night weather based on the average solar radiation for Washington State University, nine miles from Portland (Ref. 2)
Wind speed reference height	10 m	Standard for meteorological measurements.

Implication of Assumption:

The dispersion and consequences associated with propane are relatively sensitive to assumptions affecting the heat transfer to the cloud. Hence, the above values are relatively conservative representative conditions, but will not necessarily correspond to the worst-case dispersion conditions that may occur.

I.1.6 Meteorological Data

Assumption No.:	6

References:

1. Basic Engineering Design Data (BEDD) – Pembina Propane Terminal Project (14088D), Doc. No. 14088D-PR-DB-0000-001, Rev. A, date: October 20, 2014.
2. AgWeatherNet (http://weather.wsu.edu/awn.php) at 45.677726N, 122.651280W (WSU Vancouver RE, Vancouver, Clark County)

Comments

I.1.7 Ignition Probability Calculation Method

Assumption No.:	7		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA, CA	**Category:**	Analytical

Specifications

Information is required about the ignition sources, which are present in the area over which a flammable cloud may drift, to calculate the risk from flammable materials. For each ignition source considered, the following factors need to be specified:

- **Location**
  This allows the position of the source relative to the location of each release to be calculated. The results of the dispersion calculations for each flammable release are then used to determine the size and mass of the cloud when it reaches the source of ignition.
- **Presence Factor**
  This is the probability that an ignition source is active at a particular location.
- **Ignition Factor**
  This defines the "strength" of an ignition source. It is derived from the probability that a source ignites a cloud if the cloud is present over the source for a particular length of time.

If these three factors are known for each source of ignition considered, then the probability of a flammable cloud being ignited as it moves downwind over the sources can be calculated.

Operation:

The basis for determining the on-site ignition probabilities within the Pembina Propane Export Terminal is taken from the method developed by Atkins (Ref. 1). Atkins onsite ignition model is an area-based approach, which assesses the ignition probability for drifting vapor clouds over onsite areas. The model uses a grid system to address the various land use and ignition source characteristics (ignition potential, ignition source density, the frequency at which the source becomes active, and the probability of the source being active) within the path of the vapor cloud. The model determines the time the cloud takes to pass over the various ignition sources, and hence chance of ignition within the time window.

Generic estimated ignition source parameters given in the Atkins On-site Ignition Probabilities study represent those for typical industrial activities, including plants with light, medium, and heavy equipment levels, utilities areas, etc. with typical level of ignition control. The modified ignition probabilities are also proposed within the study with respect to the quality of ignition controls.

The Pembina Propane Export Terminal is assumed to be a modern, best-practice onshore facility with respect to onsite equipment, material handling as well as ignition control,. Hence the recommended ignition probabilities for this analysis fall into the "ignition source parameters with 'good' ignition controls" category proposed in Atkins ignition model (see Table I-15).

I.1.7 Ignition Probability Calculation Method

Assumption No.: 7

Table I-15: Atkins Area Ignition Probability Data with Ignition Controls

Land-use Type	Ignition Source	Ignition Probability (Typical Control)	Ignition Probability (Good Control)	Ignition Probability (Poor Control)
Parking Lot	'Rush hour' vehicles	0.2	0.2	0.3
	'Other' vehicles	0.2	0.2	0.3
	Smoking	1	0	1
Road Area	'Rush hour' vehicles	0.1	0.1	0.2
	'Other' vehicles	0.1	0.1	0.2
	'Delivery' vehicles	0.1	0.1	0.2
	Traffic control	1	0	1
Controlled Roads	'Delivery' vehicles	0.2	0.2	0.2
Boiler House	Boiler	1	0.5	1
Flames	Continuous, indoors	1	0.5	1
	Continuous, outdoors	1	0.5	1
	Infrequent, indoors	1	0.5	1
	Infrequent, outdoors	1	0.5	1
	Intermittent, indoors	1	0.5	1
	Intermittent, outdoors	1	0.5	1
Facility Areas	'Heavy' equipment levels	0.5	0.2	1
	'Medium' equipment level	0.25	0.1	0.5
	'Light' equipment levels	0.1	0	0.2
Classified Areas	None	0	0	0.05
Classified Areas (External)	Material handling	0.05	0.05	0.1
Storage (External)	Material handling	0.1	0.1	0.1
Office	'Light' equipment level	0.05	0.05	0.05

Implication of Assumption:

Key influence in determining the likelihood of flash fire and explosion hazards and the extent of each (i.e. time of ignition relative to size of cloud).

References:

1. UK HSE, "Development of a method for the determination of on-site ignition probabilities", WS Atkins Consultants Ltd., Research Report 226, 2004.

Comments:

I.1.8 Ignition Sources - People

Assumption No.:	8		
Revision:	0	**Prepared by:**	WHON 2015-02-10
Date:	February 10 2015	**Verified by:**	CSPI 2015-02-10
Relevant Analysis:	QRA	**Category:**	Analytical

Specifications:

The presence and activities of personnel that may contribute to ignition are already accounted for within the Atkins ignition model (Ref. 1).

The default value assigned within Phast Risk for the ignition source associated with onsite people is adjusted to zero to eliminate potential double-counting of contribution of personnel towards ignition potential.

The ignition source associated with offsite population is set to 1.68E-4 per person per second of cloud exposure as suggested by Purple book (Ref. 2). This value has been derived to account for the probability of ignition associated with people in general, and includes an allowance for smoking and general human behavior associated with residential areas.

Implication of Assumption:

Key influence in determining the likelihood of flash fire and explosion hazards and the extent of each (i.e. time of ignition relative to size of cloud).

References:

1. UK HSE, "Development of a method for the determination of on-site ignition probabilities", WS Atkins Consultants Ltd., Research Report 226, 2004.
2. RIVM, Guidelines for Quantitative Risk Assessment (Purple Book) Part one: Establishments.

Comments:

I.1.9 Site-Specific Delayed Ignition Locations and Probabilities

Assumption No.:	9		
Revision:	3	**Prepared by:**	WHON 2015-03-30
Date:	30 March 2015	**Verified by:**	CSPI 2015-03-30
Relevant Analysis:	QRA	**Category:**	Analytical, Operational

Specifications:

The onsite ignition sources considered in this QRA study are based on available project documentation such as PFDs and Plot Plans, specifying type and location of each onsite ignition source in relation to the Atkins ignition model areas.

Figure I-7 presents the locations of the onsite specific ignition sources / areas on the Pembina terminal plot plan and Figure I-8 presents the locations of the offsite ignition sources / areas to the Pembina terminal. The ignition probabilities for each identified ignition source are determined based on the ignition probability value from the Atkins onsite ignition probability study (Ref. 1). Table I-13 defines site specific ignition sources/areas and their relevant ignition probability input adopted in Phast Risk for the Pembina Propane Export Terminal.

The ignition probability from the propane carrier is reflected as present or not for the different situations as relevant, such as no ship or ship present.

A generic ignition source is specified for the channel to represent ship traffic.

Additional offsite ignition sources have been defined for industrial areas near the terminal.

Offsite populations have ignition potential based on the population density, refer to Assumption No. 7.

Implication of Assumption:

Key influence in determining the likelihood of flash fire and explosion hazards and the extent of each (i.e. time of ignition relative to size of cloud). The overall effect is that there are many low ignition probability sources defined, rather than combining as one overall ignition source area.

References:

1. UK HSE, "Development of a method for the determination of on-site ignition probabilities", WS Atkins Consultants Ltd., Research Report 226, 2004.
2. Pembina Propane Project Plot Plan – 14088D-PI-PP-00000-001, Rev. B

Comments:

Table I-16: Ignition Sources and Probability of Ignition

Identifier		Type	Source	Elev. (m)	Atkins Ignition Source Category	*p* - Ignition Prob.	*a* - Operating Prob.	*μ* - area (per hectare)
Red	1	Equipment	Fire Water Pumps	0.3	Facility Medium equip.	0.1	1	50
	2		Propane Unloading Compressor	0.3	Facility Medium equip.	0.1	1	50
	3		Propane Feed Pumps	0.3	Facility Medium equip.	0.1	1	50
	4		Propane Refrigerant Compressor 1	0.3	Facility Heavy equip.	0.2	1	50
	5		Propane Refrigerant Compressor 2	0.3	Facility Heavy equip.	0.2	1	50
	6		Propane Rundown Pumps 1	0.3	Facility Medium equip.	0.1	1	50
	7		Propane Rundown Pumps 2	0.3	Facility Medium equip.	0.1	1	50
	8		Propane Refrigerant Air Cooler 1	0.3	Facility Medium equip.	0.1	1	50
	9		Propane Refrigerant Air Cooler 2	0.3	Facility Medium equip.	0.1	1	50
	10		Boil of Gas Compressor	0.3	Facility Heavy equip.	0.2	1	50
	11		Boil of Gas Air Cooler	0.3	Facility Medium equip.	0.1	1	50
	12		Emergency Generator Package	0.3	Facility Heavy equip.	0.2	1	50
	13		Flare	68.6	Flame, Continuous, outdoors	0.5	1	200
Blue	14	Buildings	Administration Building	0.3	Office area	0.05	1	20
	15		MCC	0.3	Office area	0.05	1	20
	16		Control Room/Warehouse	0.3	Office area	0.05	1	20
	17		Jetty	0.3	Office area	0.05	1	20
	18		Parking Lot at Control Room	0.3	Car park, other vehicles	0.2	0.1	3
	19		Parking Lot at Admin. Building	0.3	Car park, other vehicles	0.2	0.1	3
Orange	20	Traffic Roads	Traffic Road 1	1	Controlled roads	0.2	0.2	20
	21		Traffic Road 2	1	Controlled roads	0.2	0.2	20
	22		Railcar Tracks	1	Controlled roads	0.2	0.2	20
Green	23	Power Lines	Power Line 1	30	Process Light equip.	0.04	1	50
	24		Power Line 2	30	Process Light equip.	0.04	1	50
	25	Substation	Substation	0.3	Process Light equip.	0.04	1	50
Black	26	Marine Terminal	Propane Carrier*	0	Car park, other vehicles	0.2	1	3
Purple	27	Offsite Sources	Parking Lot, North of the Facility	0.3	Car park, other vehicles	0.2	0.1	3
	28		Parking Lot, South of the Facility	0.3	Car park, other vehicles	0.2	0.1	3
	29		Parking Lot, East of the Facility	0.3	Car park, other vehicles	0.2	0.1	3
	30		Water traffic	0.3	Road, other vehicles	0.1	0.1	3
	31		Truck Transfer Warehouse	0.3	Office area	0.05	1	20

Note - The ignition probability from the Propane carrier is reflected as present or not for the different situations as relevant, such as no ship or ship present.

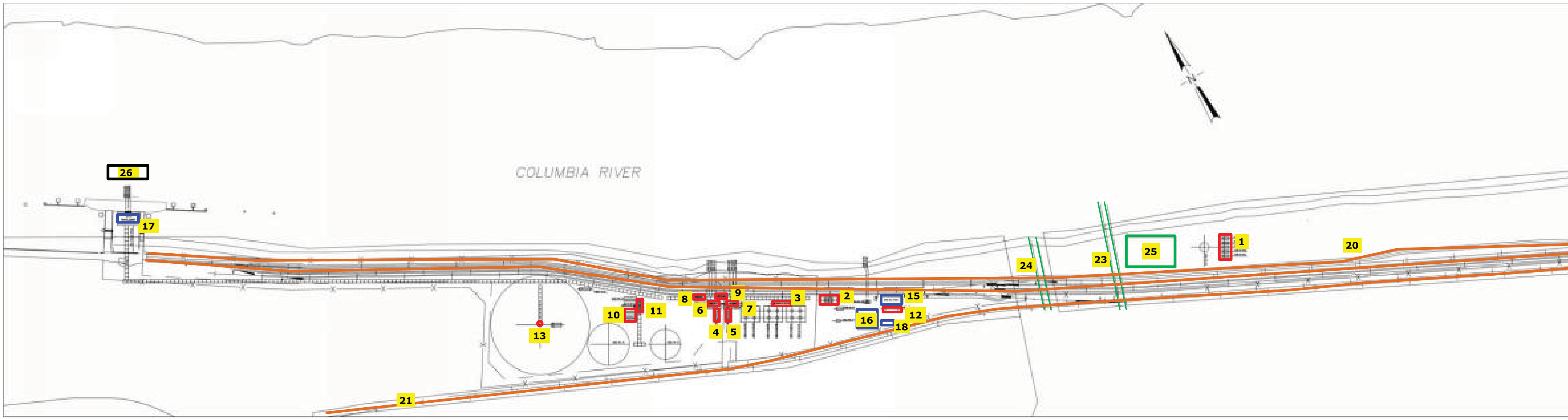


Figure I-8: Ignition Source Areas Applied to Pembina Propane Export Terminal QRA Model – part 1

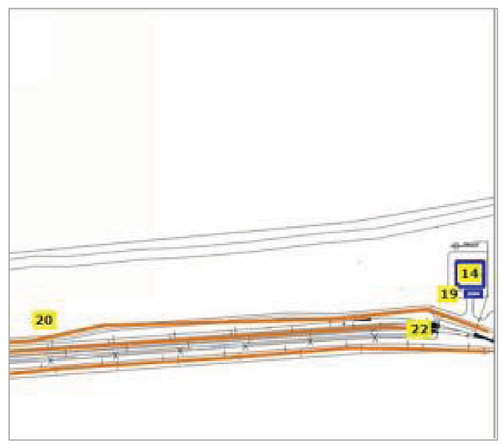


Figure I-9: Ignition Source Areas Applied to Pembina Propane Export Terminal QRA Model – part 2

Figure I-10: Offsite Ignition Source Areas Applied to Pembina Propane Export Terminal QRA Model (refer to Table I-16)

I.2 Release Scenario Definition

I.2.1 Inventory

Assumption No.:	10		
Revision:	1	**Prepared by:**	WHON
			2015-02-24
Date:	24 February 10 2015	**Verified by:**	CSPI
			2015-02-24
Relevant Analysis:	QRA, CA	**Category:**	Design

Specifications:

The quantity of material available to be released in the event of a leak is specific to each isolatable segment. Key assumptions that apply to the analysis in general are the following:

- The static inventory associated with each isolatable segment is defined as the mass within each segment under normal operating conditions.
- Total inventory is calculated as a sum of static inventory and dynamic inventory of isolatable segments. Static inventory is based on vessel and piping dimensions. Dynamic inventory is based on normal flow rate of the representative stream for the duration till isolation.
- The vapor inventory defined for each section includes an estimate of the quantity of gas that would flash from any associated liquid inventory (based on the operating temperature).
- The normal operation fill levels from each vessel are taken from design drawings (Ref. 1).
- If normal fill levels are not available, the following assumptions on the fill fraction of each equipment are applied (Ref. 2):
  - The liquid fill fraction of horizontal vessels is generally taken as 0.5.
  - Drums and other vessels that are primarily filled with gas (e.g. compressor suction drums) or liquid (e.g. refrigerant drums) are conservatively treated as 100% gas or liquid, respectively.

Estimates of the inventory associated with pipework, filters and heat exchangers are included within the inventory of each section.

Implication of Assumption:

The inventory available for release is based on isolation success or failure. In the isolation success case the release duration is determined by the isolation time, the release rate, and the available static inventory to be released after isolation; in the isolation failure case the release is assumed to last at least an hour. The inventory is a key parameter with respect to the detailed modeling of each scenario. However, any specific inventory assumption will have limited influence on the overall risks given that there are many scenarios modeled and each scenario is a small contribution to the total risk result.

I.2.1 Inventory

Assumption No.:	10

References:

1. PFDs rev A1, provided by Pembina Propane Terminal.
2. DNV GL expert judgment.

Comments:

I.2.2 Release Location/Height/Direction

Assumption No.:	11		
Revision:	2	**Prepared by:**	WHON 2015-03-07
Date:	7 March 2015	**Verified by:**	CSPI 2015-03-07
Relevant Analysis:	QRA & CA	**Category:**	Design

Specifications:

Location

A representative release location for each release scenario is derived from the plot plan of the respective area. The location is generally selected as that of the vessel containing the main inventory of the isolatable section or, where a number of vessels apply, as the center of the section.

Height

The representative release height from standard equipment has a default value of 1 m above the ground. It is considered that the majority of the equipment / fittings (where a higher leak frequency is anticipated) are located close to the ground level.

Since all entries to the refrigerated storage tanks are through the roof of the tank, the representative release height from the refrigerated storage tank is 40.8 m (the height of the storage tank: 134') above the ground.

All populations are assumed distributed on the ground level.

Direction

All releases are modeled in a horizontal orientation as a conservative estimate. Other release directions are less conservative and not modelled. Jet fires are conservatively treated as horizontal, and effectively unobstructed in all cases.

Implication on Assumption:

A change of release height will have impact on the consequence results. The current assumption tends to lead to slightly conservative impacts to personnel, since a proportion of the releases will, in reality, occur from elevations where the gas cloud do not have the potential to reach personnel or ignition sources at ground level in surrounding areas.

References:

1. DNV GL expert judgment

Comments:

I.2.3 Release Sizes

Assumption No.:	12		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA, CA	**Category:**	Design

Specifications:

Leak data is presented in most databases as a distribution. For use in a QRA, the distribution is split into representative hole sizes and ranges. Several approaches exist for doing this with the most common being where each range is represented by the upper limit of the range; or by a representative size within the range. For this study, the average representative size of the range is applied.

To define the hazardous release events applied to each standard equipment release scenario, four hole-size distributions with representative hole sizes are modeled as listed below (Ref. 1). Note that the range of hole sizes and representative size are based on standard industry practice.

Size Category	Size (mm)	Representative Hole Size for Range (mm)
Small	3 - 25	10
Medium	25 - 75	50
Large	75 - 125	100
Rupture	125 - Line diameter	Line diameter (if applicable)

Refer to Assumptions 30 and 31 for the release sizes modeled for the propane pressure storage tanks and refrigerated storage tanks, respectively.

Implication on Assumption:

The release size selected as representative is a key factor in the release parameters and subsequent consequences for each case. However, the use of representative releases is inherent in QRA and the frequencies are assigned according to each of the defined leak size ranges. Nevertheless, the representative nature of each release size should be recognized.

References:

1. DNV GL expert judgment.

Comments:

I.2.4 Detection, Isolation Philosophy (Propane Facility)

Assumption No.:	13		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA	**Category:**	Operational, Analytical

Specifications:

Facility ESD:

Local emergency isolation block valves are provided around each major piece of equipment such as each major compressor, around each individual pressure storage vessel (offload storage from rail cars), and each refrigerated tank (Ref. 1).

The activation of ESD is designed to be triggered automatically on overpressure set points and fire / gas detection levels, which operator will not be able to override.

Detection and Isolation Time:

Given that ESDs are designed mainly to be activated manually, the key factor in determining whether and when isolation occurs is the human factor aspect of the operator's response to the alarm. This can only be quantified as a representative detection and isolation time.

The times required to detect a release and then to initiate isolation and blowdown are summarized in the table below, which gives the representative times assumed for isolation events. Longer detection and isolation times are required for relatively "smaller" events assuming that "smaller" events may take time to investigate before activating isolation versus "larger" events, which would bring immediate attention and response to activate isolation. Blow down relief systems to flare is designed to drop the pressure in the equipment by half within 15 min (Ref. 1).

The following tables present the total isolation time to address events at different locations in the facility, depending on the detection level.

I.2.4 Detection, Isolation Philosophy (Propane Facility)

Assumption No.:	13

Representative Detection and Response Times*(Main Facility and Jetty):

Leak Size	Response Time (min)		Cumulative Time to Isolation (min)
	Detection	Isolation	
Small	5	1	6
Medium	5	1	6
Large	2	1	3
Rupture	1	1	2

Representative Detection and Response Times*(Aboveground Pipe Locations):

Leak Size	Response Time (min)		Cumulative Time to Isolation (min)
	Detection	Isolation	
Small	15	5	20
Medium	5	5	10
Large	2	1	3
Rupture	1	1	2

* **Definition of Response Time Categories**

A release event occurs at time = 0s.

Detection: This is the time from when the release event starts till someone (or detector) becomes aware of the release event. This may be the time for an operator in the field to detect the release or for the release cloud to trigger the gas detector alarms in the control room, further alerting the operator in the control room.

Isolation: This is the time from detection till the segment is isolated and the shutdown valves are closed. This period of time includes the time for operators to discuss the situation and decide whether to activate isolation and shutdown. This also includes the time for an operator to push the isolation / shutdown button and for the valves to close.

Implication on Assumption:

The detection and isolation assumptions influence the release duration. The inventory is a key parameter with respect to the detailed modeling of each scenario.

References:

1. Email from Chris Hayes. January 24 2015

Comments:

I.3 Frequency Analysis

I.3.1 Leak Frequency – Facility Equipment

Assumption No.:	14		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA	**Category:**	Analytical

Specifications:

Generic leak frequencies

The generic failure data used as the basis for the frequency analysis through the LEAK software (v3.3) is the UK HSE's Hydrocarbon Release Database, or HCRD (Ref. 1). Note that the HCRD generic data is applied to all onshore sections of the plant.

The majority of release events considered for risk analysis are meant to be released at normal operating conditions, or "full" pressure conditions. Experience within the oil and gas industry has shown that a significant proportion of incidents result in smaller releases than would be predicted using the data directly, due to incidents occurring during maintenance ("zero pressure" release) or due to the influence of local isolation prior to ESD activation ("limited" release). A Joint Industry Project (Ref. 2) provides detailed analysis of the proportion of leaks that are either "limited" or "zero pressure" releases. In the current project the "full" pressure leaks, which include both the "full" volume leak and "limited" volume leak are applied.

Parts-count

The frequency analysis will be conducted at a "PFD" level for the different sections identified. This entails counting only the major equipment items (from the PFDs) and the major valves, flanges and small-bore fittings. Note that since this approach is less detailed than on a "P&ID" level, a factor of 2 will be applied to the frequency result.

Inter-unit piping & Loading lines

Facility piping failure frequencies are applied to estimate the inter-unit piping and loading line release frequencies. It is widely accepted that the application of facility pipework failure data tends to give overly conservative values with respect to longer inter-unit pipe segments, particularly for loading lines. Based on discussions from previous QRA studies for a range of operators, and drawing from operations experience, it is considered appropriate to apply a factor of 10 reduction (multiply by 0.1) to the estimated frequency for inter-unit piping (Ref. 3).

It should also be noted that the generic frequency data is not modified to account for dropped objects. The generic data includes leaks from all causes, including dropped objects, such that additional dropped object risks should only be included where identified as a particular hazard or potential leak cause.

Implication on Assumption:

Key influence on the risks (i.e. risk is directly proportional to frequency).

I.3.1 Leak Frequency – Facility Equipment

Assumption No.:	14

References:

1. HSE, 2010. Offshore Hydrocarbon Release Statistics, HSE Offshore Safety Division (OSD), March 2010.
2. DNV, 2009. Offshore QRA Standardized Hydrocarbon Leak Frequencies (for Hydro ASA), DNV Report No. 2008-1768, Revision 0, January 2009.
3. DNV GL internal expert judgment

Comments:

I.3.2 Isolation Failure

Assumption No.:	15		
Revision:	0	**Prepared by:**	WHON 2015-02-10
Date:	February 10 2015	**Verified by:**	CSPI 2015-02-10
Relevant Analysis:	QRA	**Category:**	Analytical

Specifications:

For simplification, isolation failure scenarios are not considered and modelled.

If applicable, isolation failure may be included in the sensitivity modelling.

Implication on Assumption:

The probability of isolation (and blow down) failure has a key influence on the frequency of release events that have sufficient duration to lead to escalation.

References:

1. IEC 61508-1, Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 1: General requirements, Edition 2.0, 2010-04.

Comments:

I.3.3 Immediate Ignition Probabilities

Assumption No.:	16		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA	**Category:**	Analytical

Specifications:

Immediate Ignition Probability from Release

Immediate ignition takes place when there is an active ignition source present at where the release happens. In this study, the immediate ignition probability is calculated from the total estimated ignition probability for propane releases (Ref. 1) from the UKOOA look-up correlations, published in the Energy Institute report.

The UKOOA look-up correlations (Ref. 2) which relate ignition probabilities in air to release rates for typical scenarios both onshore and offshore are used to estimate the total ignition probability of a propane release. The relative probabilities of ignition of 0.24, which applies for releases happening at the jetty and above ground pipes within the first second of release, and 0.22, which applies for releases happening at the facility, are applied to estimate the immediate ignition probability in this study (Ref. 1).

Therefore, the immediate ignition probability can be calculated as,

Jetty and above ground pipes: $P_{immediate} = P_{total} \times 0.24$,

Facility: $P_{immediate} = P_{total} \times 0.22$,

Where, P_{total} is calculated from UKOOA look-up table (Ref. 3).

Implication on Assumption:

The immediate ignition probability has a direct influence on the risks associated with jet and pool fire risks to personnel (and to assets). The immediate ignition probability also directly affects the potential reduction of flammable cloud and explosion hazards.

References:

1. IP Research Report – Ignition Probability Review, Model Development and Look-Up Correlations, January 2006, Energy Institute, London
2. OGP Risk Assessment Data Directory – Ignition Probabilities, Report No. 434-6.1, March 2010, International Association of Oil & Gas Producers
3. UKOOA/HSE/EI Look-up Correlation Workbook (Version D1), ESR Technology (formerly the Engineering Safety and Risk Business of AEA Technology).

Comments:

I.3.4 Isolation of Ignition Sources

Assumption No.:	17		
Revision:	0	**Prepared by:**	WHON 2015-02-10
Date:	February 10 2015	**Verified by:**	CSPI 2015-02-10
Relevant Analysis:	QRA	**Category:**	Operational, Analytical

Specifications:

The Atkins ignition model already takes into account ignition source control measures, thus no further calculations are performed to reflect the impact of the ignition isolation.

Refer to Assumption I.1.7. Pembina facility is assumed to be a modern, best-practice onshore facility, the ignition probabilities for the analysis fall into the "ignition source parameters with 'good' ignition controls" category from the Atkins ignition model.

Implication on Assumption:

Overall effect of the various ignition sources has a key influence on the risk from delayed ignition hazards.

References:

1. UK HSE, "Development of a method for the determination of on-site ignition probabilities", WS Atkins Consultants Ltd., Research Report 226, 2004.

Comments:

I.4 Consequence Modeling

I.4.1 Release/Discharge Parameters: Release Rate

Assumption No.:	18		
Revision:	0	**Prepared by:**	WHON 2015-02-10
Date:	February 10 2015	**Verified by:**	CSPI 2015-02-10
Relevant Analysis:	QRA & CA	**Category:**	Analytical

Specifications:

The representative release rate, Q (kg/s), selected in each case is generally taken as the initial maximum release rate, Qo (kg/s), which is calculated within the Phast discharge model. However, certain key scenarios are considered where the representative release rate is adjusted from the initial maximum Qo:

- If the initial maximum release rate, Qo, is very large (greater than 2 x NFR [normal flow rate]) the initial peak release rate is very short in duration and hence, the representative release rate (to be considered in Phast) is instead based on the average rate over the first minute. This typically results in Q being between 1/4 and 2/3 of Qo, where any residual release at the inflow rate (after depletion of the segment inventory, before isolation occurs) hasa negligible impact in comparison to this initial release.
- For less substantial releases (i.e. Qo lower than 2 x NFR) the representative release rate is taken as the initial peak rate (i.e. Q = Qo). Where Qo is greater than the inflow rate, this assumption is conservative and compensates for the likelihood of a longer duration residual release at the NFR.
- The above considerations apply where the initial release is driven by the inventory of the segment, or by that of a specific vessel. Where releases occur downstream of a pump, expansion turbine or compressor, the release rate is typically driven by the normal flow rate of the section in forward flow. Therefore, where back-flow from the upstream inventory is not credible, the release rate (Q) is capped at a maximum of 125% of the inflow rate, i.e. Q = 1.25 x NFR.

Implication of Assumption:

The selection of a representative release rate is a key assumption in ensuring that the model is as realistic as possible in reflecting the likely consequences. The release rate directly impacts the modeled duration and released inventory.

References:

1. DNV GL expert judgment – using Phast Risk defaults and DNV GL Technical data

Comments:

I.4.2 Release/Discharge Parameters: Release Duration

Assumption No.:	19		
Revision:	0	**Prepared by:**	WHON 2015-02-10
Date:	February 10 2015	**Verified by:**	CSPI 2015-02-10
Relevant Analysis:	QRA & CA	**Category:**	Analytical

Specifications:

The representative release duration applied is based on the total mass inventory (static + dynamic) of the isolatable segment and the selected release rate:

- If the segment inventory is depleted before isolation occurs, i.e. if the release rate, Qo, is significantly greater than the inflow rate to the segment (i.e. Qo > 2 x NFR) then the duration is assumed to be the time required to release the initial inventory of the segment. T = Mass / Qo.
- If the opposite applies, i.e. Qo < 2 NFR, then the release duration is based on the time assumed for isolation to occur, plus the time required to release the residual inventory of the segment after isolation. $T = T_{isolation}$ + Mass / Qo. In this case, if isolation does not occur the duration is set to a maximum of 60 minutes.

For reference, static inventory refers to the isolated inventory defined by the volume of the isolated equipment. Dynamic inventory refers to the inventory flowing into the system until time of isolation, NFR x $T_{isolation}$.

Implication of Assumption:

The selection of representative release duration is linked to the representative release rate and inventory and hence is a key assumption in ensuring that the model is as realistic as possible in reflecting the likely consequences.

References:

1. DNV GL Expert Judgment

Comments:

I.4.3 Release/Discharge Parameters: Inventory

Assumption No.:	20		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA & CA	**Category:**	Analytical

Specifications:

The total segment inventory is calculated simply as the total mass of gas/liquid contained in the section based on available facility information. The following assumptions are made for inventory calculation:

- Isolatable segments are defined based on the PFDs provided by the client. Isolatable segments are piping/equipment between ESDs/blocking equipment (such as compressor and pumps).
- For all the facility piping not running on the piperack, the lengths have been estimated based on the equipment/facility placement as shown in Plot Plan and equipment layouts.
- For the inter-unit piping/pipelines running on the piperack, the lengths have been estimated based on the measured lengths from the Plot plan.

It should be noted that the *inventory released* is distinct from the inventory of the isolatable segment, or the *inventory available for release*, which is a key factor in determining the release duration. The selection of the inventory or mass available for release is specific to the isolatable segment considered, where the key considerations are summarized below.

- Where the inventory of the isolatable segment is not depleted before isolation occurs, the isolatable mass of the segment is the key factor.
- For releases that are restricted by a pump, turbine or compressor, the inventory available for release is that of the isolatable segment plus any flow into the segment before isolation.

Implication of Assumption

The selection of a representative release inventory is linked to the representative rate and duration and hence is a key assumption in ensuring that the model is as realistic as possible in reflecting the likely consequences and enabling the influence of isolation on the duration and released inventory to be accounted for.

References:

1. Pembina Propane Export Terminal PFDs, Rev A1 provided by Pembina Marine Terminal Inc.

Comments:

I.4.4 Release/Discharge Parameters: Other Inputs

Assumption No.:	21		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA & CA	**Category:**	Analytical

Specifications:

The velocity is calculated within the Phast discharge model for each release, where the maximum limit for all gas releases is the sonic velocity. However, important corrections are applied if the velocity calculated by the Phast discharge model corresponds to the initial peak release (i.e. accompanies the maximum release rate, Qo). The velocity calculated by the Phast discharge model corresponds to the initial peak release (i.e. accompanies the maximum release rate, Qo). Where Qo is not used in the model (as described in Assumption - Release / Discharge Parameters: release rate), the velocity used is decreased by the same proportion as the release rate (i.e. a factor of Q/Qo is applied).

The discharge temperature required for input to the Phast dispersion model is the temperature of the material after expansion to atmospheric pressure and before the addition of any air for pre-dilution. This is generally calculated within the Phast discharge model, although it is noted that the approach used within Phast is theoretical and generally reduces the temperature of vapor releases to close to the boiling point. In many cases, the facility temperature is significantly above the material's boiling point and the maximum temperature drop that is considered credible, for vapor releases, is to up 40 ^{o}C below the operational temperature.

The droplet diameter and liquid fraction are also required to define liquid releases. Together with the velocity, these parameters determine how far the droplets travel in the release before raining out, or conversely whether they evaporate before rain-out occurs. These parameters are derived from the initial discharge modeling conducted within Phast.

Implication of Assumption

The above assumptions each have key influences on the Phast consequence modeling results.

References:

1. DNV GL expert judgment – using PhastRisk defaults and DNV GL Technical data

Comments:

I.4.5 Obstructed Regions

Assumption No.:	22		
Revision:	2	**Prepared by:**	WHON 2015-03-30
Date:	30 March 2015	**Verified by:**	CSPI 2015-03-30
Relevant Analysis:	QRA & CA	**Category:**	Analytical

Specifications:

Within the facility areas, obstructed regions are defined as areas with the potential for confinement and congestion of a flammable cloud, which may promote explosion hazards.

The critical separation distance is a parameter that is used to determine if confined areas can essentially be considered as one area if a flammable plume were to occupy both areas. A 9.1 m (30 ft) separation distance between adjacent congested volumes is suggested for the volumes to be treated as separate explosion sources (separate potential explosion sites, separate PESs). The 9.1 m (30 ft) separation distance is intended to be conservative (Ref. 1).

The height of a congested region is taken to be the lesser of the actual height of a congested region and 7.6 m (25 ft). That is, 7.6 m (25 ft) is to be taken as the maximum congested volume height, with any portion of the volume above 7.6 m (25 ft) neglected. A maximum height is selected since a unit fill approach is adopted. It is judged unlikely that a flammable cloud filling the entire congested volume footprint would extend from ground level past 7.6 m (25 ft). The 7.6 m (25 ft) maximum height restriction also applies to fin-fan coolers. While it is recognized that such coolers draw air upwards and hence could pull a cloud into them, it is judged that the use of a 7.6 m (25 ft) height across the footprint of the congested area is sufficiently conservative (Ref. 1).

Table I-14 presents a list of the congested regions and their defining properties related to the explosion calculation. Figure I-10 presents the location/area of the congested regions defined on the layout.

The Multi-Energy (ME) model predicts explosion effects in terms of peak overpressure in the vicinity around an explosion, for an explosion occurring at the stoichiometric concentration within a congested region. The congested regions are defined in terms of location, geometry, and the degree of congestion/confinement. The amount of obstructions within each volume is further defined by use of the volume blockage ratio, i.e., the amount of the volume occupied by piping/equipment. Each congested region is given a corresponding ME curve number (Ref. 2).

The correlation of the TNO's ME curve number to peak side-on-overpressure is displayed as curves in Figure I-9.

I.4.5 Obstructed Regions

Assumption No.:	22

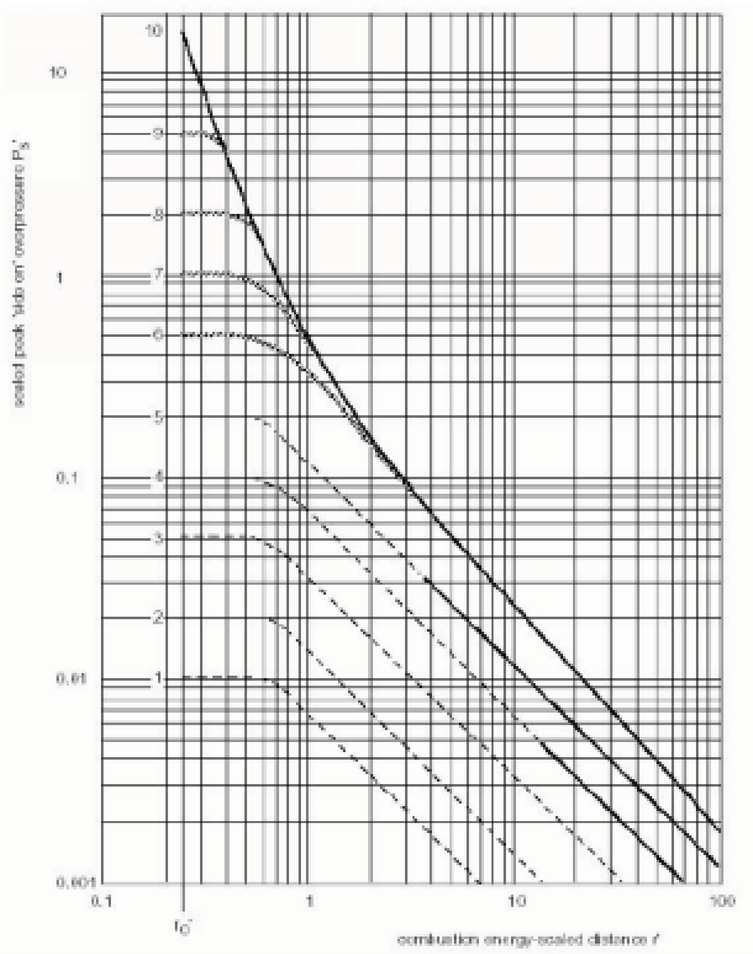


Figure I-11: TNO Multi-Energy Curves (Ref.3)

The following strength levels (Multi-Energy curve numbers) are used as guidance in determining the strength of the congestion level:

- Curve 4 - for ponds in Tank farm, for any unconfined area such as a pipeline corridor, street, etc.
- Curve 5 - for low congested units; typically a unit where most of the equipment is on the ground and there is no upper level
- Curve 5.5 - typical for a unit designed with standard distances between equipment items
- Curve 6 - typical for a unit with several open (no concrete) floors but without excessive confinement, for example, the internal volume of a congested pipe-rack
- Curve 7 - typical for very congested units

I.4.5 Obstructed Regions

Assumption No.:	22

The volume blockage ratio (VBR) is defined as the "volume of obstacles divided by the total volume of the obstructed region." A VBR of 0.2 is typically used for high congestion, 0.15 is used for medium, and 0.1 for low congestion.

Implication of Assumption

The above assumptions each have key influences on the consequence results predicted in Phast.

References:

1. Pitblado, et al., "Facility Siting Rule Set for the TNO Multi-Energy Model for Congested Volumes (PES) and Severity Levels", 10th Global Congress on Process Safety, 2014Obstructed region explosion model (OREM) theory, DNV Software, March 2010.
2. TNO GAMES Report, 1998. Application of correlations to quantify the source strength of vapour cloud explosions in realistic situations.

Comments:

Table I-17: Congested Regions

Region #	Description	Curve Number	Volume Blockage Ratio	Upper Elevation (m)
1	Emergency Generator Package	5	0.1	7.6
2	IA / PA Package	5	0.1	7.6
3	Propane Unloading Compressor	5.5	0.1	7.6
4	Nitrogen Package	5	0.1	7.6
5	Propane Pressure Storage Vessels	5.5	0.1	7.6
6	Propane Refrigeration	5.5	0.1	7.6
7	Propane Refrigerant Compressor	5.5	0.1	7.6
8	Propane Custody Transfer Meter Station Package	5	0.1	7.6
9	Boil of Gas Compressor	5.5	0.1	7.6
10	Propane Storage	5.5	0.1	7.6
11	In-line Railcars	5	0.1	7.6
12	Side-by-side Railcars	7	0.17	7.6

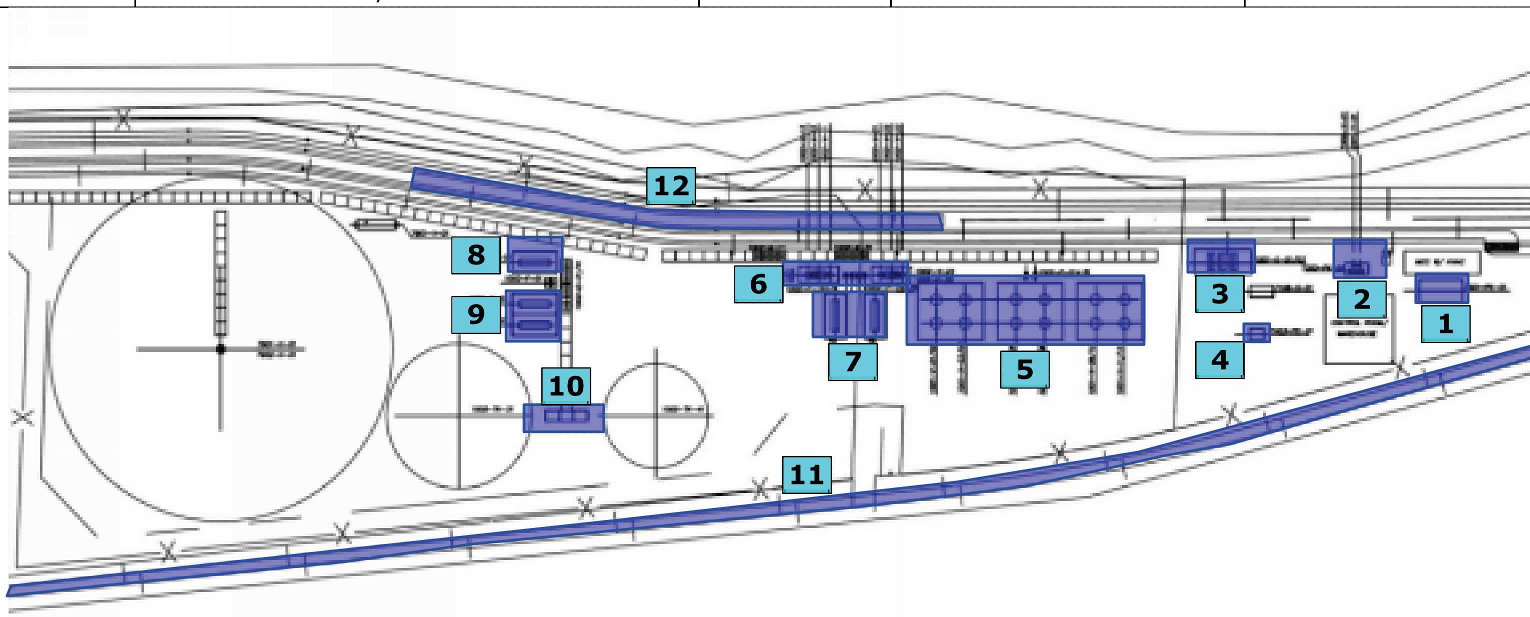


Figure I-12: Pembina Propane Export Terminal Congested Regions

I.4.6 Consequence Modeling Parameters

Assumption No.:	23		
Revision:	0	**Prepared by:**	WHON 2015-02-10
Date:	February 10 2015	**Verified by:**	CSPI 2015-02-10
Relevant Analysis:	QRA & CA	**Category:**	Analytical

Specifications:

The key inputs to the consequence modeling are taken directly from the discharge and dispersion modeling inputs and results. A wide range of additional parameters are applied within the models, where in general the widely accepted Phast Risk default values are applied. The key parameters that are specific to the consequence models for this study are summarized below.

- Jet fire – maximum surface emissive power (SEP): 250 kW/m^2
- Jet fire – release rate modification factor (determines the proportion of the liquid fraction that contributes to the jet fire for 2-phase jets): 3
- Pool fire – minimum duration – 10 seconds
- Pool fire – maximum surface emissive power (SEP): 150 kW/m^2
- Fireball / BLEVE – maximum SEP: 400 kW/m^2
- Fireball / BLEVE – mass modification factor: 3
- Flammable mass for explosion – calculation based on mass between LFL and UFL

End-point criteria for reporting consequence results can be found in Assumption I.4.7.

Explanation of Jet fire, rate modification factor:

The default value for the parameter ($f_{correction}$) is 3. This is used in calculating $M_{flammable}$, the flammable release rate involved in a jet fire:

$$M_{flammable} = \begin{cases} M_{input} & f_{vapor} \geq \frac{1}{f_{correction}} \\ f_{correction} f_{vapor} M_{input} & f_{vapor} < \frac{1}{f_{correction}} \end{cases}$$

where M_{Input} is the mass release rate, $f_{correction}$ is the Rate Modification Factor, and f_{vapor} is the mass fraction of vapor calculated in the discharge calculations.

Explanation of Fireball/BLEVE, mass modification factor

The default value for the parameter ($f_{correction}$) is 3. This is used in calculating the mass of material, $M_{flammable}$, involved in the fireball:

$$M_{flammable} = \begin{cases} M_{input} & f_{vapor} \geq \frac{1}{f_{correction}} \\ f_{correction} f_{vapor} M_{input} & f_{vapor} < \frac{1}{f_{correction}} \end{cases}$$

I.4.6 Consequence Modeling Parameters

Assumption No.:	23

where M_{Input} is the mass release rate, $f_{correction}$ is the Mass Modification Factor, and f_{vapor} is the mass fraction of vapor released following the rupture of the vessel.

Explanation of Flash fire mass calculation

The flammable masses used in explosion calculations are calculated by numerical integration of the concentration profile of the plume or cloud. This parameter sets the choice for the upper and lower limits of the integration. One option is "Mass above LFL" which produces a larger flammable mass and therefore more conservative result; whilst the "Mass between LFL and UFL" option is more correct theoretically.

The flash fire hazard zone will be determined based on the shape of the cloud and its footprint extending to the criteria endpoint, either LFL or 1/2 LFL.

Implication of Assumption

The above assumptions each have key influences on the consequence results.

References:

1. DNV GL Expert Judgment– using PhastRisk defaults and DNV GL Technical data

Comments:

I.4.7 Consequence Model Outputs

Assumption No.:	24		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA & CA	**Category:**	Analytical

Specifications:

The following consequence results are reported for this study:

Consequence results:

- Thermal radiation heat flux
  - Hazard zone distances to the thermal radiation levels – 35, 12.5, and 5 kW/m^2 (Ref. 1)

Thermal Radiation	Effect
5 kW/m^2	Will cause pain in 15-20 seconds and injury after 30 seconds exposure
12.5 kW/m^2	Significant chance of fatality for medium duration exposure. Thin steel with insulation on the side away from the fire may reach thermal stress level high enough to cause structural failure.
35 kW/m^2	Cellulosic material will pilot ignite within one minute's exposure. Significant chance of fatality for people exposed instantaneously.

- Flammable vapor dispersion
  - Hazard zone distances – LFL (2% propane concentration) and ½ LFL (1% propane concentration)
- Explosion overpressure
  - Explosion hazard frequency contours for 1 psi (0.07 bar), 3 psi (0.2 bar) and 5 psi (0.3 bar) (Ref. 2)

Overpressure	Effect
1 psi (0.07 bar)	Partial damage of houses
3 psi (0.2 bar)	Steel frame building distort and pulled away from foundations
5 psi (0.3 bar)	Wooden utility poles snap; nearly complete destruction of houses

Implication of Assumption

The above assumptions influence the presentation of the consequence results that are reported.

I.4.7 Consequence Model Outputs

Assumption No.:	24

References:

1. UK HSE, Indicative human vulnerability to the hazardous agents present offshore fore application in risk assessment of major accidents, Supporting Document: "Methods of approximation and determination of human vulnerability for offshore major accident hazard assessment", SPC/Tech/OSD/30, Version 3, 2013.
2. Daniel A Crowl and Joseph F. Louvar, Chemical Process Safety : Fundamentals with Applications 2nd Edition 2001

Comments:

I.4.8 Drainage

Assumption No.:	25		
Revision:	1	**Prepared by:**	WHON 2015-03-30
Date:	30 March 2015	**Verified by:**	CSPI 2015-03-30
Relevant Analysis:	QRA	**Category:**	Design, Analytical

Specifications:

There are no dikes or walls around the refrigerated storage tanks. The tanks are bounded by rail line embankments to the NE and SW. The rail lines converge to the SE. The area to the NW past the flare area is open parking lot for autos offloaded from ship by Honda. This paved area to the NW is relatively flat but with a mild grade such that all water and liquid drains toward a storm water drain system located along the NE boundary of the parking lot. The drain system parallels the road and rail tracks that themselves generally parallel the river to the NE of the parking lot. There is a ditch planned between storage tanks and the road to the SW. There is also a ditch between the SW road and existing SW rail lines as shown in the picture below Figure I-13. The new rail to the NE will have a ditch between it and the storage tanks. The rail bed itself is 1 – 2' above the site elevation.

Figure I-13: Ditch location

I.4.8 Drainage

Assumption No.:	25

The QRA study assumes that pools form around the release location.

The elevated rail lines will form a natural bunding that will limit the spread of large liquid releases. A large bund area (124 m diameter and 1 m height) is proposed by DNV GL to account for railroad tracks channeling potential liquid releases.

Implication of Assumption

The above assumptions have key influences on the pool fire consequence modeling.

References:

1. Email from Chris Hayes, January 24 1015.

Comments:

I.5 Impact and Risk Analysis

I.5.1 Impact to People

Assumption No.	26		
Revision:	3	**Prepared by:**	WHON 2015-03-30
Date:	30 March 2015	**Verified by:**	CSPI 2015-03-30
Relevant Analysis:	QRA	**Category:**	Analytical

Specifications:

The consequence assessments conducted within the risk analysis can be used to predict the distance to (or strictly, the area covered by) any desired hazard level, such as a specific radiation level or overpressure. However, for risk calculations, it is necessary to associate hazard levels with their effect, or impact, on personnel.

This is done by setting the modeling end point (i.e. impact) criteria for the various consequences to correspond to levels at which the likelihood of fatality is estimated (for example, based on established best-practice). With a simple cut-off model, as possible in Phast Risk, the assumption is that if the hazard exceeds the specified level (the "end-point criterion") at that location, any exposed people suffer fatality with the defined probability (the "vulnerability criterion").

The end-point criteria, used to determine the impacts at a given location, and the corresponding vulnerability parameters, defining the probability of fatality of any exposed people, are summarized in the tables below.

End Point (Impact) and Vulnerability (Fatality) Criteria for Thermal Radiation (Jet Fire, Pool Fire, Flash Fire and Fireball) (Ref. 1)

Area	Individual Risk	Societal Risk Indoors	Societal Risk Outdoors
Inside flame area (LFL)	1	0	1
Radiation above 35 kW/m^2	1	0.5	1
Radiation below 35 kW/m^2	P_{lethal} (P_{lethal} = -36.38 + 2.56× ln[(W/m^{-2})$^{4/3}$×T] where exposure time T is in seconds and maximum exposure time is 20 seconds)	0	0.14*P_{lethal} (it is assumed that people outdoors are protected from heat radiation by clothing until it catches fire. The protection of clothing reduces the number of people dying by a factor of 0.14 compared to no protection of clothing)

Based on the above table, the LFL is used as the flash fire end point for estimating fatality risk. A thermal radiation probit is used to estimate the risk from jet and pool fires. People located indoors are assumed to be protected from flash fire and thermal radiation hazards.

I.5.1 Impact to People

Assumption No.	26

Explosion Criteria (Ref. 2&3)

Population / Building Type	0.1 bar	>0.35 bar	>0.5 bar
Brick building, indoor population	0.15	0.7	1
Outdoor population	0.01	0.3	0.5

Explosion loads to buildings may cause collapse of the building and result in injury or fatality to personnel indoors. Outdoor people may receive a higher explosion load without injury.

For the control room, DNV GL assumes that the overpressure design is in accordance with CIA1 category – hardened structure building (Ref. 3).

Control Room Overpressure Design (Ref. 3)

Building	0.45 bar	0.6 bar	1 bar
Control room	0.01	0.55	1

Injury

To evaluate the potential risk of injury to the surrounding areas, the following endpoint criteria are applied, and the combined frequency of occurrence is evaluated.

- 0.15 barg / 2.2 psig overpressure (Personnel outdoors are expected to survive overpressures of 0.17 barg or lower, Ref. 4. Missiles may travel and cause lacerations with overpressures between 0.07-0.15 barg, Ref. 4)
- 2 kW/m^2 thermal radiation (minimum value to cause pain after 1 minute of exposure, Ref. 4)

Implication of Assumption:

The risks are directly influenced by the impact and fatality assumptions, which quantify the severity of the consequences. The above assumptions include some allowance for different escape characteristics in different areas of the facility, but remain consistent with established, conservative best-practice.

References:

1. VROM, Guidelines for Quantitative Risk Assessment (Purple Book), PGS 3, Ministerie van Verkeer en Waterstaat, December 2005.
2. International Association of Oil and Gas Producers, OGP, Risk Assessment Data Directory, "Vulnerability of Humans", Report No. 434-41.1, March 2010.
3. CIA Chemical Industries Association (CIA), 2003. *Guidance for the location and design of occupied buildings on chemical manufacturing sites*, 2nd. ed., London: Chemical Industires Association, ISBN 1 85897 114 4.
4. UK HSE, "Methods of approximation and determination of human vulnerability for offshore

I.5.1 Impact to People	
Assumption No.	26
major accident hazard assessment".	
Comments:	

I.5.2 Receptor Identification

Assumption No. :	27		
Revision:	3	**Prepared by:**	WHON 2015-03-30
Date:	30 March 2015	**Verified by:**	CSPI 2015-03-30
Relevant Analysis:	QRA, CA	**Category:**	Analytical

Specifications:

The following key locations are evaluated as receptors for the various hazard impacts. Detailed location of the receptors can be found in Figure I-14 - Figure I-17.

Receptor No.	Receptor Description
Onsite Locations	
1	Admin. Building
2	Substation
3	MCC
4	Control Room / Warehouse
5	Propane Pressure Storage Tank Group 1
6	Propane Pressure Storage Tank Group 2
7	Propane Pressure Storage Tank Group 3
8	Railcar Unloading
9	Refrigerated Propane Storage Tank 1
10	Refrigerated Propane Storage Tank 2
11	Jetty
Offsite Locations	
12	Neighboring Point1 (NP1)
13	Neighboring Point2 (NP2)
14	Neighboring Point3 (NP3)
15	Neighboring Point4 (NP4)
16	Hayden Island West Point (HIWP)
17	Hayden Island North East Point (HINEP)
18	Hayden Island East Point (HIEP)
19	Kelley Point Park (KPP)
20	Oregon West Point (WR)
21	Smith Natural Area (SNA)
22	Residential Area (RA)
23	Floating Home Community (FH)
24	Grain Terminal (GT)

Implication of Assumption:

LSIR results are reported on those receptor locations, which are used to assess the individual risk to key locations of interest, such as the onsite buildings, fence lines, and storage area.

References:

Comments:

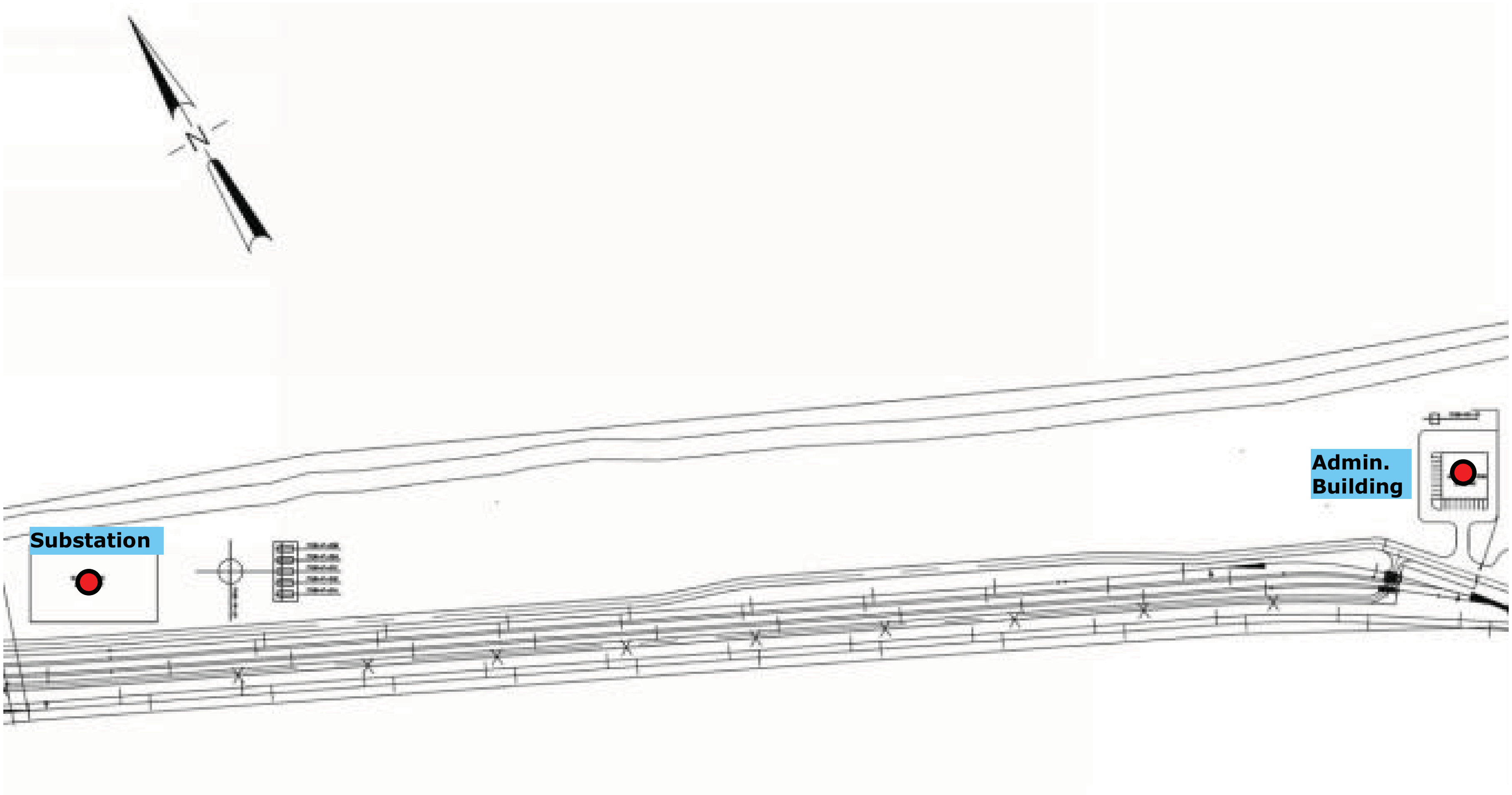


Figure I-14: Receptor Locations-1

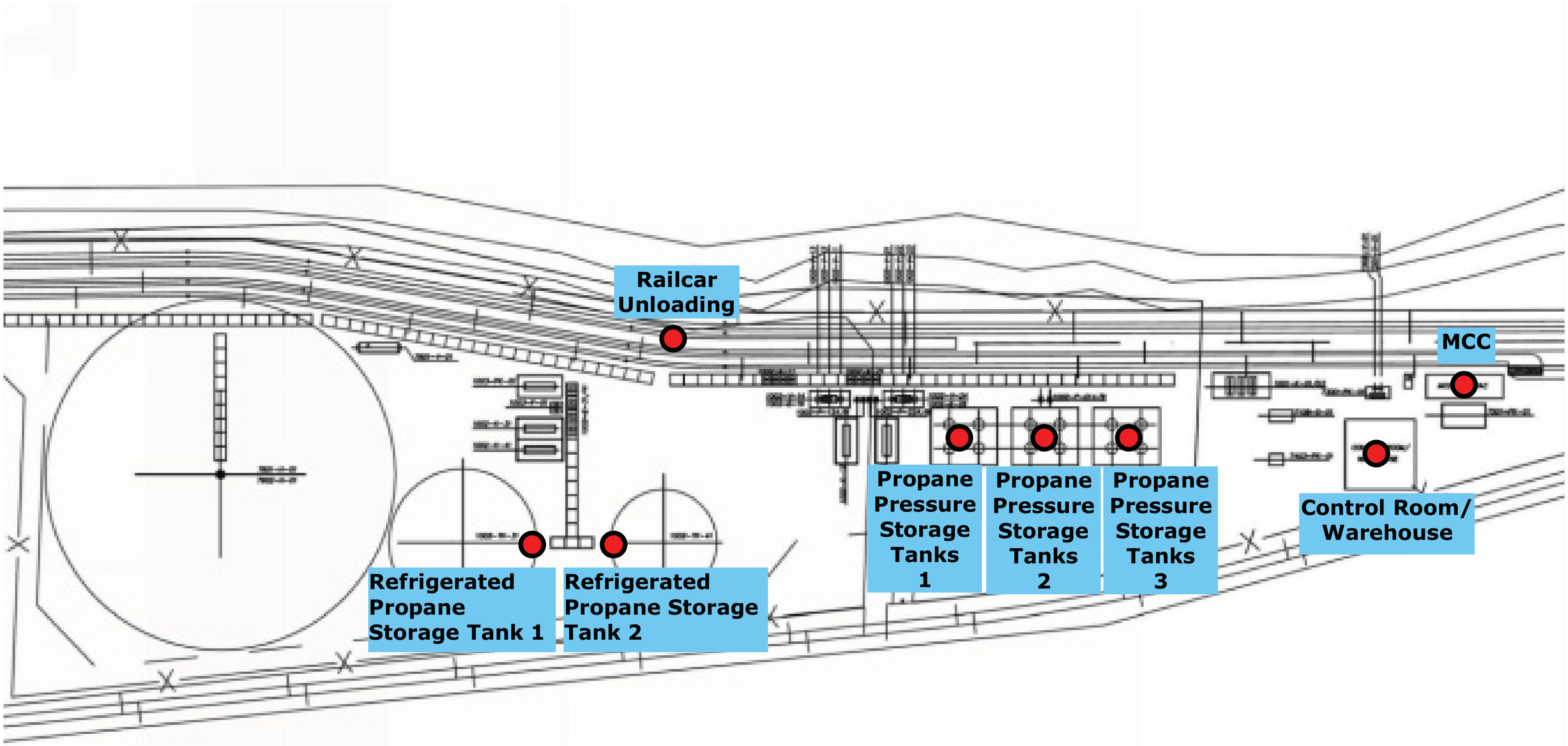


Figure I-15: Receptor Locations-2

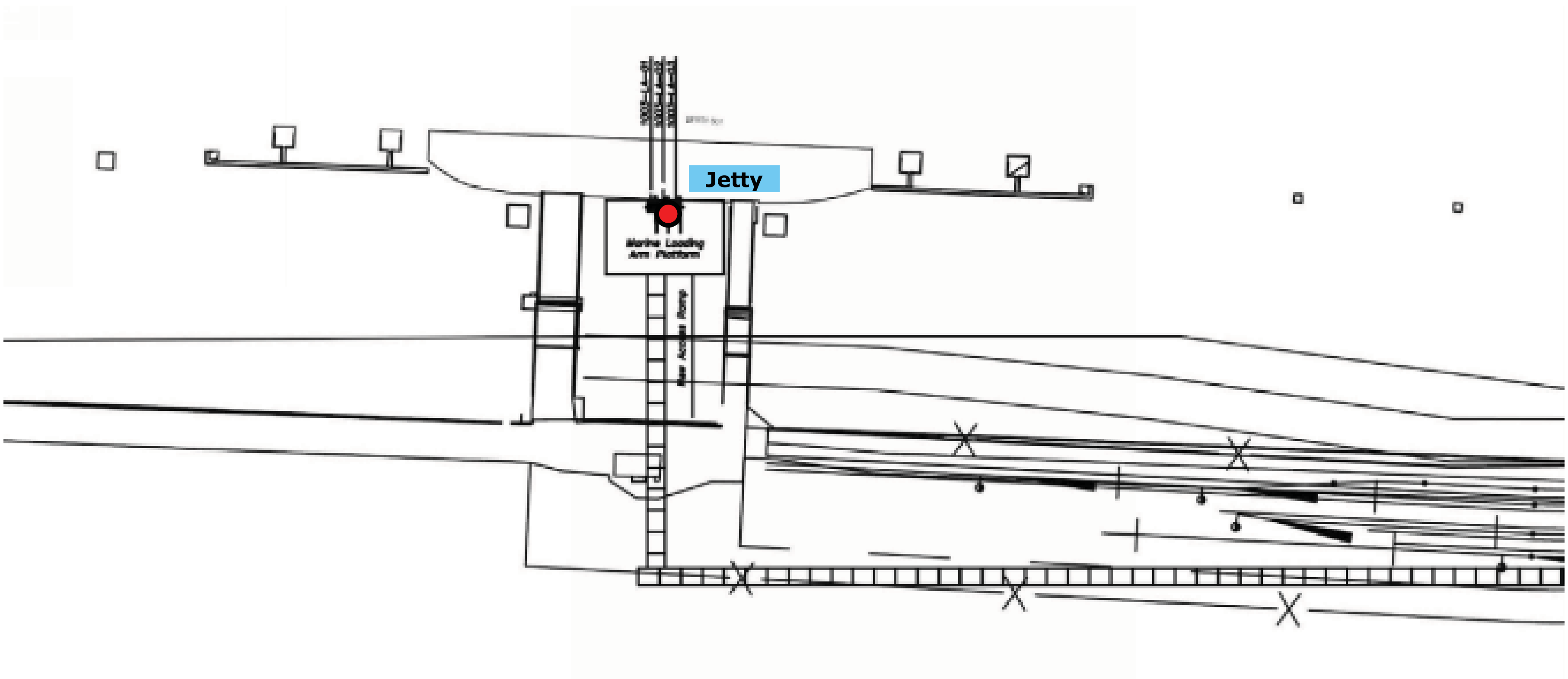


Figure I-16: Receptor Locations-3

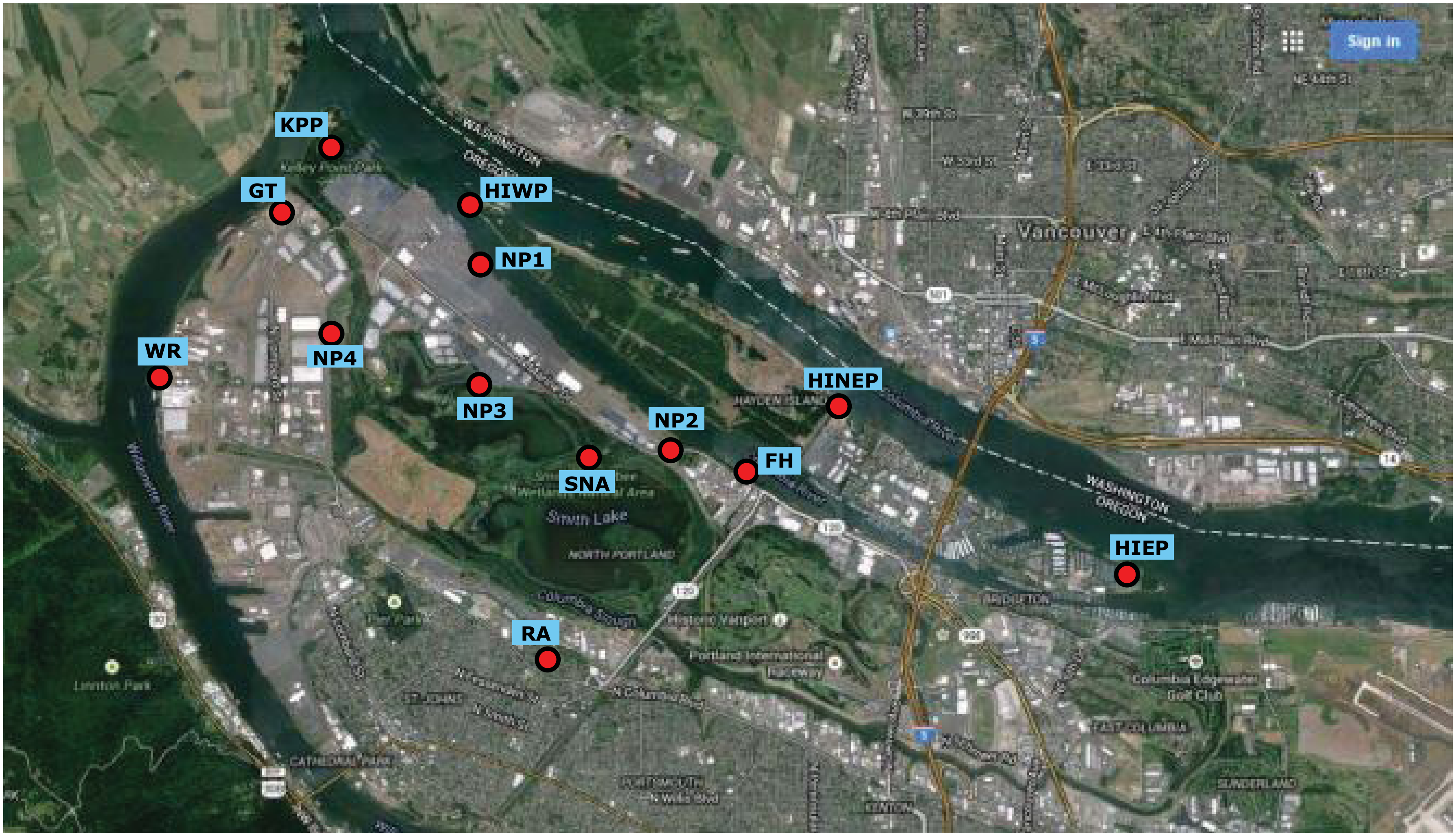


Figure I-17: Offsite Receptor Locations

I.5.3 Risk Results			
Assumption No.:	28		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA	**Category:**	Analytical

Specifications:

The following risk results are reported in the QRA:

- Location Specific Individual Risk (LSIR) contours, indicating potential onsite and offsite exposure
- LSIR at point locations
- FN (cumulative frequency vs. number of fatalities) curve for both onsite and offsite populations

Refer to Section 1.5.4 for further discussion.

Implication of Assumption:

References:

Comments:

I.5.4 IR Criteria and SR Criteria

Assumption No.:	29		
Revision:	1	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA	**Category:**	Operational, Analytical

Specifications:

No risk criteria have been identified related to Federal, State, or Portland regulations or Pembina, based on DNV GL's regulatory review. Therefore the following risk criteria are proposed for the evaluation of the site:

Individual Risk

A determination of individual risks to the public, and to employees, forms the basis for risk-decision making. It provides an overall assessment of the level of risk to the exposed population and highlights the major contributors to the risk. Individual risk assessment combines the results of the consequence modeling, with a detailed assessment of frequencies, utilizing event tree analysis, fault tree analysis, and failure frequency data bases.

The following risk criteria are used by the UK Health & Safety Executive (HSE) to assess the individual risk exposed to employees, contractors as well as public people (Ref. 1):

- Maximum tolerable risk for workers 1E-03 per year
- Maximum tolerable risk for the public 1E-04 per year
- Broadly acceptable risk 1E-06 per year

In between the maximum tolerable and broadly acceptable levels, the UK HSE requires that risk be reduced to a level which is as low as reasonably practicable (ALARP), taking account of the costs and benefits of any further risk reduction. Near to the broadly acceptable criterion, the risks are considered tolerable if the cost of risk reduction exceeds the improvement gained. Near to the maximum tolerable criterion, the risks are only considered tolerable if risk reduction is impracticable or if its cost is grossly disproportionate to the improvement gained.

Assumption No.:	29

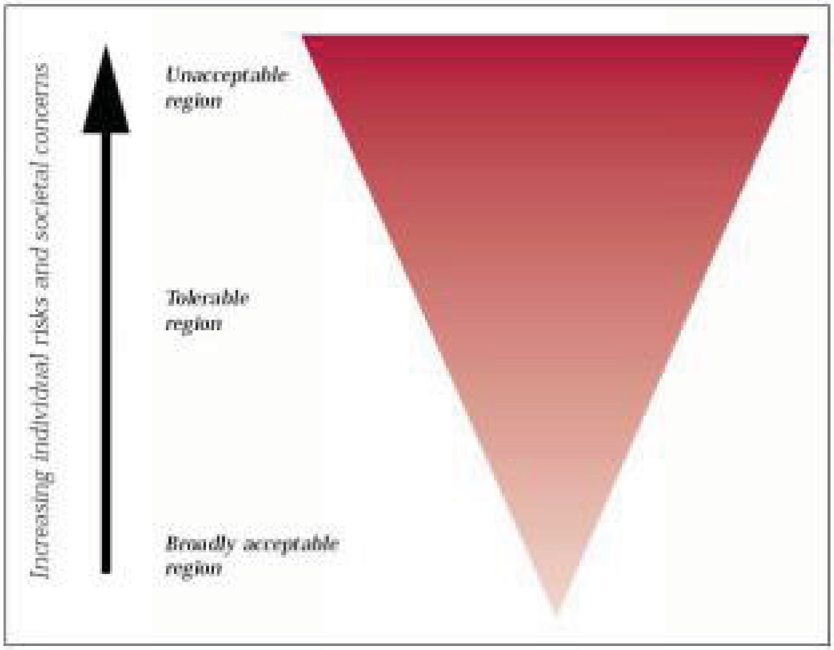


Figure I-18: HSE Framework for the tolerability of risk (Ref. 1)

Societal Risk

A determination of societal risks to the public and to employees provides important input to risk-decision making. It provides an assessment of the magnitude of risk associated with major events, in terms of impact to large numbers of people. Major contributors to the societal risks are also identified.

Societal risk can be represented

- graphically, in the form of FN curves
- numerically, in the form of a risk integral

FN Curves

Societal risk can be represented by FN curves, which are plots of the cumulative frequency (F) of various accident scenarios against the number (N) of casualties associated with the modelled incidents. The plot is cumulative in the sense that, for each frequency, N is the number of casualties that could be equalled or exceeded. Often 'casualties' are defined in a risk assessment as fatal injuries, in which case N is the number of people that could be killed by the incidents. 'Criterion lines' on FN plots have been suggested as a means to define risk zones/ categories.

In 2001, HSE published "Reducing Risks, Protecting People" (known as "R2P2"), with the purpose of informing external stakeholders about HSE's approach to regulatory decision-making (Ref .2). R2P2 gives limited guidance on criterion values for societal risks. R2P2 defines one point, (N=50,

I.5.4 IR Criteria and SR Criteria

Assumption No.:	29

F(N)=1/5000 per year), and if this point is placed on an FN curve, and a line drawn through it, with a slope of −1, it can provide a criteria comparison line. To use this, a calculated curve for a site can be superimposed, and if any point of this curve lies above the criterion line at any point, then this could indicate unacceptability. This begs the question whether the actual curve must be below the criterion line at all points, or can some excursions above the line be allowed, if these are balanced by points where the curve is below the criterion line. There is no universal agreement on this (Figure I-19).

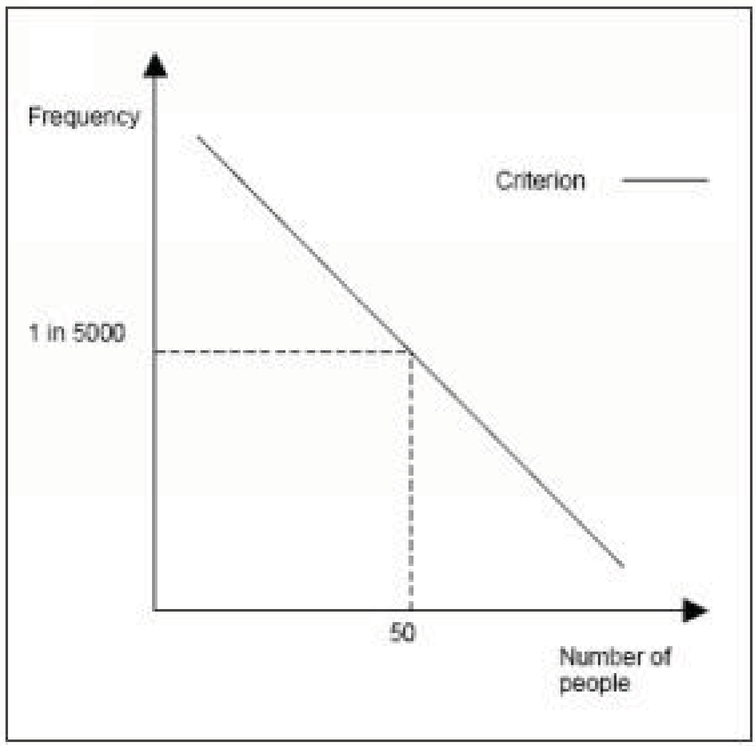


Figure I-19: The R2P2 criterion point for FN Curves (Ref. 2)

Risk Integrals
The potential loss of life (PLL) is the average number of fatalities per year. HSE does not have the criteria for PLL of onsite population. PLL will only be presented to discuss the relative ranking of hazards and the key risk contributors.

I.5.4 IR Criteria and SR Criteria

Assumption No.:	29

Implication of Assumption:

Risk acceptance criteria are used to evaluate whether the risk to people is unacceptable or within tolerable limits.

References:

1. HSE (1989a) : "Quantified Risk Assessment : Its Input to Decision-Making", Health & Safety Executive, HMSO
2. HSE, 2001. *Reducing Risks, Protecting People: HSE's decision-making process, (R2P2),* HSE Books. London: HSE. [Online] Available at: http://www.hse.gov.uk/risk/theory/r2p2.pdf
3. Societal Risk; Initial Briefing to Societal Risk Technical Advisory Group, HSE 2009

Comments:

I.6 Facility & Other Specific

I.6.1 Propane Pressure Storage Tanks

Assumption No.:	30		
Revision:	0	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA	**Category:**	Design, Analytical

Specifications:

There are twelve propane pressure storage tanks at the railcar unloading area. Each tank (16' dia x 90' high) is assumed to have 461 m^3 working volume (assumed to be 90% full) (Ref. 1).

The table below presents the failure rate for use within the risk assessment for the propane pressure vessels (Ref. 2). The below frequencies are based on propane vessel failures in the UK.

Size Category	Size (mm)	Failure Rate (per vessel)
Small	13	1E-05
Medium	25	5E-06
Large	50	5E-06
Catastrophic Rupture	-	2E-06
BLEVE*	-	1E-05

Note: For BLEVE event, DNV GL will assess the frequency of thermal loads to the pressure storage tank area (in order for BLEVE to occur, external fire must be present at the tank location).

Implication of Assumption:

The above assumptions influence the selection of release scenarios for the consequence and risk modeling.

References:

1. Email from Chris Hayes, February 03 2015.
2. Failure Rate and Event Data for Use within Risk Assessment, UK HSE, June 28 2012.

Comments:

I.6.2 Propane Refrigerated Storage Tanks

Assumption No.:	31		
Revision:	0	**Prepared by:**	WHON 2015-02-24
Date:	24 February 2015	**Verified by:**	CSPI 2015-02-24
Relevant Analysis:	QRA	**Category:**	Design, Analytical

Specifications:

There are two propane storage tanks at the storage area. The larger refrigerated propane storage tank (176' dia x 134' high) is assumed to have 550,000 bbl (87,443 m^3) working volume (assumed to be full) (Ref. 1) and the smaller tank (140' dia x 100' high) is assumed to have 250,000 bbl (39,747 m^3) working volume (Ref. 2).

The tanks are double walled steel tank within a tank. They are single primary containers with an outer shell designed and constructed so that the primary container is required to meet the low temperature ductility requirements for storage of the product.

A leak or rupture of the tank, releasing some or all of its contents, can be caused by brittle failure of tank walls, welds or connected pipework due to use of inadequate materials, combined with loading such as wind, earthquake or impact. DNV GL considers a catastrophic rupture of a double-walled tank credible and hence this is considered and modeled in the QRA.

The table below shows the failure rates and release sizes used in the risk model for double-walled refrigerated storage tanks that are larger than 12,000m^3 (Ref. 3). The below frequencies are based on refrigerated storage tank failures in the UK

Size Category	Size (mm)	Failure Rate (per vessel)
Minor Release	300	3E-05
Major Release	1000	1E-05
Catastrophic Rupture	-	5E-07

Implication of Assumption:

The above assumptions influence the selection of release scenarios for the consequence and risk modeling.

References:

1. Propane Storage Tanks TK-02A Equipment Datasheet, Doc. Number: 14088D-ME-DS-1002-001, rev.1, Oct 01 2014 and Email from Chris Hayes "Facility QRA Model Run", January 16, 2015.
2. Propane Storage Tanks TK-02B Equipment Datasheet, Doc. Number: 14088D-ME-DS-1002-002, rev.0, Oct 01 2014.
3. Failure Rate and Event Data for Use within Risk Assessment, June 28 2012, UK HSE.

Comments:

I.6.3 Earthquake Hazard

Assumption No.:	32		
Revision:	3	**Prepared by:**	WHON 2015-03-16
Date:	16 March 2015	**Verified by:**	CSPI 2015-03-16
Relevant Analysis:	QRA, CA	**Category:**	Design, Analytical

Specifications:

According to 2014 Oregon structural code, every structure, and portion thereof, including nonstructural components that are permanently attached to structures and their supports and attachments, shall be designed and constructed to resist the effects of earthquake motions in accordance with ASCE 7 (Ref 1).

Two levels of seismic performance will be adopted for the wharf structures:

Operating Level Earthquakes (OLE)

- Minor or no structural damage
- Temporary or no shutdown in operations

Contingency Level Earthquake (CLE)

- Controlled inelastic structural behaviour with repairable damage
- Life safety must be maintained
- Prevention of structural collapse
- Temporary loss of operations, restorable within months

1 in 72-year event and 1 in 475-year event are reported for OLE and CLE, respectively (Ref.2).

Note that the tank is to be designed to a 1 in 2,475-year event. Two models representing the releases due to the earthquakes are chosen in the QRA model.

- A small release (10% of the 300mm release rate) from the larger propane storage tank is selected to reflect the potential consequence at the design tank frequency (1 in 2,475-year).
- A large release event (300mm hole) from the propane storage tank is modeled with a 10 times lower frequency (1 in 24,750-year).

Implication of Assumption:

References:

1. 2014 Oregon Structural Specialty Code. Chapter 16 Section 1613: Structural Design - Earthquake Loads
2. Basic Engineering Design Data (BEDD) – Pembina Propane Terminal Project (14088D), Doc. No. 14088D-PR-DB-0000-001, Rev. A, date: October 20, 2014

Comments:

I.7 Rail Car Unloading

I.7.1 Rail Unloading Description

Assumption No.:	33		
Revision:	0	**Prepared by:**	MINMIN 2015-02-24
Date:	24 February 2015	**Verified by:**	LDEAL 2015-02-24
Relevant Analysis:	Rail Car Consequence Study	**Category:**	Design

Specifications:

Feedstock for the Pembina Portland Propane facility, pressurized propane at ambient temperature, is planned to be shipped along two rail lines in dedicated rail cars and offloaded at the facility using articulated loading arms. The facility is expected to receive approximately 3.2 million gallons of liquid propane from rail tracks every two day via one train equipped with 100 rail cars (tankers) (Ref. 1, 2).

Based on the tentative facility layout of the Pembina Portland propane terminal, there are two rail tracks each capable of accommodating one 7,000 ft unit train (one track to receive a loaded train and one track to contain an empty train for departure). A third track is anticipated to move the locomotives from one end of the train to the other. The facility rail offloading racks have 13 double-side racks planned, for a total of 26 unloading stations (Ref. 3).

There will be two liquid arms (2 inch) and one vapor arm (2 inch) attached to each propane tanker during propane unloading along the double-side rail racks (see Figure I-20). The peak unloading rate is approximately 1,700,000 pounds per hour when 26 rail cars are all hooked up for unloading (around 66,000 lbs/hr for each propane tanker).

Implication of Assumption:

Defines boundaries and scope of the analysis.

References:

1. DNV GL Report PP118986 Rev. 2, Preliminary WSA for Pembina - Columbia River Preliminary Waterway Suitability Assessment, 01/27/2015.
2. Chris Hayes, RE: Pembina facility QRA data request, Attachment: Copy of Stream Data for Unloading Compressor and Rundown Pumps (2), pdf. [email] Pembina, dated 2/19/2015.
3. LPG Export Terminal Design Summary - USCG 2014 11 06.pdf

Comments:


Figure I-20: Rail Car Offloading Arrangement (Ref. 3)

I.7.2 Rail Car Specification

Assumption No.:	34		
Revision:	1	**Prepared by:**	MINMIN 2015-03-30
Date:	30 March 2015	**Verified by:**	LDEAL 2015-03-30
Relevant Analysis:	Rail car consequence	**Category:**	Design

Specifications:

Figure I-21 provides a schematic view of the rail car configuration (Ref. 1). There are no bottom outlets on the propane rail car tank and the top fittings are listed as below:

- Manway Diameter: 20 inch
- Siphon Pipes (2) Sch 40: 3 inch
- Liquid Angle Valves, (2) with check valves: 2 inch
- Vapor Angle Valves, with check valve: 2 inch
- Sample Line, Sch 80: ¾ inch
- Thermowell, Sch 80: ¾ inch
- Safety Valve: 280.5 psi
- Gauging Device: magnetic

One rail car has a capacity of 33,800 gallons with the shipping capacity at 5% outage of 32,000 gallons. The load limit is 162,800 pounds and lightweight limit is 100,200 pounds. The tank test pressure is 340 psi and the safety valve set pressure is 280.5 psi.

Assuming propane will reach the maximum ambient temperature of 85 °F during transit in summer time, this leads to a storage pressure of 150 psia (Ref. 2). During winter time, DNV GL assumes the propane will reach the ambient temperature of 35 °F with a storage pressure of 75 psia.

The Pembina Facility QRA is scoped to assess the risk from and including the railcar unloading up to the marine loading arms. Potential rail tanker releases due to collision, derailment or equipment failures are also within the scope of this facility study (see Assumption 35).

Implication of Assumption:

The rail car configuration and its top fittings/bottom outlet will aid in identifying the potential unloading release locations.

References:

1. Anhydrous Ammonia & Liquefied Petroleum Gas (LPG) Car Non-Insulated, Thermally Protected Rail Car Configuration, Received from Chris Hayes Dated January 14, 2015.
2. Email from Chris Hayes, Subject: Input for Worst-Case Rail Car, Dated January 29 2015.

Comments:

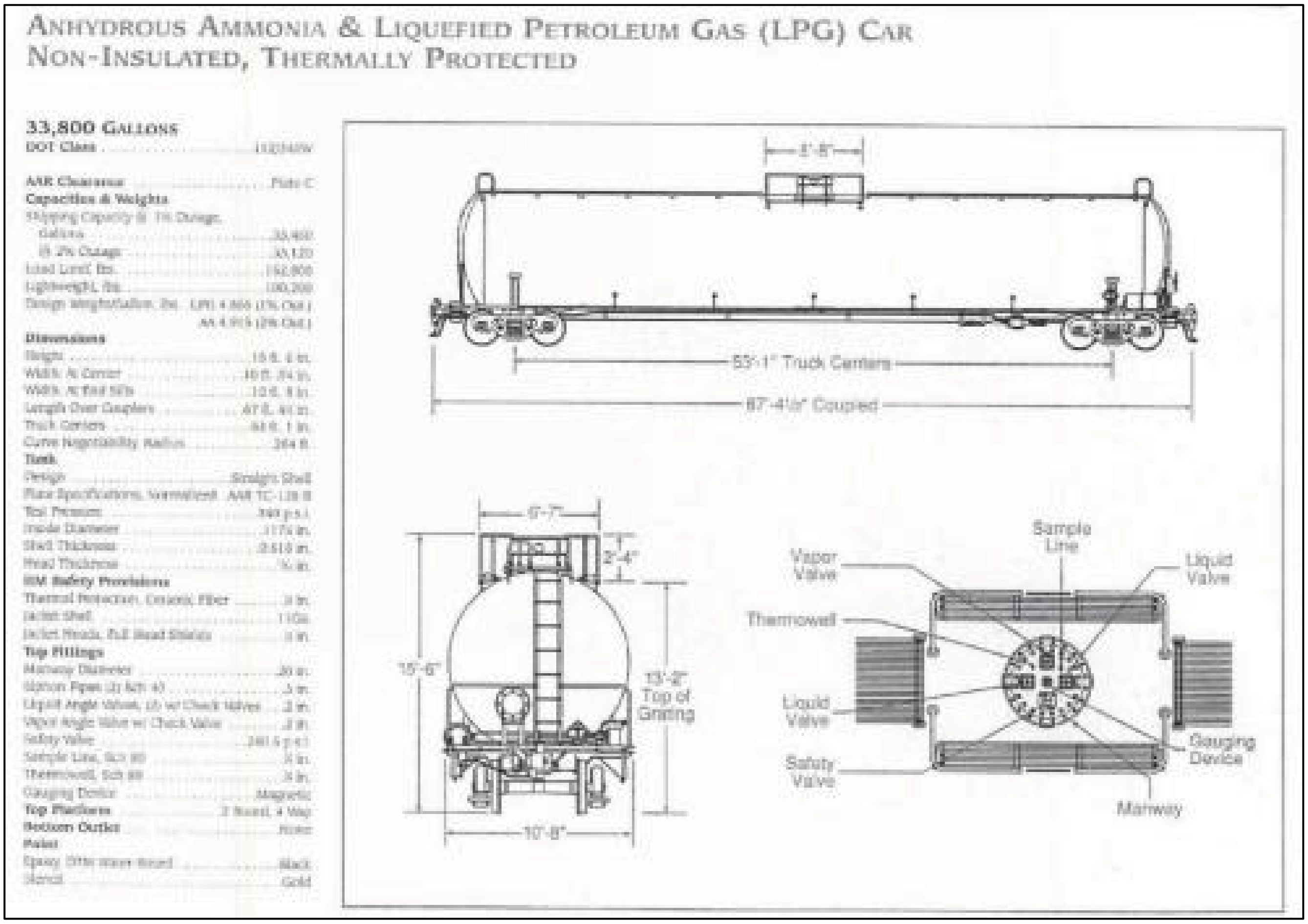


Figure I-21: Rail Car Configuration (Ref. 1)

I.7.3 Railcar Release and Derailment Scenarios & Leak Frequency

Assumption No.:	35		
Revision:	0	**Prepared by:**	WHON 2015-03-31
Date:	31 March 2015	**Verified by:**	CSPI 2015-03-31
Relevant Analysis:	Railcar Risk	**Category:**	Methodology

Specifications:

In order to estimate the railcar release frequencies, a recent 10-year railroad accident history (2005 ~ 2014) published by the Federal Railroad administration (FRA) Office of Safety Analysis (one of the ten agencies within the U.S. Department of Transportation (DOT) concerned with various modes of transportation) is analysed (Ref. 1). The FRA database updates the accident record on a monthly basis and specifies each railroad related accident by region, state, type of accident, type of track, track class, cause of accident, casualty subset, hazard material involved or not, and asset damage level. The upstream physical boundary of the facility QRA study is from the railway switching point where the propane carriers enter the Pembina facility. Therefore, in this study the railcar accident frequency analysis only focuses on the railcar accident statistics related to the yard track.

By reviewing and processing the railroad accident records between 2005 and 2014, the frequency of having a railcar accident within a railroad yard is about 14 accidents per million yard switching miles. To better understand the accident statistic specific to railcars carrying hazardous materials, the 10-year database is filtered by the "hazard material options" category. It is found that among all railroad accidents involving railroad carriers transporting hazardous materials, approximately 2.2% will lead to actual releases of the hazardous material. Therefore, the overall railcar accident rate causing hazardous material releases is calculated at 6.80E-05 per year (based on the frequency of 0.31 railcar accidents per million yard switching miles and 1.2 yard miles per train visit every other day). This is equivalent to one railcar release accident every 14,700 years if the train comes every other day.

As for the severity of the railcar release accidents, the 10-year accident database (specific to yard track, hazardous material railroad carriers) is further analyzed with focus on the number of derailed cars per accident. The maximum number of derailed cars from one train carrying hazardous material in an individual yard accident is found to be 39. The statistics (Figure I-22) indicate that 17% of the accidents did not lead to derailment. The majority of the accidents happened with 1 to 3 cars derailed (44%); less than 5% of the accidents have derailed car numbers greater than 10; and the rest of the accidents (34%) fall into the range of 4 to 9 cars derailed.

I.7.3 Railcar Release and Derailment Scenarios & Leak Frequency

Assumption No.:	35

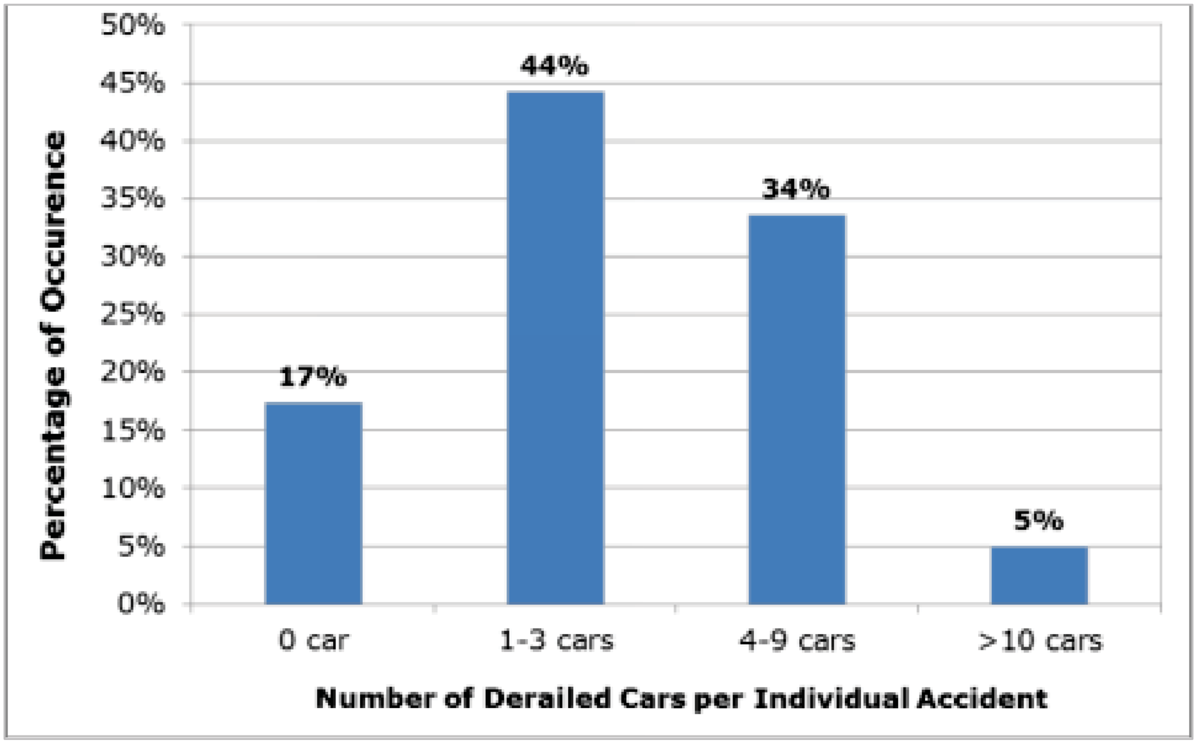


Figure I-22: Accident Distribution by Involved Number of Derailed Cars

Table I-18 summaries the railcar release frequencies for the above discussed scenarios on a per mile basis and also on a per year basis assuming the facility receives one train (100 railcars per train) every other day and travels 1.2 yard miles per visit (measured from the facility plot plan, Ref. 2). Note that a 3-inch hole release scenario is defined for accidents with no derailment. With regards to the derailed accidents, the representative number of derailed cars defined for the other three scenarios are taken as the weighted average number within the defined range. Derailment scenarios are conservatively modeled as a release of the total derailed car inventory in 10 minutes.

Table I-18: Summary of Railcar Release Frequencies

Failure Case	Derailed Railcar Number	Release Size/Duration	Frequency (per yard mile)	Total Frequency (per year)*	Percentage
3 - inch release	0	3 inch	5.37E-08	1.18E-05	17.3%
2 cars rupture	1 ~ 3	10 minutes	1.37E-07	3.01E-05	44.2%
6 cars rupture	4 ~ 9	10 minutes	1.04E-07	2.28E-05	33.6%
14 cars rupture	10 ~ 39	10 minutes	1.53E-08	3.35E-06	4.9%
Total:			**3.10E-07**	**6.80E-05**	**100.0%**

* This is estimated based on 183 trips (one train every other day) per year and 1.2 yard miles per trip.

I.7.3 Railcar Release and Derailment Scenarios & Leak Frequency

Assumption No.:	35

Implication on Assumption:

Key influence on the risks (i.e. risk is directly proportional to frequency).

References:

1. Federal Railroad Administration Office of Safety Analysis. [Online] U.S. Department of Transportation, 2015. http://safetydata.fra.dot.gov/OfficeofSafety/Default.aspx.
2. *Pembina LPG Project Protland, Oregon Overall Plot Plan, Rev. B.* SK E&C USA, 01-12-2015. 14088D-PI-PP-00000-01.

Comments:

I.7.4 Rail Car Unloading Arm Scenarios & Leak Frequency

Assumption No.:	36		
Revision:	0	**Prepared by:**	MINMIN 2015-02-24
Date:	24 February 2015	**Verified by:**	LDEAL 2015-02-24
Relevant Analysis:	Railcar Risk	**Category:**	Methodology

Specifications:

The best available source of leak frequencies from transfer equipment for rail is provided by ACDS (Ref. 1), based on LPG road tanker data. The frequency per DNV GL standard hole sizes is presented in the table below.

Table I-19: Summary of Onshore Transfer Leak Frequencies for Liquefied Gas

Range	Nominal	Frequency (per transfer)
3-10 mm	5 mm	9.0E-07
10-50 mm	25 mm	9.0E-07
Full bore	50 mm	1.8E-07
Total		2.0E-06

In the current study, the "per transfer" based frequency is used to estimate the propane unloading leak rate accounting for 2 liquid arms. Three hole size categories are defined to cover the possible release ranges (from a 3 mm hole to the full bore rupture of a 2 inch arm). Each category is represented by an nominal hole size (representative hole size) assigned with a generic leak frequency on a per transfer base.

In order to unload 100 rail cars per every two days, each unloading station along the 13 double-side racks needs to offload on average 3.8 times every other day, which equates to about 702 times per station per year. Table I-20 summarizes the calculated propane unloading scenarios and leak frequencies analyzed in the Pembina facility QRA.

Since it takes time to hook up all 26 stations to reach the peak unloading rate of 1,700,000 pounds per hour, it is assumed that unloading of the 100 rail cars will take around 12 hours.

Table I-20: Summary of Propane Unload Leak Frequencies

Hole Diameter		Frequency (per unload station)			Frequency Total (26 stations)
Size (mm)	Range	per transfer	# of transfer per year	Frequency per year	Double-side racks per year
5	3 - 10 mm	9.0E-07	702	6.32E-04	1.64E-02
25	10 - 50 mm	9.0E-07	702	6.32E-04	1.64E-02
50	Full Bore (2 inch)	1.8E-07	702	1.26E-04	3.29E-03
			Total:	**1.39E-03**	**3.61E-02**

I.7.4 Rail Car Unloading Arm Scenarios & Leak Frequency

Assumption No.:	36
Implication on Assumption: Key influence on the risks (i.e. risk is directly proportional to frequency).	
References: 1. ACDS (1991), "Major Hazard Aspects of the Transport of Dangerous Substances", Advisory Committee on Dangerous Substances, Health & Safety Commission, HMSO.	
Comments:	

I.8 Marine Loading

I.8.1 Vessel Visits and Propane Loading Operation

Assumption No.:	37		
Revision:	0	**Prepared by:**	MINMIN 2015-02-24
Date:	24 February 2015	**Verified by:**	LDEAL 2015-02-24
Relevant Analysis:	Marine Loading Risk	**Category:**	Design

Specifications:

Marine Loading preparations at the facility begin before the propane carrier arrives. Propane is circulated through the recirculation line to cool the loading equipment to a suitable temperature. Recirculation occurs for a maximum of 24 hours prior to ship arrival. Loading is assumed to start within a couple of hours after the ship is berthed. After all preparations are complete, the vessel begins to receive propane through the loading line and simultaneously deballast. During this process, some of the cargo is boiled-off and returned to the facility through the vapor return line. Time to load a very large propane carrier with the capacity of 83,000 m^3 is assumed to be approximately 38 hours.

Upon completion of loading, the marine loading arms are isolated, and propane load line/vapor lines are left open to the large refrigerate storage tanks allowing the remaining inventory from the lines to vaporize. These lines are connected to the large propane storage tanks such that the pressure in the lines reaches equilibrium with that of the tanks (maximum of 19 psia). The lines remain in this state until preparations for the next vessel arrival begin. Once the vessel has undergone preparations for departing, it is ready to be pulled off the dock and back down the river, around 5000 ft to where it is turned, off Kelly Point. The ship could be held at dock up to 12 hours after being loaded waiting to sail based on passage availability at the mouth of the Columbia River.

In summary, the following key assumptions are applied for marine loading operations:

- Propane carrier proposed for the Pembina Portland terminal has the capacity of 83,000 m^3
- Approximately 26 vessel calls are assumed per year (averagely 2 ship visits per month) for the selected representative carrier
- Actual propane loading time is approximately 38 hours (based on ship size and propane loading rate of approximately 2200 m^3/hour) per visit
- Propane loading always begins during the day time
- There are two (2) 16” propane loading arm and one (1) 16” vapor return arm at the loading dock
- Size of the propane loading above ground pipe: loading line – 24”, vapor return line – 20”, recirculation line – 8”.

I.8.1 Vessel Visits and Propane Loading Operation

Assumption No.:	37

Implication on Assumption:

Key influence on the risks (i.e. risk is directly proportional to frequency).

References:

1. Hayes, Chris. Additional data request. [Email] Pembina, Jan-27-2015.
2. Process Flow Diagram Propane Ship Loading, Pembina Propane Terminal Portland Oregon, Rev. A1. SK E&C USA, Drawing no.14088D-PR-PF-1003-001.
3. DNV GL Expert Judgment.

Comments:

I.8.2 Marine Loading Arms, Scenarios & Leak Frequency

Assumption No.:	38		
Revision:	0	**Prepared by:**	MINMIN 2015-02-24
Date:	24 February 2015	**Verified by:**	LDEAL 2015-02-24
Relevant Analysis:	Propane Loading Risk	**Category:**	Design

Specifications:

The estimated leak frequency for loading arms per transfer is 7.6E-05 (Ref. 1). This is a generic failure rate for liquefied gas loading arm releases, and is considered likely to give a conservative total leak frequency. Note that it is largely based on loading with 2 arms, and thus could be factored to account for the actual number of arms. Assuming 26 transfers per year, the total loading arm leak frequency is 2.0E-03 per year.

Based on the failure data the following release sizes and probabilities are applied based on DNV GL's experience and comparison against hole size distributions for typical process leaks and road tanker loading arm failures (Ref. 2):

1. Full bore rupture - disconnection events such as ranging and PERC failures, major leaks or loading arm failures, due to mechanical or other failure modes (13%)
2. Large leak - as above, but release size is limited to hole size diameter of 75 mm; will apply the "Medium" category hole size of 50 mm (23%)
3. Small leak - as above, but release size is limited to hole size diameter of 12 mm; will apply the "Small" category hole size of 10 mm (64%).

Implication of Assumption

Key influence on the loading arm risks (i.e. risk is directly proportional to frequency).

References:

1. DNV GL Expert Judgement based on ACDS. Major hazard Aspects of the Transport of Dangerous Substances Advisory Committee on Dangerous Substances. *HMSO Major hazard aspects of the transport of dangerous substances.* Health & Safety Commission, 1991.
2. DNV GL Expert Judgment.

Comments:

APPENDIX II: SCENARIO DEVELOPMENT

Table of Contents

II SCENARIO DEVELOPMENT

II.1 Introduction

This appendix presents the analysis of major accident hazards identified and assessed for the Pembina Propane Terminal QRA Study, which includes all sections from the railcar release to the propane marine loading arms at the jetty. Above ground pipe release scenarios, such as the inter-unit pipe within the facility area, the rundown pipe, the propane loading/circulation pipe, and the vapor return pipe are also included in this QRA study.

II.2 Scenario Definition

The following sections provides a summary of the general approach adopted in defining representative release scenarios and describes the scenarios and key assumptions relevant to all the processes covered within the scope of this study.

II.2.1 Release Scenario Selection

The analysis was conducted on a sectional basis. Failure cases (i.e., specific release scenarios to be modeled in the QRA) have been defined by dividing the facility and systems into sections with similar characteristics using the following approach:

1. The first sectionalizing is achieved by identifying the equipment within an isolatable section. An isolatable section is defined as all equipment and piping between Emergency Shutdown Valves (ESDs). In doing so, the maximum inventory available for release is defined, assuming that shutdown will be initiated within a specified time after a release occurs.

2. Further sectionalizing of the plant is then performed on the basis of location. Equipment items in the same section with significantly different geographical locations are identified and different failure cases applied to each. However, the inventory available for release may be the same for both locations.

3. Having divided the facility according to isolatable sections and location, the next step is to further sectionalize according to the material or operating conditions handled by each equipment item. This process involves identifying the physical nature (i.e. phase, pressure, and temperature) of the material within each subsection and deciding if the subsections present significantly different characteristics that are worth differentiating.

To summarize, the key factors in the selection of these representative sections are:

- Isolation (consideration is given to whether the inventory that may be released can be isolated by ESD, noting that the time taken for such isolation to occur will be a key factor)
- Release location (the area in which the release occurs, including the height)
- Material / phase released (gas, pressurized liquid, cryogenic liquid, etc.)
- Operation conditions (temperature and pressure)

The representative release scenarios applied to the model are listed in Table II-1. The table gives a brief description of the release scenarios applied to the Phast Risk model for each section. An event ID is given to each release event representative of the defined sections:

- The first letter (area code) of the event ID corresponds to the area where the event occurs: R - railcar unloading, B – pressurized propane storage bullets, F – facility, S – refrigerated propane storage tanks, and M – marine propane loading.
- The number after the area code corresponds to the unit to which that event belongs.
- The number after the "-" corresponds to the isolatable segment within the related unit.
- Letters of the alphabet in the last digit of the ID (e.g. A and B) are used to further differentiate any related events within the same isolatable segment. Z denotes that this is the only event defined for the isolatable segment within the unit.

The following facility systems and corresponding unit number are included in the analysis:

- Propane Railcar Unloading: Unit 1001
- Propane Refrigeration: Unit 1002
- Propane Ship Loading: Unit 1003
- Propane Refrigerated Storage Tanks: Unit 1004

The Process Flow Diagrams (PFDs) marked up with the isolatable sections are attached to this appendix.

Table II-1: Release Scenario Piping and Equipment Groups

Event ID	Event Name	Representative Material (mole %)	Phase (Gas or Liquid)	Flow Rate (lb/hr)
R00-01Z	Propane Railcar Transit	97% C3, 3%C2	L	
R01-01Z	Railcar Unloading Arm	97% C3, 3%C2	L	33,000
R01-02Z	Railcar Vapor Return Arm	97% C3, 3%C2	G	77,704
R01-03Z	Unload Vapor Return – Compressor	97% C3, 3%C2	G	77,704
R01-04Z	Unloading Vapor Return - Piping to Railcar	97% C3, 3%C2	G	77,704
R01-05Z	Propane Unloading Pipe	97% C3, 3%C2	L	1,723,926
B01-06A	Propane Unloading Storage Group1 (connections) – Liquid	97% C3, 3%C2	L	1,723,926
B01-06B	Propane Unloading Storage Group1 (connections) – Gas	97% C3, 3%C2	G	77,704
B01-07A	Propane Unloading Storage Group2 (connections) – Liquid	97% C3, 3%C2	L	1,723,926
B01-07B	Propane Unloading Storage Group2 (connections) – Gas	97% C3, 3%C2	G	77,704
B01-08A	Propane Unloading Storage Group3 (connections) – Liquid	97% C3, 3%C2	L	1,723,926
B01-08B	Propane Unloading Storage Group3 (connections) – Gas	97% C3, 3%C2	G	77,704
B01-06C	Propane Unloading Storage Group1 – Bullets	97% C3, 3%C2	L	1,723,926
B01-07C	Propane Unloading Storage Group2 – Bullets	97% C3, 3%C2	L	1,723,926
B01-08C	Propane Unloading Storage Group3 – Bullets	97% C3, 3%C2	L	1,723,926
F02-06A	Propane Rundown Pumps	96% C3, 4%C2	L	348,044
F02-06B	Propane Rundown Pipe to Storage tanks	96% C3, 4%C2	L	348,096
S04-01A	Storage Tank 1 (connections) – Gas	86% C3, 14%C2	G	52,136
S04-01B	Storage Tank 1 (connections) – Liquid	96% C3, 4%C2	L	348,044
S04-02A	Storage Tank 2 (connections) – Gas	86% C3, 14%C2	G	52,136
S04-02B	Storage Tank 2 (connections) – Liquid	96% C3, 4%C2	L	348,044
S04-01C	Storage Tank 1	96% C3, 4%C2	L	
S04-02C	Storage Tank 2	96% C3, 4%C2	L	
S04-03Z	Vapor from Tank to BOG – Pipe	86% C3, 14%C2	G	52,136
M03-01L	Marine Propane Loading Line to Onshore ESD - Loading Mode	97% C3, 3%C2	L	2,935,173
M03-01H	Marine Propane Loading Line to Onshore ESD - Holding Mode	97% C3, 3%C2	L	348,044
M03-01R	Marine Propane Loading Line to Onshore ESD - Recirculation Mode	97% C3, 3%C2	L	100,000
M03-03Z	Propane Recirculation	97% C3, 3%C2	L	100,000
M03-04Z	Loading Vapor Return Line from Onshore ESD to Tank	97% C3, 3%C2	G	13,826
M03-05Z	Jetty Loading Pipe	97% C3, 3%C2	L	2,933,707
M03-06Z	Vapor Return from Jetty Pipe	97% C3, 3%C2	G	13,826
M03-07Z	Liquid Loading Arm	97% C3, 3%C2	L	2,933,707
M03-08Z	Vapor Recovery Loading Arm	97% C3, 3%C2	G	13,826
F02-01A	Propane Feed Pumps	97% C3, 3%C2	L	295,964
F02-01B	Propane Subcooler	97% C3, 3%C2	G	295,964
F02-01C	HP Suction Drum – Liquid	91% C3, 9%C2	L	459,052
F02-01D	HP Suction Drum – Gas	74% C3, 26%C2	G	234,666
F02-01E	HP Propane Compression	76% C3, 24%C2	G	345,673
F02-01F	BOG Air Cooler	86% C3, 14%C2	G	52,142
F02-02Z	BOG Compressor	86% C3, 14%C2	G	52,136

Event ID	Event Name	Representative Material (mole %)	Phase (Gas or Liquid)	Flow Rate (lb/hr)
F02-03A	MP Suction Drum – Liquid	94% C3, 6%C2	L	386,842
F02-03B	MP Suction Drum – Gas	77% C3, 23%C2	G	72,210
F02-03C	MP Propane Compression	78% C3, 22%C2	G	111,008
F02-04A	LP Suction Drum – Liquid	96% C3, 4%C2	L	348,044
F02-04B	LP Suction Drum – Gas	80%C3, 20%C2	G	38,798
F02-04C	LP Propane Compression	80%C3, 20%C2	G	38,798
F02-05A	Propane Air Cooler – Liquid	76% C3, 24%C2	L	345,673
F02-05B	Propane Air Cooler – Gas	76% C3, 24%C2	G	345,673
F02-05C	Propane Accumulator & Condenser – Liquid	76% C3, 24%C2	L	345,673
F02-05D	Propane Accumulator & Condenser – Gas	76% C3, 24%C2	G	345,673
EQ-01C-L	Propane Storage Tank Large Release (95 mm) due to Earthquake	96% C3, 4%C2	L	
EQ-01C-R	Propane Storage Tank Rupture Release (300 mm) due to Earthquake	96% C3, 4%C2	L	

II.2.2 Scenario Group Operation Conditions

The representative location and operating conditions selected for each of the release scenarios defined in the previous section are summarized in Table II-5. The selection of the group scenarios is based on the assumptions summarized below:

- The operating conditions (normal flow rate, pressure and temperature) are taken from the Pembina Propane Terminal PFDs Rev A1, Ref. (1).
- The representative release height from equipment has a default value of 1 m above ground.
- Releases related to the connections to the propane refrigerated storage tank (S04-01A/B and S04-02A/B) are assumed to be at 40.8 m (S04-01A/B) and 30.5 m (S04-02A/B) above ground level since the majority of the flanges, valves and connection points are located on top of the propane storage tanks. The large and rupture scenarios related to the tanks (S04-01C and S04-02C) are located at 1 m above ground.
- The material in each case is defined as either a single representative material or a mixture (the composition of which is described in terms of the mole % of each component) as described in the Heat & Material Balances (H&MB) Sheet, Ref (2).
- Note that the phase in each case is defined as either vapor or liquid, which corresponds to the phase of the fluid in the system (rather than the fluid on release). Two-phase releases apply to certain sections and are accounted for within the discharge modeling.

II.2.3 Hole Size Scenarios

For each of the release scenarios from equipment or piping, four representative release sizes are considered as listed below. This is also reported in Appendix I, Study Basis Assumption 12, Ref. (3).

Table II-2: Hole Size Categories – Leaks

Size Category	Representative Hole Size Range	Representative Hole Size	
	(mm)	(mm)	(in)
Small	3 - 25	10	0.4
Medium	25 - 75	50	2
Large	75 - 125	100	4
Full Bore Rupture	125 – Line Diameter	Line Diameter (if applicable)	

II.2.4 Release Detection and Isolation

A leak from any release source can be broken down into four distinct phases:

- Dynamic
- Detection and shutdown
- Isolation
- Static leak

During the dynamic phase, the operators have not yet recognized that a leak has occurred and the leak is continually fed by the source of supply. If the leak size is sufficiently large, the pressure will noticeably drop in the system and will be detected before making a decision to isolate the leak. The function of isolation valves is to limit the amount of material that can ultimately escape from the release point. Following closure of the isolation valves, the leak will continue until the pressure of the fluid in the system equals the atmospheric pressure. This phase could last for an extended period of time, depending on the size of the leak.

The detection and isolation time has key influence on the release duration and the total release inventory from the representative release hole size. The response time (detection and isolation) is affected by many factors including release size, release conditions, release material, etc. In general, the larger release rate (either caused by large hole size or high operation pressure), the shorter the response time; i.e. the worse consequence, the shorter the response time.

The following tables present the total isolation time to address release events at different locations in the facility, depending on the detection level (Appendix I, Study Basis Assumption 13), Ref. (3). Note that detection and response times may be considered conservative.

Table II-3: Representative Detection and Response Times*(Main Facility and Jetty)

Leak Size	Response Time (min)		Cumulative Time to Isolation Success (min)
	Detection	Isolation	
Small	5	1	6
Medium	5	1	6
Large	2	1	3
Full Bore Rupture	1	1	2

Table II-4: Representative Detection and Response Times*(Aboveground Pipe Locations)

Leak Size	Response Time (min)		Cumulative Time to Isolation (min)
	Detection	Isolation	
Small	15	5	20
Medium	5	5	10
Large	2	1	3
Rupture	1	1	2

* **Definition of Response Time Categories**

A release event occurs at time = 0s.

Detection: This is the time from when the release event starts till someone (or a detector) becomes aware of the release event. This may be the time for an operator in the field to detect the release or for the release cloud to trigger the gas detector alarms in the control room, further alerting the operator in the control room.

Isolation: This is the time from detection till the segment is isolated and the shutdown valves are closed. This period of time includes the time for operators to discuss the situation and decide whether to activate isolation and shutdown. This also includes the time for an operator to push the isolation / shutdown button and for the valves to close.

The total release inventory is calculated as a summation of static inventory and dynamic inventory feeding each isolatable segment. The static inventory is estimated based on vessel and piping dimensions combined with the density of the release material within the vessels and piping. In the event of an accidental release it is assumed that the associated shutdown valves will be actuated (where present), with some delay. The inventory source of supply continues to send release material to the release point until isolation valves close. The inventory that continues to flow into the system (e.g. delivered by pumps) during the detection and isolation periods is referred to as dynamic inventory. Dynamic inventory is considered to be the release amount through the leak hole until isolation takes place, which is calculated by multiplying the release rate by the time to isolation for each hole size category.

The representative release scenarios are listed in Table II-5. The total inventory released considers the static inventory (inventory in the equipment group) plus the dynamic inventory (inventory flowing into the system, prior to isolation). Storage tank scenarios were modeled as “liquid inventory”, where the inventory is more relevant than incoming flow.

Table II-5: Scenario Summary

Event Description	Scenario ID	Leak Size	Material (mole %)	Gas or Liquid	T (°F)	P (psia)	Static Inventory (lb)	Flow Rate (lb/hr)	Total Inventory	
									(kg)	(lb)
Railcar Transit	R00-01Z-3H	3 inch leak	97% C3, 3%C2	L	85 (summer) 35 (winter)	150 (summer) 75 (winter)	162,946		73,911	162,946
	R00-01Z-2C	2 car rupture	97% C3, 3%C2	L	85 (summer) 35 (winter)	150 (summer) 75 (winter)	325,892		147,822	325,892
	R00-01Z-6C	6 car rupture	97% C3, 3%C2	L	85 (summer) 35 (winter)	150 (summer) 75 (winter)	977,676		443,466	977,676
	R00-01Z-14C	14 car rupture	97% C3, 3%C2	L	85 (summer) 35 (winter)	150 (summer) 75 (winter)	2,281,244		1,034,754	2,281,244
Railcar Unloading arm	R01-01Z-S	Small leak	97% C3, 3%C2	L	85	150	162,946		73,911	162,946
	R01-01Z-M	Medium leak	97% C3, 3%C2	L	85	150	162,946		73,911	162,946
Railcar vapor return arm	R01-02Z-S	Small leak	97% C3, 3%C2	G	82	147.3	162,946	77,779	73,911	162,946
	R01-02Z-M	Medium leak	97% C3, 3%C2	G	82	147.3	162,946	77,779	73,911	162,946
Unloading Vapor Return - compressor	R01-03Z-S	Small leak	97% C3, 3%C2	G	108.3	195.1	459	77,779	302	666
	R01-03Z-M	Medium leak	97% C3, 3%C2	G	108.3	195.1	459	77,779	2,548	5,617
	R01-03Z-L	Large leak	97% C3, 3%C2	G	108.3	195.1	459	77,779	1,970	4,343
	R01-03Z-R	Rupture	97% C3, 3%C2	G	108.3	195.1	459	77,779	1,383	3,049
Unloading Vapor Return - piping to railcar	R01-04Z-S	Small leak	97% C3, 3%C2	G	82	147.3	348	77,779	396	873
	R01-04Z-M	Medium leak	97% C3, 3%C2	G	82	147.3	348	77,779	3,127	6,894
	R01-04Z-L	Large leak	97% C3, 3%C2	G	82	147.3	348	77,779	1,920	4,233
	R01-04Z-R	Rupture	97% C3, 3%C2	G	82	147.3	348	77,779	1,333	2,939
Propane Unloading Pipe	R01-05Z-S	Small leak	97% C3, 3%C2	L	82	189.7	22,441	1,723,043	12,196	26,888
	R01-05Z-M	Medium leak	97% C3, 3%C2	L	82	189.7	22,441	1,723,043	35,394	78,030
	R01-05Z-L	Large leak	97% C3, 3%C2	L	82	189.7	22,441	1,723,043	40,437	89,148
	R01-05Z-R	Rupture	97% C3, 3%C2	L	82	189.7	22,441	1,723,043	36,235	79,884
Propane Unloading Storage Group1 (connections) – Liquid*	B01-06A-S	Small leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-06A-M	Medium leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-06A-L	Large leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-06A-R	Rupture	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
Propane Unloading Storage Group1 (connections) – Gas*	B01-06B-S	Small leak	97% C3, 3%C2	G	82	147.3	491,776	77,779	223,066	491,776
	B01-06B-M	Medium leak	97% C3, 3%C2	G	82	147.3	491,776	77,779	223,066	491,776
	B01-06B-L	Large leak	97% C3, 3%C2	G	82	147.3	491,776	77,779	223,066	491,776
	B01-06B-R	Rupture	97% C3, 3%C2	G	82	147.3	491,776	77,779	223,066	491,776
Propane Unloading Storage Group2 (connections) – Liquid*	B01-07A-S	Small leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-07A-M	Medium leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-07A-L	Large leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-07A-R	Rupture	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
Propane Unloading Storage Group2 (connections) – Gas*	B01-07B-S	Small leak	97% C3, 3%C2	G	82	147.3	491,776	77,779	223,066	491,776
	B01-07B-M	Medium leak	97% C3, 3%C2	G	82	147.3	491,776	77,779	223,066	491,776
	B01-07B-L	Large leak	97% C3, 3%C2	G	82	147.3	491,776	77,779	223,066	491,776
	B01-07B-R	Rupture	97% C3, 3%C2	G	82	147.3	491,776	77,779	223,066	491,776
Propane Unloading Storage Group3 (connections) – Liquid*	B01-08A-S	Small leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-08A-M	Medium leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-08A-L	Large leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-08A-R	Rupture	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
Propane Unloading Storage Group3 (connections) – Gas*	B01-08B-S	Small leak	97% C3, 3%C2	G	82	147.3	491,776	77,779	223,066	491,776
	B01-08B-M	Medium leak	97% C3, 3%C2	G	82	147.3	491,776	77,779	223,066	491,776
	B01-08B-L	Large leak	97% C3, 3%C2	G	82	147.3	491,776	77,779	223,066	491,776
	B01-08B-R	Rupture	97% C3, 3%C2	G	82	147.3	491,776	77,779	223,066	491,776
Propane Unloading Storage Group1 – Bullets	B01-06C-S	Small leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-06C-M	Medium leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-06C-L	Large leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-06C-R	Rupture	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-06C-BLEVE	BLEVE	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
Propane Unloading Storage Group2 – Bullets	B01-07C-S	Small leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-07C-M	Medium leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-07C-L	Large leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-07C-R	Rupture	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-07C-BLEVE	BLEVE	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
Propane Unloading Storage Group3 – Bullets	B01-08C-S	Small leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-08C-M	Medium leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-08C-L	Large leak	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-08C-R	Rupture	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
	B01-08C-BLEVE	BLEVE	97% C3, 3%C2	L	85	174.7	491,776	1,723,043	223,066	491,776
Propane Rundown Pumps	F02-06A-S	Small leak	96% C3, 4%C2	L	-42.2	18.5	450	347,624	300	661
	F02-06A-M	Medium leak	96% C3, 4%C2	L	-42.2	18.5	450	347,624	2,607	5,747
	F02-06A-L	Large leak	96% C3, 4%C2	L	-42.2	18.5	450	347,624	5,010	11,045
	F02-06A-R	Rupture	96% C3, 4%C2	L	-42.2	18.5	450	347,624	5,465	12,048
Propane Rundown Pipe to Storage	F02-06B-S	Small leak	96% C3, 4%C2	L	-46.5	16.5	22,979	347,624	10,645	23,468
	F02-06B-M	Medium leak	96% C3, 4%C2	L	-46.5	16.5	22,979	347,624	13,189	29,077
	F02-06B-L	Large leak	96% C3, 4%C2	L	-46.5	16.5	22,979	347,624	13,743	30,298

Event Description	Scenario ID	Leak Size	Material (mole %)	Gas or Liquid	T (°F)	P (psia)	Static Inventory (lb)	Flow Rate (lb/hr)	Total Inventory	
									(kg)	(lb)
Tank	F02-06B-R	Rupture	96% C3, 4%C2	L	-46.5	16.5	22,979	347,624	15,685	34,579
Storage Tank 1 - connections – Gas*	S04-01A-S	Small leak	86% C3, 14%C2	G	-41	15.7	118,076,193	52,382	53,558,524	118,076,193
	S04-01A-M	Medium leak	86% C3, 14%C2	G	-41	15.7	118,076,193	52,382	53,558,524	118,076,193
	S04-01A-L	Large leak	86% C3, 14%C2	G	-41	15.7	118,076,193	52,382	53,558,524	118,076,193
	S04-01A-R	Rupture	86% C3, 14%C2	G	-41	15.7	118,076,193	52,382	53,558,524	118,076,193
Storage Tank 1 - connections – Liquid*	S04-01B-S	Small leak	96% C3, 4%C2	L	-44	19	313	347,624	483	1,065
	S04-01B-M	Medium leak	96% C3, 4%C2	L	-44	19	313	347,624	4,405	9,711
	S04-01B-L	Large leak	96% C3, 4%C2	L	-44	19	313	347,624	5,258	11,592
	S04-01B-R	Rupture	96% C3, 4%C2	L	-44	19	313	347,624	5,403	11,912
Storage Tank 2 - connections – Gas*	S04-02A-S	Small leak	86% C3, 14%C2	G	-41	15.7	55,755,572	52,382	25,290,332	55,755,572
	S04-02A-M	Medium leak	86% C3, 14%C2	G	-41	15.7	55,755,572	52,382	25,290,332	55,755,572
	S04-02A-L	Large leak	86% C3, 14%C2	G	-41	15.7	55,755,572	52,382	25,290,332	55,755,572
	S04-02A-R	Rupture	86% C3, 14%C2	G	-41	15.7	55,755,572	52,382	25,290,332	55,755,572
Storage Tank 2 - connections – Liquid*	S04-02B-S	Small leak	96% C3, 4%C2	L	-44	19	313	347,624	483	1,065
	S04-02B-M	Medium leak	96% C3, 4%C2	L	-44	19	313	347,624	4,405	9,711
	S04-02B-L	Large leak	96% C3, 4%C2	L	-44	19	313	347,624	5,258	11,592
	S04-02B-R	Rupture	96% C3, 4%C2	L	-44	19	313	347,624	5,403	11,912
Storage Tank 1	S04-01C-R1	Rupture1	96% C3, 4%C2	L	-44	19	118,076,193		53,558,524	118,076,193
	S04-01C-R2	Rupture2	96% C3, 4%C2	L	-44	19	118,076,193		53,558,524	118,076,193
	S04-01C-R3	Rupture3	96% C3, 4%C2	L	-44	19	118,076,193		53,558,524	118,076,193
Storage Tank 2	S04-02C-R1	Rupture1	96% C3, 4%C2	L	-44	19	55,755,572		25,290,332	55,755,572
	S04-02C-R2	Rupture2	96% C3, 4%C2	L	-44	19	55,755,572		25,290,332	55,755,572
	S04-02C-R3	Rupture3	96% C3, 4%C2	L	-44	19	55,755,572		25,290,332	55,755,572
Vapor from Tank to BOG – pipe	S04-03Z-S	Small leak	86% C3, 14%C2	G	-41	15.7	71	52,382	42	93
	S04-03Z-M	Medium leak	86% C3, 14%C2	G	-41	15.7	71	52,382	159	351
	S04-03Z-L	Large leak	86% C3, 14%C2	G	-41	15.7	71	52,382	185	408
	S04-03Z-R	Rupture	86% C3, 14%C2	G	-41	15.7	71	52,382	820	1,808
Marine Propane Loading Line - Loading Mode	M03-01L-S	Small leak	97% C3, 3%C2	L	-42.9	110.9	354,778	2,934,173	162,538	358,335
	M03-01L-M	Medium leak	97% C3, 3%C2	L	-42.9	110.9	354,778	2,934,173	181,085	399,224
	M03-01L-L	Large leak	97% C3, 3%C2	L	-42.9	110.9	354,778	2,934,173	185,117	408,113
	M03-01L-R	Rupture	97% C3, 3%C2	L	-42.9	110.9	354,778	2,934,173	205,288	452,582
Marine Propane Loading Line - Holding Mode**	M03-01H-S	Small leak	97% C3, 3%C2	L	-42.9	19	177,388		80,462	177,388
	M03-01H-M	Medium leak	97% C3, 3%C2	L	-42.9	19	177,388		80,462	177,388
	M03-01H-L	Large leak	97% C3, 3%C2	L	-42.9	19	177,388		80,462	177,388
	M03-01H-R	Rupture	97% C3, 3%C2	L	-42.9	19	177,388		80,462	177,388
Marine Propane Loading Line – Recirculation Mode	M03-01R-S	Small leak	97% C3, 3%C2	L	-42.6	81.1	354,485	100,002	162,132	357,439
	M03-01R-M	Medium leak	97% C3, 3%C2	L	-42.6	81.1	354,485	100,002	168,349	371,146
	M03-01R-L	Large leak	97% C3, 3%C2	L	-42.6	81.1	354,485	100,002	163,059	359,483
	M03-01R-R	Rupture	97% C3, 3%C2	L	-42.6	81.1	354,485	100,002	162,303	357,816
Propane Recirculation	M03-03Z-S	Small leak	97% C3, 3%C2	L	-42.6	81.1	40,470	100,002	19,698	43,427
	M03-03Z-M	Medium leak	97% C3, 3%C2	L	-42.6	81.1	40,470	100,002	25,915	57,133
	M03-03Z-L	Large leak	97% C3, 3%C2	L	-42.6	81.1	40,470	100,002	20,625	45,470
	M03-03Z-R	Rupture	97% C3, 3%C2	L	-42.6	81.1	40,470	100,002	19,869	43,804
Loading Vapor Return Line to Tank	M03-04Z-S	Small leak	97% C3, 3%C2	G	-10	17.6	1,129	13,492	530	1,168
	M03-04Z-M	Medium leak	97% C3, 3%C2	G	-10	17.6	1,129	13,492	730	1,609
	M03-04Z-L	Large leak	97% C3, 3%C2	G	-10	17.6	1,129	13,492	773	1,704
	M03-04Z-R	Rupture	97% C3, 3%C2	G	-10	17.6	1,129	13,492	721	1,590
Jetty Loading Pipe	M03-05Z-S	Small leak	97% C3, 3%C2	L	-42.9	110.9	3,616	2,932,586	3,253	7,172
	M03-05Z-M	Medium leak	97% C3, 3%C2	L	-42.9	110.9	3,616	2,932,586	21,800	48,061
	M03-05Z-L	Large leak	97% C3, 3%C2	L	-42.9	110.9	3,616	2,932,586	25,832	56,950
	M03-05Z-R	Rupture	97% C3, 3%C2	L	-42.9	110.9	3,616	2,932,586	45,982	101,373
Vapor Return from Jetty Pipe	M03-06Z-S	Small leak	97% C3, 3%C2	G	-10	17.6	37	13,492	35	77
	M03-06Z-M	Medium leak	97% C3, 3%C2	G	-10	17.6	37	13,492	234	516
	M03-06Z-L	Large leak	97% C3, 3%C2	G	-10	17.6	37	13,492	278	613
	M03-06Z-R	Rupture	97% C3, 3%C2	G	-10	17.6	37	13,492	226	498
Liquid Loading Arm	M03-07Z-S	Small leak	97% C3, 3%C2	L	-42.9	110.9	805	2,932,586	848	1,870
	M03-07Z-M	Medium leak	97% C3, 3%C2	L	-42.9	110.9	805	2,932,586	12,461	27,472
	M03-07Z-R	Rupture	97% C3, 3%C2	L	-42.9	110.9	805	2,932,586	44,706	98,560
Vapor Recovery Loading Arm	M03-08Z-S	Small leak	97% C3, 3%C2	G	-10	17.6	4	13,492	7	15
	M03-08Z-M	Medium leak	97% C3, 3%C2	G	-10	17.6	4	13,492	132	291
	M03-08Z-R	Rupture	97% C3, 3%C2	G	-10	17.6	4	13,492	211	465
Propane Feed Pumps	F02-01A-S	Small leak	97% C3, 3%C2	L	85	161.2	8,064	296,036	4,213	9,288
	F02-01A-M	Medium leak	97% C3, 3%C2	L	85	161.2	8,064	296,036	17,078	37,651
	F02-01A-L	Large leak	97% C3, 3%C2	L	85	161.2	8,064	296,036	10,368	22,858
	F02-01A-R	Rupture	97% C3, 3%C2	L	85	161.2	8,064	296,036	8,132	17,928
Propane Subcooler	F02-01B-S	Small leak	97% C3, 3%C2	G	50.3	96	170	296,036	124	273
	F02-01B-M	Medium leak	97% C3, 3%C2	G	50.3	96	170	296,036	1,245	2,745
	F02-01B-L	Large leak	97% C3, 3%C2	G	50.3	96	170	296,036	2,412	5,318
	F02-01B-R	Rupture	97% C3, 3%C2	G	50.3	96	170	296,036	4,551	10,033
HP Suction Drum –	F02-01C-S	Small leak	91% C3, 9%C2	L	37.6	96	11,964	458,737	5,850	12,897
	F02-01C-M	Medium leak	91% C3, 9%C2	L	37.6	96	11,964	458,737	15,993	35,258

Event Description	Scenario ID	Leak Size	Material (mole %)	Gas or Liquid	T (°F)	P (psia)	Static Inventory (lb)	Flow Rate (lb/hr)	Total Inventory	
									(kg)	(lb)
liquid	F02-01C-L	Large leak	91% C3, 9%C2	L	37.6	96	11,964	458,737	11,687	25,765
	F02-01C-R	Rupture	91% C3, 9%C2	L	37.6	96	11,964	458,737	12,365	27,260
HP Suction Drum – gas	F02-01D-S	Small leak	74% C3, 26%C2	G	37.6	96	11,462	234,924	5,245	11,563
	F02-01D-M	Medium leak	74% C3, 26%C2	G	37.6	96	11,462	234,924	6,337	13,971
	F02-01D-L	Large leak	74% C3, 26%C2	G	37.6	96	11,462	234,924	7,475	16,480
	F02-01D-R	Rupture	74% C3, 26%C2	G	37.6	96	11,462	234,924	8,746	19,282
HP Propane Compression	F02-01E-S	Small leak	76% C3, 24%C2	G	174.5	341.9	46	345,243	173	381
	F02-01E-M	Medium leak	76% C3, 24%C2	G	174.5	341.9	46	345,243	3,822	8,426
	F02-01E-L	Large leak	76% C3, 24%C2	G	174.5	341.9	46	345,243	7,622	16,804
	F02-01E-R	Rupture	76% C3, 24%C2	G	174.5	341.9	46	345,243	5,246	11,565
BOG Air Cooler	F02-01F-S	Small leak	86% C3, 14%C2	G	107.9	96	159	52,382	115	254
	F02-01F-M	Medium leak	86% C3, 14%C2	G	107.9	96	159	52,382	1,137	2,507
	F02-01F-L	Large leak	86% C3, 14%C2	G	107.9	96	159	52,382	1,254	2,765
	F02-01F-R	Rupture	86% C3, 14%C2	G	107.9	96	159	52,382	860	1,896
BOG Compressor	F02-02Z-S	Small leak	86% C3, 14%C2	G	122	113	15	52,382	57	126
	F02-02Z-M	Medium leak	86% C3, 14%C2	G	122	113	15	52,382	1,253	2,762
	F02-02Z-L	Large leak	86% C3, 14%C2	G	122	113	15	52,382	1,189	2,621
	F02-02Z-R	Rupture	86% C3, 14%C2	G	122	113	15	52,382	795	1,753
MP Suction Drum – liquid	F02-03A-S	Small leak	94% C3, 6%C2	L	-8.5	40	12,804	386,514	6,051	13,340
	F02-03A-M	Medium leak	94% C3, 6%C2	L	-8.5	40	12,804	386,514	11,884	26,200
	F02-03A-L	Large leak	94% C3, 6%C2	L	-8.5	40	12,804	386,514	14,578	32,139
	F02-03A-R	Rupture	94% C3, 6%C2	L	-8.5	40	12,804	386,514	11,655	25,695
MP Suction Drum – gas	F02-03B-S	Small leak	77% C3, 23%C2	G	-8.5	40	12,229	72,223	5,566	12,271
	F02-03B-M	Medium leak	77% C3, 23%C2	G	-8.5	40	12,229	72,223	6,013	13,256
	F02-03B-L	Large leak	77% C3, 23%C2	G	-8.5	40	12,229	72,223	6,478	14,282
	F02-03B-R	Rupture	77% C3, 23%C2	G	-8.5	40	12,229	72,223	6,639	14,636
MP Propane Compression	F02-03C-S	Small leak	78% C3, 22%C2	G	78.3	96	13	111,113	49	108
	F02-03C-M	Medium leak	78% C3, 22%C2	G	78.3	96	13	111,113	1,093	2,410
	F02-03C-L	Large leak	78% C3, 22%C2	G	78.3	96	13	111,113	2,180	4,806
	F02-03C-R	Rupture	78% C3, 22%C2	G	78.3	96	13	111,113	1,684	3,713
LP Suction Drum – liquid	F02-04A-S	Small leak	96% C3, 4%C2	L	-42.2	18.5	13,360	347,624	6,156	13,572
	F02-04A-M	Medium leak	96% C3, 4%C2	L	-42.2	18.5	13,360	347,624	8,463	18,658
	F02-04A-L	Large leak	96% C3, 4%C2	L	-42.2	18.5	13,360	347,624	10,866	23,955
	F02-04A-R	Rupture	96% C3, 4%C2	L	-42.2	18.5	13,360	347,624	9,691	21,365
LP Suction Drum – gas	F02-04B-S	Small leak	80%C3, 20%C2	G	-42.8	16.5	12,745	38,889	5,785	12,754
	F02-04B-M	Medium leak	80%C3, 20%C2	G	-42.8	16.5	12,745	38,889	5,884	12,972
	F02-04B-L	Large leak	80%C3, 20%C2	G	-42.8	16.5	12,745	38,889	5,986	13,197
	F02-04B-R	Rupture	80%C3, 20%C2	G	-42.8	16.5	12,745	38,889	6,368	14,039
LP Propane Compression	F02-04C-S	Small leak	80%C3, 20%C2	G	27.5	40	7	38,889	20	44
	F02-04C-M	Medium leak	80%C3, 20%C2	G	27.5	40	7	38,889	450	992
	F02-04C-L	Large leak	80%C3, 20%C2	G	27.5	40	7	38,889	882	1,944
	F02-04C-R	Rupture	80%C3, 20%C2	G	27.5	40	7	38,889	589	1,299
Propane Air Cooler – Liquid	F02-05A-S	Small leak	76% C3, 24%C2	L	110	336.9	2,608	345,243	1,881	4,147
	F02-05A-M	Medium leak	76% C3, 24%C2	L	110	336.9	2,608	345,243	16,857	37,163
	F02-05A-L	Large leak	76% C3, 24%C2	L	110	336.9	2,608	345,243	9,020	19,886
	F02-05A-R	Rupture	76% C3, 24%C2	L	110	336.9	2,608	345,243	6,407	14,125
Propane Air Cooler – Gas	F02-05B-S	Small leak	76% C3, 24%C2	G	174.5	341.9	143	345,243	217	478
	F02-05B-M	Medium leak	76% C3, 24%C2	G	174.5	341.9	143	345,243	3,863	8,516
	F02-05B-L	Large leak	76% C3, 24%C2	G	174.5	341.9	143	345,243	7,661	16,890
	F02-05B-R	Rupture	76% C3, 24%C2	G	174.5	341.9	143	345,243	5,290	11,662
Propane Accumulator & Condenser - Liquid	F02-05C-S	Small leak	76% C3, 24%C2	L	110	336.9	9,952	345,243	5,212	11,490
	F02-05C-M	Medium leak	76% C3, 24%C2	L	110	336.9	9,952	345,243	20,188	44,507
	F02-05C-L	Large leak	76% C3, 24%C2	L	110	336.9	9,952	345,243	12,351	27,229
	F02-05C-R	Rupture	76% C3, 24%C2	L	110	336.9	9,952	345,243	9,738	21,469
Propane Accumulator & Condenser - Gas	F02-05D-S	Small leak	76% C3, 24%C2	G	174.5	341.9	9,689	345,243	4,547	10,024
	F02-05D-M	Medium leak	76% C3, 24%C2	G	174.5	341.9	9,689	345,243	8,193	18,062
	F02-05D-L	Large leak	76% C3, 24%C2	G	174.5	341.9	9,689	345,243	11,991	26,436
	F02-05D-R	Rupture	76% C3, 24%C2	G	174.5	341.9	9,689	345,243	9,620	21,208
Earthquake	EQ-01C-L	Large leak	96% C3, 4%C2	L	-44	19	118,076,193		53,558,524	118,076,193
	EQ-01C-R	Rupture	96% C3, 4%C2	L	-44	19	118,076,193		53,558,524	118,076,193

Note:

*: These events are not releases from the tanks but releases from the connections associated with the tanks.

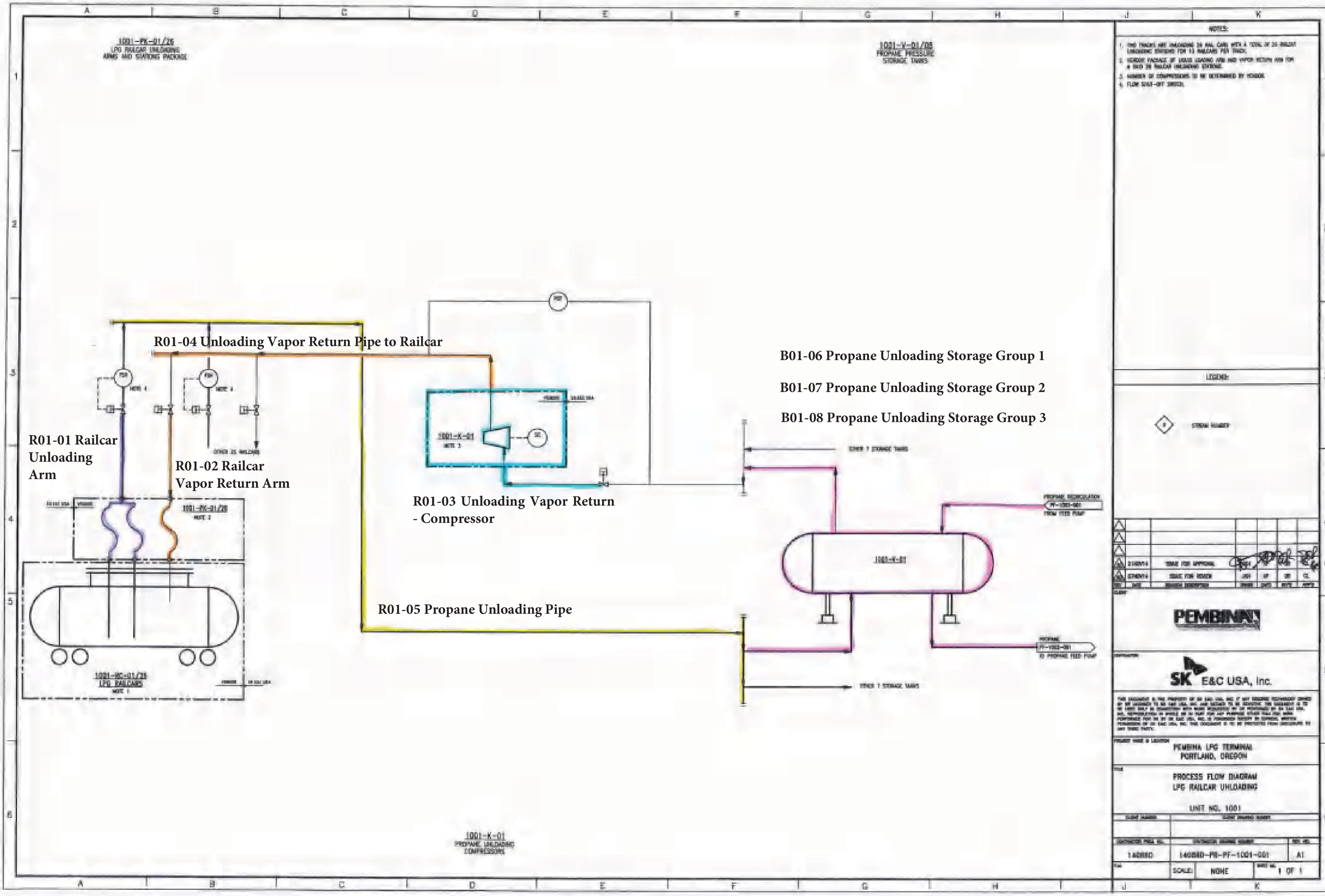
**: This event reflects the marine loading pipe during the holding mode. Once the ship finishes loading, the marine loading pipe will be full of propane. The pipe will be left full, but open to the storage tank. Thus propane will slowly vaporize and go back to the tank. The pipe is expected to be empty by the time the next ship comes in. Hence the pipe is conservatively assumed to be 50% full and has no dynamic inventory.

II.3 References

1. *Pembina LPG Terminal Process Flow Diagram, Rev. A1, SK E&C USA, 2014-11-21.*
2. *Pembina LPG Terminal Project Heat & Mass Balances, SK E&C USA, Rev. A, 2014-11-18.*
3. *Pembina Propane Facility QRA Study - Study Basis, Rev. 0, DNV GL 2015-02-24.*

ATTACHMENT II-1

PFDS MARKED BY ISOLATABLE SECTIONS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1001-V-01/08
PROPANE PRESSURE STORAGE TANKS
R01-04 Unloading Vapor Return Pipe to Railcar
B01-06 Propane Unloading Storage Group 1
B01-07 Propane Unloading Storage Group 2
B01-08 Propane Unloading Storage Group 3
R01-01 Railcar Unloading Arm
R01-02 Railcar Vapor Return Arm
1001-K-01
R01-03 Unloading Vapor Return - Compressor
R01-05 Propane Unloading Pipe
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PROPANE UNLOADING COMPRESSORS
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SK E&C USA, Inc.
PEMBINA LPG TERMINAL
PORTLAND, OREGON
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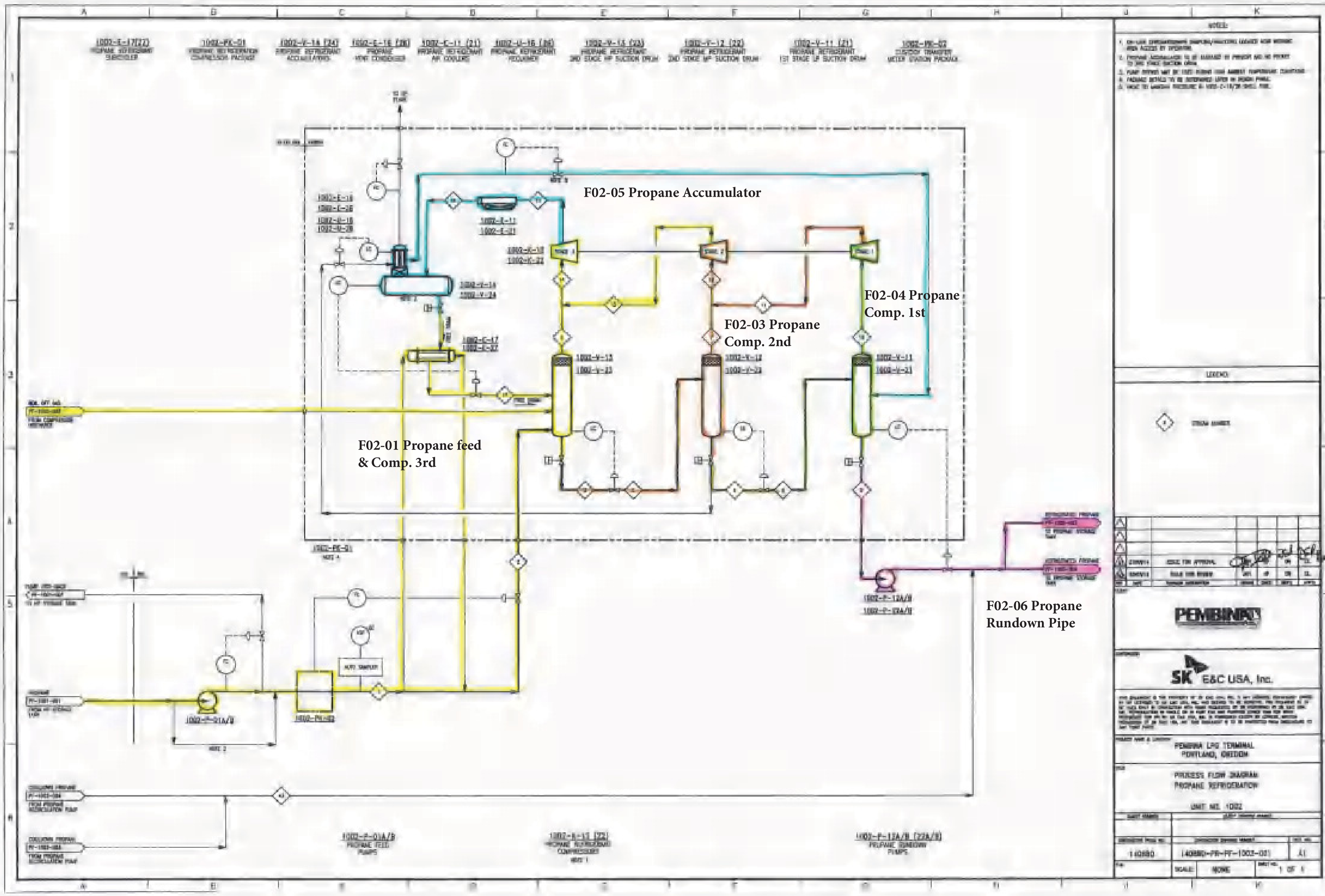

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F02-04 Propane Comp. 1st
F02-03 Propane Comp. 2nd
F02-01 Propane feed & Comp. 3rd
F02-06 Propane Rundown Pipe
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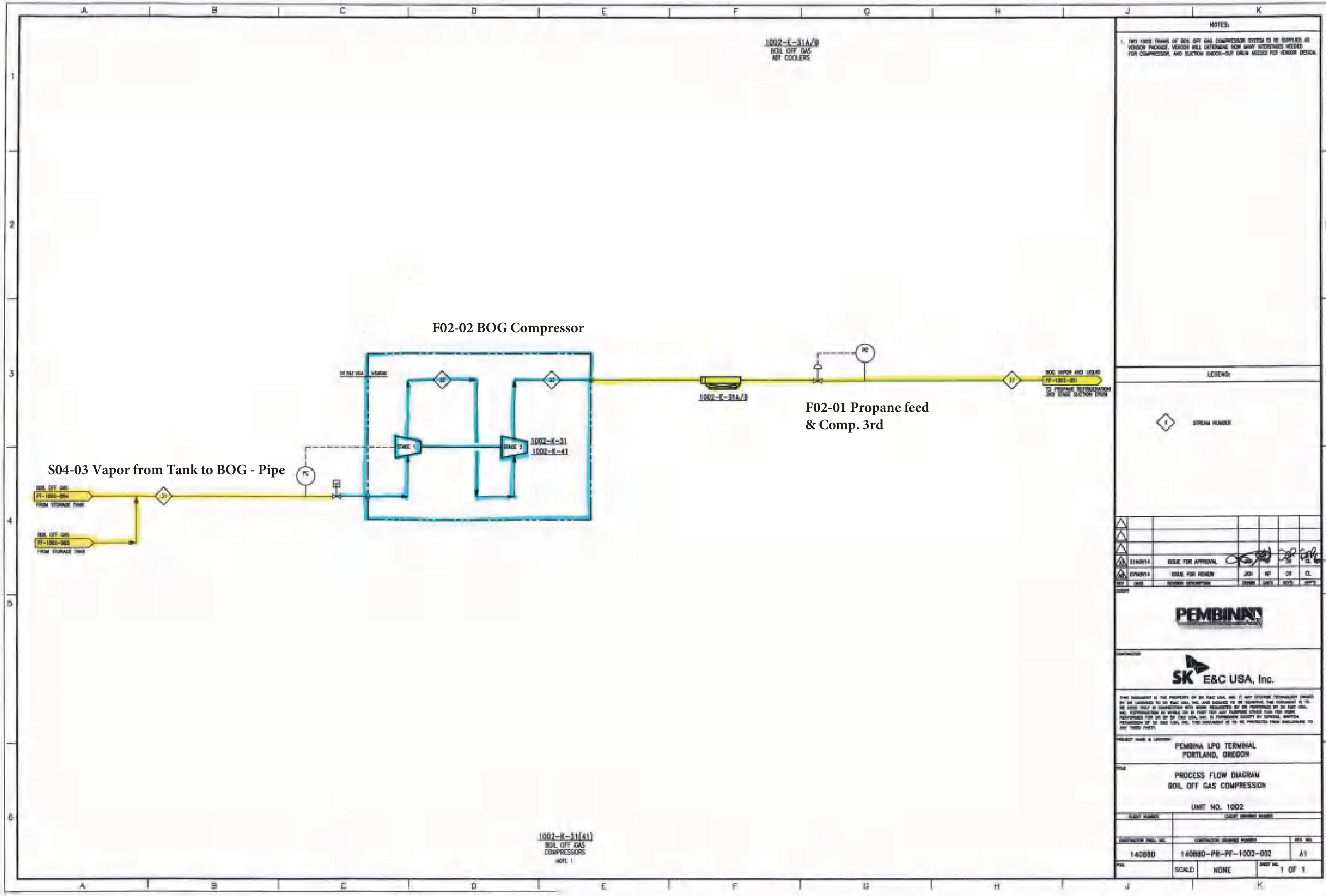
SK E&C USA, Inc.
PEMBINA LPG TERMINAL PORTLAND, OREGON
PROCESS FLOW DIAGRAM PROPANE REFRIGERATION
UNIT NO. 1002



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F02-01 Propane feed
& Comp. 3rd
S04-03 Vapor from Tank to BOG - Pipe
1002-E-31A/B
1002-K-31
1002-K-41
BOIL OFF GAS
FROM STORAGE TANK
BOG VAPOR AND LIQUID
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COMPRESSORS
NOTE 1
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ISSUE FOR APPROVAL
ISSUE FOR REVIEW
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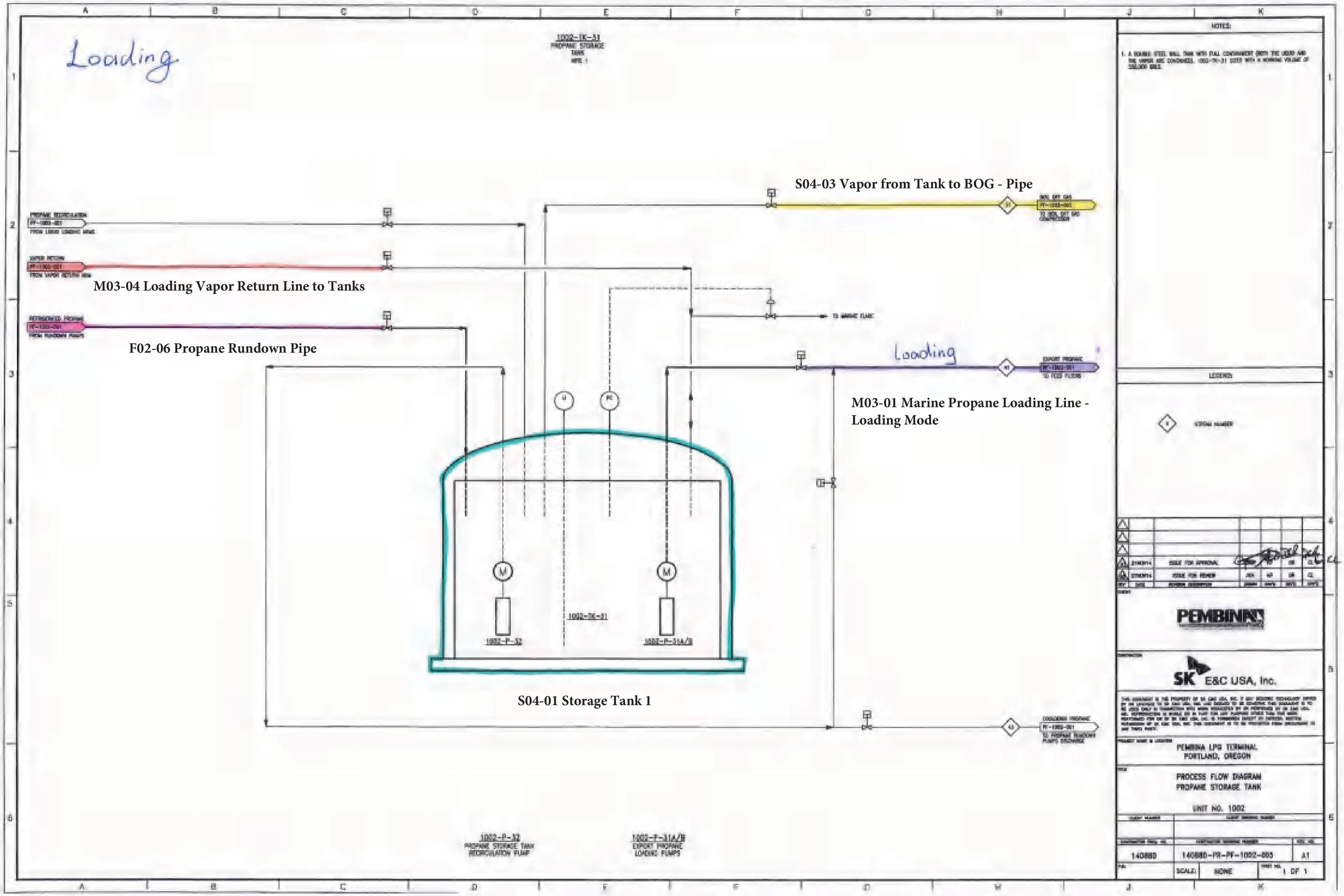
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M03-04 Loading Vapor Return Line to Tanks
F02-06 Propane Rundown Pipe
Loading
M03-01 Marine Propane Loading Line - Loading Mode
S04-01 Storage Tank 1
1002-P-32
1002-P-31A/B
1002-TK-31
1002-P-32
PROPANE STORAGE TANK RECIRCULATION PUMP
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EXPORT PROPANE LOADING PUMPS
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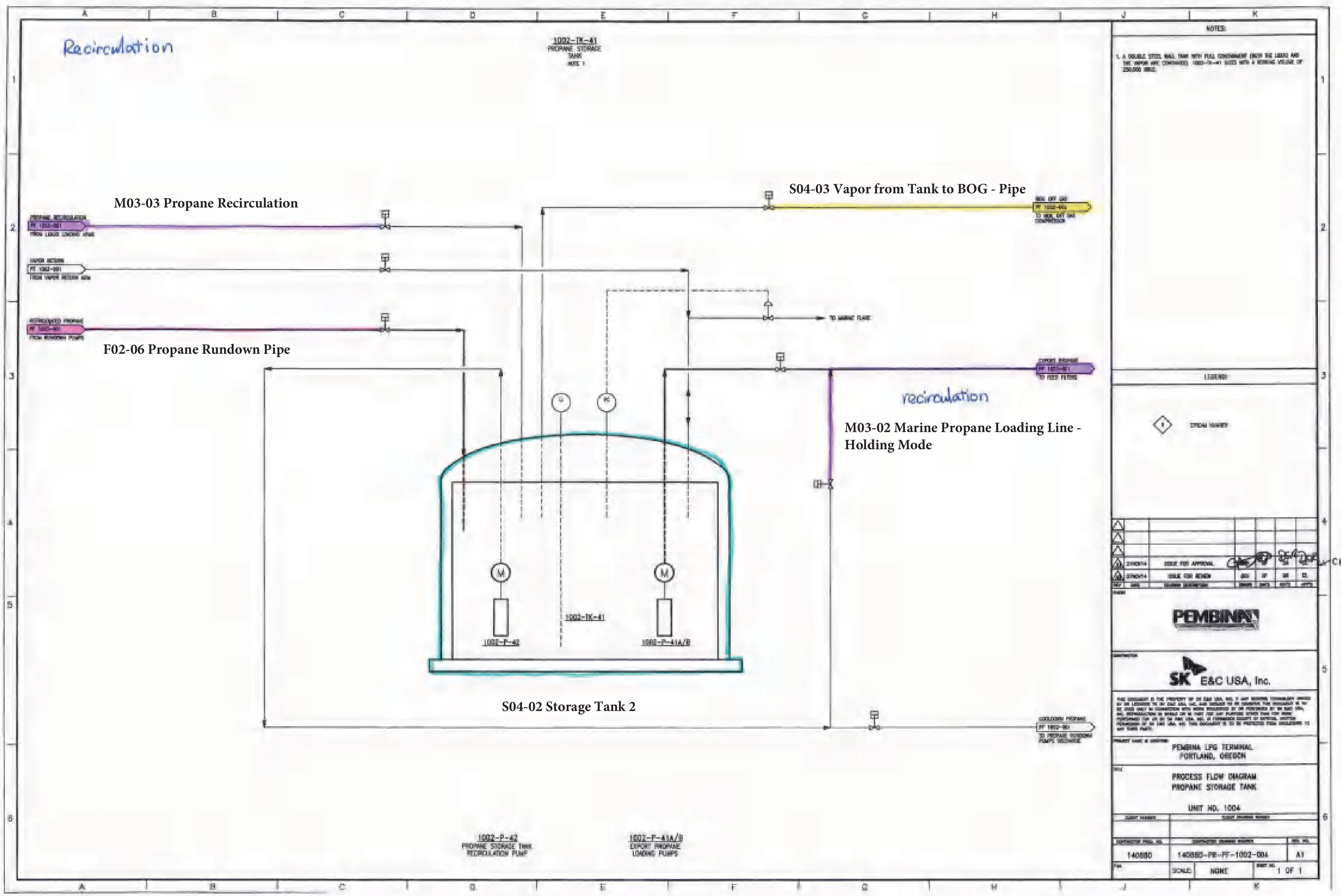
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F02-06 Propane Rundown Pipe
TO MARINE FLARE
recirculation
M03-02 Marine Propane Loading Line - Holding Mode
S04-02 Storage Tank 2
1002-TK-41
1002-P-42
1002-P-41A/B
1002-P-42
PROPANE STORAGE TANK
RECIRCULATION PUMP
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EXPORT PROPANE
LOADING PUMPS
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ISSUE FOR REVIEW
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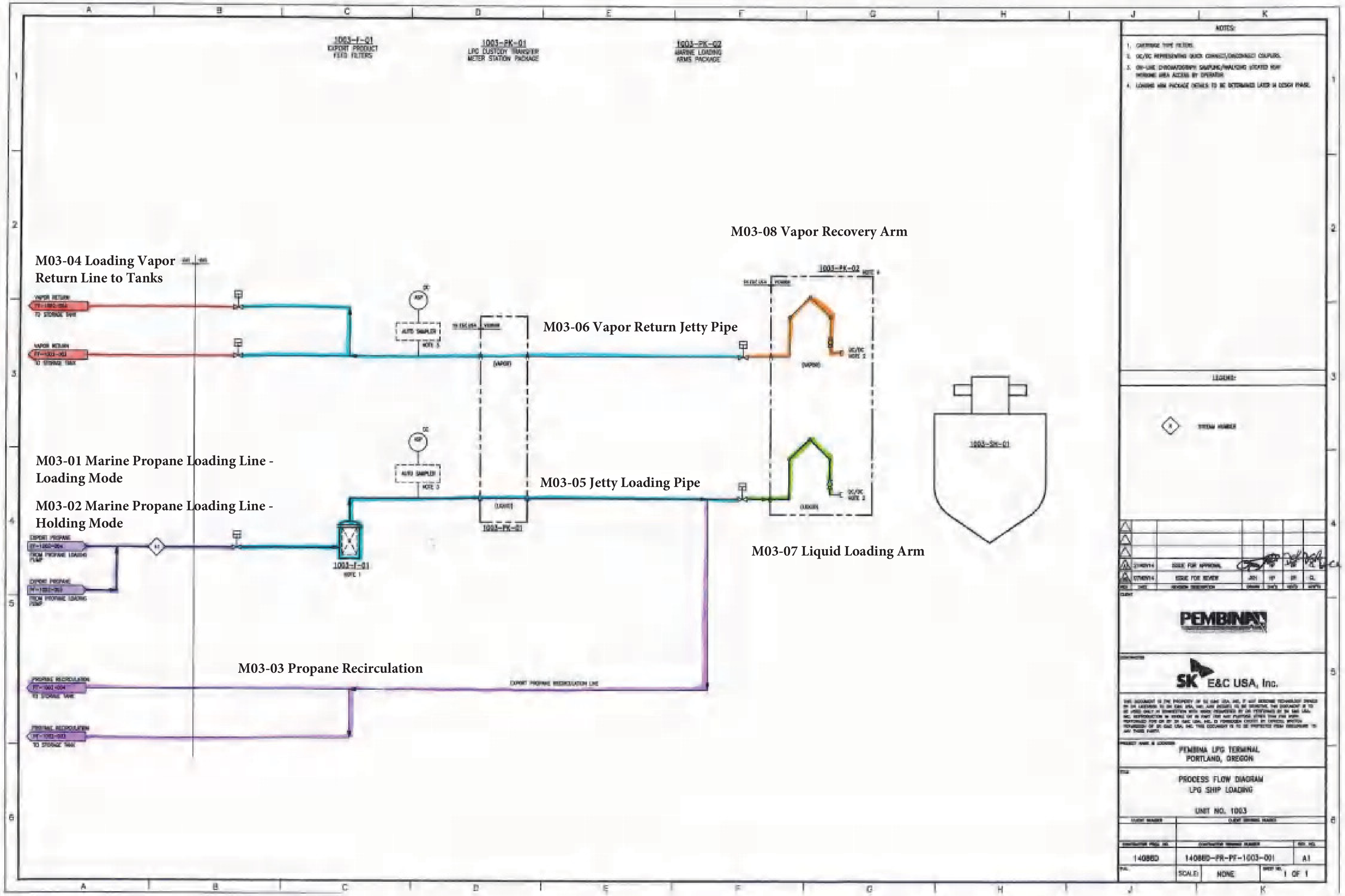
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ARMS PACKAGE
M03-04 Loading Vapor
Return Line to Tanks
M03-08 Vapor Recovery Arm
M03-06 Vapor Return Jetty Pipe
M03-01 Marine Propane Loading Line -
Loading Mode
M03-02 Marine Propane Loading Line -
Holding Mode
M03-05 Jetty Loading Pipe
M03-07 Liquid Loading Arm
M03-03 Propane Recirculation
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SCALE: NONE
1 OF 1

APPENDIX III: FREQUENCY ANALYSIS

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III. FREQUENCY ANALYSIS

This appendix describes the general approach used to derive the release frequencies and details the values obtained for each release scenario. Note that the earthquake frequency is not documented in this appendix and can be found in Appendix I- Study Basis Ref. (1)

III.1 Frequency Estimation from Historical Databases

For typical facility and mechanical equipment failures, application of data from historical databases was used to estimate release frequencies. The UK HSE Hydrocarbon Release Database (HCRD) Ref. (2), provides the base frequency data for most scenarios, complemented by the frequency data from the UK Advisory Committee on Dangerous Substances (ACDS), Ref. (3), specifically for loading arms and hoses.

Railcar release frequencies are estimated based on the railroad accidental database published by the Federal Railroad Administration Office (FRA) Ref. (4), which is one of the ten agencies within the U.S. Department of Transportation (DOT) concerned with various modes of transportation.

A parts count was performed on the "PFDs" to estimate the number of equipment parts, to which the historical failure data was applied for estimation of the scenario-specific release frequencies. Section III.1.4.6 discusses the detailed parts count approach.

III.1.1 Background of the Hydrocarbon Release Database (HCRD)

Following the Piper Alpha accident, UK North Sea Operators were required to record data on incidents involving the release of hydrocarbons on offshore installations for submission to the HSE. These submissions are compiled and published each year, resulting in the HCRD. The HCRD provides a large, high quality collection of leak experience with matching equipment populations. It has become the industry standard source of leak frequencies for offshore QRA and can be applied to or adjusted for onshore QRA.

In 2004, DNV GL performed an analysis of the HCRD as part of a joint venture project involving most of the major North Sea operators to develop leak frequency correlations. The leak frequency correlations have been updated in accordance with the HCRD 2010 and documented in DNV GL's newly published guidance on the process equipment leak frequency data for use in QRA Ref. (5).

III.1.2 HCRD Hole Size Distribution

Experience shows that when using all data from the HCRD to establish leak frequencies, the calculated leak frequencies of very large releases are found to be higher than actually experienced. To make best use of the data, the HCRD information is divided into two main scenarios: full pressure leaks and zero pressure leaks. (Note that zero pressure leak data was not applied in this study.)

HCRD full pressure leaks are represented by modeling a release through a defined hole size, beginning at the normal operating pressure, until controlled by Automated Block Valve (ABV) or Emergency Block Valve (EBV) and blowdown, with a probability of ABV/blowdown failure. Full pressure leaks are of two types:

Full leaks, consisting of:

- ABV/EBV isolated leaks.
- Late isolated leaks, modeled as cases where there is no effective ABV/EBV for the leaking system, resulting in the highest outflow.

Limited leaks are presumed to be cases where the outflow is less than from a leak at the operational pressure controlled by the quickest credible ESD (after 30 seconds) and blowdown (according to API) initiated 60 seconds later. The limited leaks are relevant for releases where the flow is restricted, as a result of local isolation valves initiated by human intervention or process safety systems other than ABV/EBV and blowdown.

The probabilities listed in Figure III-1 were the averages for all releases.

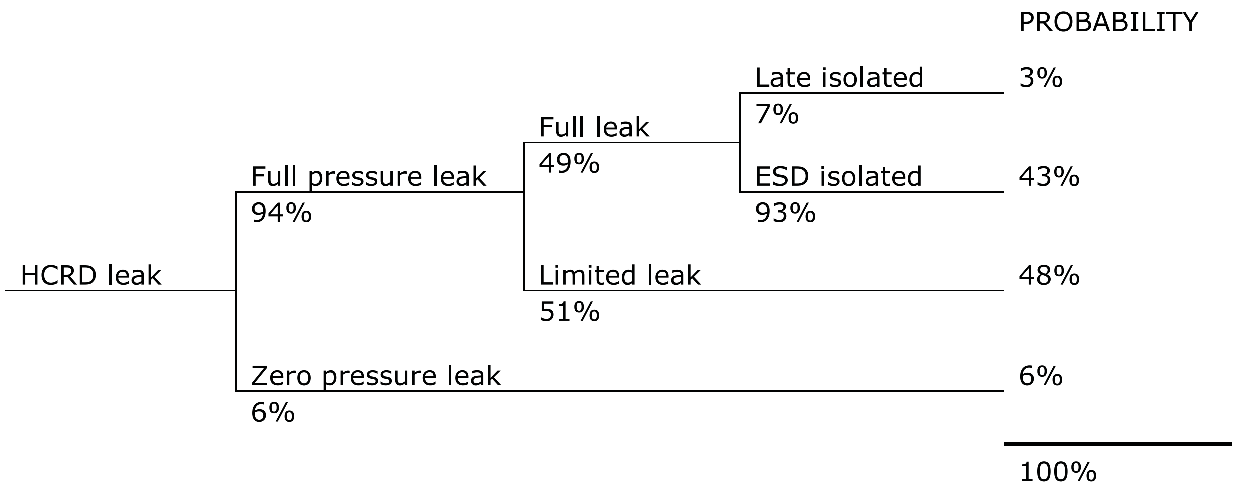

Figure III-1: Event Tree Presentation of Leak Scenarios

For this study, only Full pressure leak frequency data (including *Full* and *Limited* leaks) were applied to develop the leak frequencies for the release scenarios. The Limited leak scenarios are conservatively modeled as Full leak scenarios.

III.1.3 HCRD Frequency Modification Estimates

A key aspect of quantitative risk assessment is the derivation of leak frequencies, which are necessarily representative. Direct application of the generic data described is dependent on the assumption that the leak frequencies associated with the facility correspond to 'typical' industry levels of inspection, maintenance, and so forth.

As a new facility, it may be the case that the leak frequencies associated with the facility are generally lower than that derived from historical incident data. However, while a new, modern facility may be less likely to have leaks due to deterioration of parts, the leak rates associated with start-up and the early stages of operation are historically higher than during normal, established operation. On balance, the generic failure data corresponding to 'typical' industry failure levels is considered to be the most appropriate for this study, providing a conservative best estimate of the process failure rates.

By applying the generic failure data directly, no account is taken of the potential for increased corrosion / failure rates due to pipelines and equipment operating at low / high temperatures. This has not been considered further on the basis that:

- The generic failure data used does not contain sufficient detail to enable any correlation between the operating temperature and corrosion / failure rate. It is not known of any other source that would provide a reliable statistical basis for such an interpretation.
- It is assumed that the overall design is consistent with best-practice, and the pipelines and equipment are designed in accordance with codes that account for operating temperature aspects.

III.1.4 Frequencies Applied to this Study

III.1.4.1 HCRD Frequencies

The HCRD leak frequencies are applied to the equipment considered typical for both onshore and offshore such as pressure vessels, compressors, pumps, heat exchangers, filters, valves, flanges, and small bore fittings.

III.1.4.2 Propane Storage Tanks

In addition to the process release events, which include all facility equipment and pipework up to and including the connections to the propane storage tanks, consideration was also given to releases from the tanks themselves.

There are twelve propane pressure storage tanks/bullets at the railcar unloading area, each with the estimated working capacity of 461 m^3.

The two refrigerated propane storage tanks (with the capacity of 87,000 m^3 and 40,000 m^3, respectively) located closer to the jetty area are double-wall steel tanks, storing the liquid propane at close to atmospheric pressure. The failure rates and release hole sizes associated with these two refrigerated storage tanks are defined based on the failure rate and event data for use in risk assessments recommended by UK HSE, Ref. (6).

III.1.4.3 Inter-Unit Piping & Loading Lines

Facility piping failure frequencies are applied to estimate the inter-unit piping and loading line release frequencies. It is widely accepted that the application of facility pipework failure data tend to give overly conservative values with respect to longer inter-unit pipe segments, particularly for loading lines. Based on operations experience, it is considered appropriate to apply a factor of 0.1 to the estimated frequency for the above ground transfer pipe.

It should also be noted that the generic frequency data is not modified to account for dropped objects. The generic data includes leaks from all causes, including dropped objects, such that additional dropped object risks should only be included where identified as a particular hazard or potential leak cause.

III.1.4.4 Marine Loading Arms

The leak frequency for marine loading arms per cargo is 7.6E-05 per year, Ref. (3). This is a generic failure rate for liquefied gas loading arm releases, and is considered likely to give a conservative total leak frequency. Note that it is largely based on loading with 2 arms. There are 26 shipments per year; therefore the leak frequency of 1.98E-03 per year is applied to represent the two liquid loading arms. For one vapor return arm, half of this frequency (9.89E-04/year) is applied.

Using the above failure data the following release sizes and probabilities are applied based on DNV GL's experience and comparison against hole size distributions for typical process leaks and road tanker loading arm failures:

- Full bore rupture – considered disconnection events such as ranging and PERC failures, major leaks or loading arm failures, due to mechanical or other failure modes (13%)
- Large leak – as above, but release size is limited to hole size diameter of 75mm; will apply the "Medium" category hole size of 50mm (23%)

- Small leak – as above, but release size is limited to hole size diameter of 12mm; will apply the "Small" category hole size of 10mm (64%).

III.1.4.5 Railcar Unloading Arms

The best available source of leak frequencies from transfer equipment for rail is provided by ACDS, Ref. (3), based on LPG road tanker data. This is expressed in the DNV GL standard hole sizes in the table below.

Table III-1: Summary of Onshore Transfer Leak Frequencies for Liquefied Gas

Range	Nominal	Frequency (per transfer)
3-10 mm	5 mm	9.0E-07
10-50 mm	25 mm	9.0E-07
Full bore	50 mm	1.8E-07
Total		**2.0E-06**

In the current study, the "per transfer" based frequency is used to estimate the propane unloading leak rate accounting for 2 liquid arms. Three hole size categories are defined to cover the possible release ranges (from a 3 mm hole to the full bore rupture of a 2 inch arm). Each category is represented by a nominal hole size (representative hole size) assigned to a generic leak frequency on a per transfer base.

In order to unload 100 rail cars every two days, each unloading station along the 13 double-side racks needs to offload on average 3.8 times every other day, which equates to about 702 times per station per year. Table III-2 summarizes the calculated propane unloading scenarios and leak frequencies to be analyzed in the Pembina facility QRA.

Since it takes time to prepare all 26 stations to reach the peak unloading rate of 1,700,000 pounds per hour, it is assumed that unloading of the 100 rail cars will take around 12 hours Ref. (1).

Table III-2: Summary of Propane Unload Leak Frequencies

Hole Diameter		Frequency (per unload station)			Frequency Total (26 stations)
Size (mm)	Range	per transfer	# of transfer per year	Frequency per year	Double-side racks per year
5	3 - 10 mm	9.0E-07	702	6.32E-04	1.64E-02
25	10 - 50 mm	9.0E-07	702	6.32E-04	1.64E-02
50	Full Bore (2 inch)	1.8E-07	702	1.26E-04	3.29E-03
			Total:	**1.39E-03**	**3.61E-02**

III.1.4.6 Railcar Release and Derailment

A recent 10-year railroad accident history (2005-2014) published by the Federal Railroad administration (FRA) Office of Safety Analysis is analyzed to estimate the railcar release frequencies, Ref. (4). The FRA database updates the accident records monthly and specifies each railroad related accident by region, state, type of accident, type of track, track class, cause of accident, casualty subset, hazard material involved or not, and asset damage level. The upstream physical boundary of the facility QRA study is from the railway switching point where the propane railcars enter the Pembina facility. Therefore, in this study the railcar accident frequency analysis only focuses on the railcar accident statistics related to the yard track.

By reviewing and processing the railroad accident records between 2005 and 2014, the frequency of having a railcar accident within the railroad yard is about 14 accidents per million yard switching miles. To better understand the accident statistics only involving railcars carrying hazardous materials, the 10-year database is filtered by the “hazard material options” category. It is found that among all railroad accidents involving railroad carriers transporting hazardous materials, approximately 2.2% lead to actual releases of the hazard material. Therefore, the overall railcar accident rate causing hazardous material releases is calculated to be 6.80E-05 per year (based on the frequency of 0.31 railcar accidents per million yard switching miles and 1.2 yard miles per train visit every other day). This is equivalent to one railcar release accident every 14,700 years if the train comes every other day.

As for the severity of the railcar release accidents, the 10-year accident database (specific to yard track, hazardous material railroad carriers) is further analyzed with focus on the number of the derailed cars per accident. The maximum number of derailed cars from one train carrying hazardous material in an individual yard accident is found to be 39. The odds (see Figure III-2) indicate that 17% of the accidents did not lead to derailment; the majority of the accidents happened with 1 to 3 cars derailed (44%); less than 5% of the accidents with derailment involved greater than 10 cars; and the rest of the accidents (34%) fell into the range with 4 to 9 cars derailed.

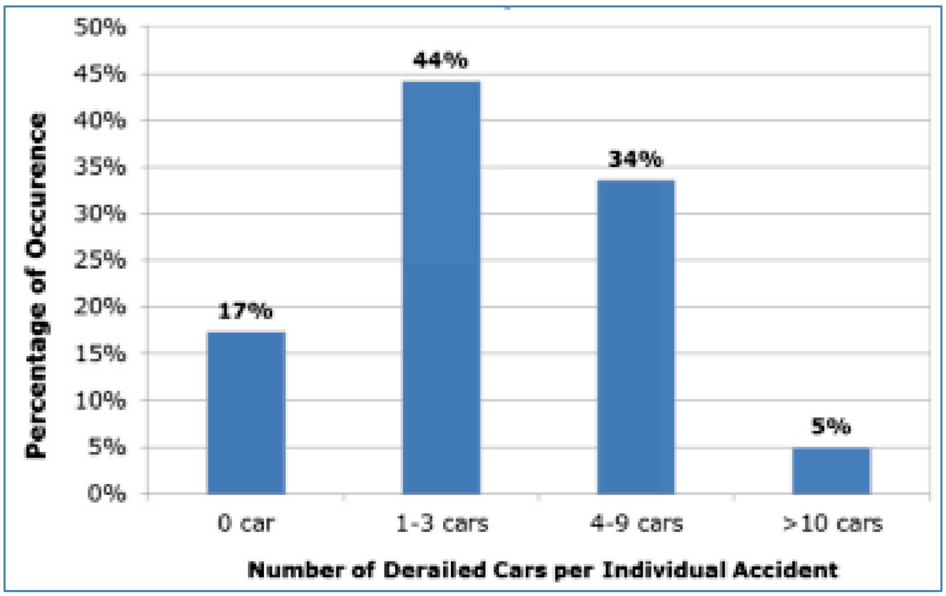

Figure III-2: Accident Distribution by Involved Number of Derailed Cars

Table III-3 summarizes the railcar release frequencies for the above discussed scenarios on a per mile basis and also on a per year basis assuming the facility receives one train (100 railcars per train) every other day and travels 1.2 yard miles per visit (measured from the facility plot plan, Ref. (7)). Note that a 3-inch hole release scenario is defined for accidents with no derailment. The representative number of derailed cars defined for the other three scenarios are taken as the weighted average number among the defined range.

Table III-3: Summary of Railcar Release Frequencies

Failure Case	Derailed Railcar Number	Release Size/Duration	Frequency (per yard mile)	Total Frequency (per year)*	Percentage
3 - inch release	0	3 inch	5.37E-08	1.18E-05	17.3%
2 cars rupture	1 ~ 3	10 minutes	1.37E-07	3.01E-05	44.2%
6 cars rupture	4 ~ 9	10 minutes	1.04E-07	2.28E-05	33.6%
14 cars rupture	10 ~ 39	10 minutes	1.53E-08	3.35E-06	4.9%
Total:			**3.10E-07**	**6.80E-05**	**100.0%**

* This is estimated based on 183 trips (one train every other day) per year and 1.2 yard miles per trip.

III.2 Equipment Parts Estimation

A parts count approach was carried out at the "PFD" level for the different isolatable sections identified for this study. This approach entails counting only the major equipment items, valves, flanges, facility pipework, and small bore fittings. From the equipment item size (based on incoming and exit piping diameters), the scenario frequencies were then estimated based on the historical leak database. Since this parts count is less detailed than one performed on a "P&ID" level, the estimated leak frequencies estimated from PFDs were multiplied by a factor of 2 to account for less conservative leak frequency numbers.

In the current study, DNV GL also performed a facility piping estimate from facility drawings. The frequency analysis was performed for the counted piping by using the actual line diameter and estimated length. It should be noted that by either approach the failure frequencies for above ground transfer pipe, such as unloading line to storage tanks, unloading vapor return line, vapor line from tank to BOG and from Jetty to tank, propane loading and recirculation line are estimated based on length measures from the facility plot plan.

III.3 Frequency Results Discussion

To represent a more realistic frequency distribution across different hole size categories, a small adjustment was made to the frequency of the large hole size (75mm~125mm) and the full bore rupture (> 125 mm) release categories. A 90/10 split was applied to the summation of the large and full bore rupture release frequencies, except for the frequencies of unloading/loading arms releases, propane storage bullet ruptures and storage tank ruptures. The adjusted large release frequency is taken as 90% of this summed frequency while the full bore rupture frequency is assumed to be 10% of this summed value.

The following sections present and discuss the frequency results in greater detail.

III.3.1 Frequency by Sub-Area

Table III-4 and Figure III-3 present the total release frequency estimates by sub-area. Propane Refrigeration has the highest contribution to the overall frequency with 40% of the total. Small leaks contribute approximately 83% to the overall release frequency.

Table III-4: Summary of Leak Frequency by Sub-Area

Unit Sub Area	Small (3mm~ 25mm)	Medium (25mm~ 75mm)	Large (75mm~ 125mm)	Full Bore Rupture (>125mm)	BLEVE/ Tank Rupture	Total (per year)	%
Railcar Unloading	5.1E-02	5.1E-03	1.7E-04	1.8E-05	5.6E-05	5.7E-02	27.1%
Propane Bullets	4.2E-02	3.6E-03	5.9E-03	6.7E-04	1.2E-04	5.2E-02	24.8%
Propane Refrigeration	6.6E-02	7.3E-03	8.6E-03	9.5E-04	-	8.3E-02	39.7%
Propane Ship Loading	4.8E-03	9.3E-04	3.5E-04	4.3E-04	-	6.5E-03	3.1%
Propane Storage Tank	9.0E-03	9.6E-04	8.2E-04	1.5E-04	2.1E-05	1.1E-02	5.2%
Total	1.7E-01	1.8E-02	1.6E-02	2.2E-03	2.0E-04	2.1E-01	**100.0%**
%	**82.7%**	**8.6%**	**7.6%**	**1.1%**	**0.1%**	**100.0%**	

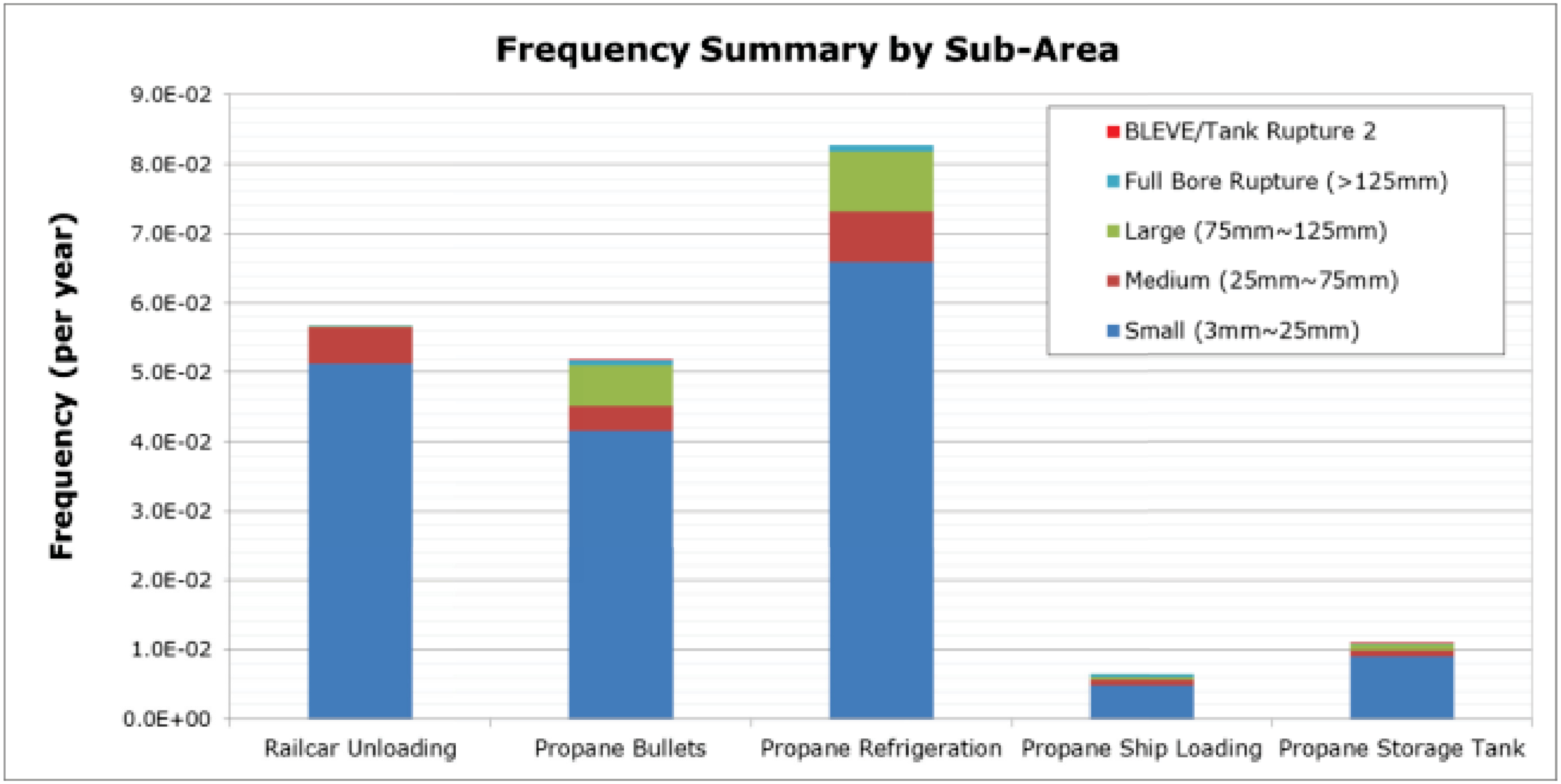

Figure III-3: Leak Frequency (per year), by Sub-Area

III.3.2 Frequency by Isolatable Section

Table III-5 and Figure III-4 present the release frequency according to the isolatable sections defined for the process. There are 25 defined isolatable sections for the railcar unloading, common area and marine loading. The railcar unloading arms and vapor return arm contribute about 26% to the total release frequency. The large contribution from the railcar unloading arms results from the high frequency of the operation and the large number of unloading stations. The 12 pressurized propane storage bullets contribute about 25% of the total frequency.

The top 10 contributors to the frequency are indicated in Table III-5 in red text color.

Table III-5: Summary of Leak Frequency, by Isolatable Segment

#	ISO-Segment ID	Unit Name	ISO-Segment Name	Small (3mm~ 25mm)	Medium (25mm~ 75mm)	Large (75mm~ 125mm)	Full Bore Rupture (>125mm)	BLEVE/ Tank Rupture	Total	%
1	R-00	Railcar Unloading	Railcar Releases	0.0E+00	0.0E+00	1.2E-05	0.0E+00	5.6E-05	6.8E-05	0.03%
2	R-01	Railcar Unloading	Railcar Unload Arms	3.3E-02	3.3E-03	0.0E+00	0.0E+00	0.0E+00	3.6E-02	17.3%
3	R-02	Railcar Unloading	Railcar Vapor Arms	1.6E-02	1.6E-03	0.0E+00	0.0E+00	0.0E+00	1.8E-02	8.7%
4	R-03	Railcar Unloading	Unloading Vapor Return - Compressor	1.9E-03	2.1E-04	1.5E-04	1.6E-05	0.0E+00	2.3E-03	1.09%
5	R-04	Railcar Unloading	Unloading Vapor Return - Pipe to Railcar	3.3E-05	3.0E-06	6.5E-06	7.2E-07	0.0E+00	4.3E-05	0.02%
6	R-05	Railcar Unloading	Propane Unloading Pipe	3.9E-05	3.6E-06	8.4E-06	9.3E-07	0.0E+00	5.2E-05	0.03%
7	B-06	Propane Bullets	Propane Unloading Storage Group 1	1.4E-02	1.2E-03	2.0E-03	2.2E-04	4.0E-05	1.7E-02	8.3%
8	B-07	Propane Bullets	Propane Unloading Storage Group 2	1.4E-02	1.2E-03	2.0E-03	2.2E-04	4.0E-05	1.7E-02	8.3%
9	B-08	Propane Bullets	Propane Unloading Storage Group 3	1.4E-02	1.2E-03	2.0E-03	2.2E-04	4.0E-05	1.7E-02	8.3%
10	F-06	Propane Refrigeration	Propane Rundown Pipe	5.4E-03	4.8E-04	3.5E-04	3.9E-05	0.0E+00	6.2E-03	3.0%
11	S-01	Propane Storage Tank	Storage Tank 1	4.2E-03	4.5E-04	3.7E-04	7.2E-05	1.1E-05	5.1E-03	2.4%
12	S-02	Propane Storage Tank	Storage Tank 2	4.2E-03	4.5E-04	3.7E-04	7.2E-05	1.1E-05	5.1E-03	2.4%
13	S-03	Propane Storage Tank	Vapor from Tank to BOG	6.8E-04	5.5E-05	6.8E-05	7.5E-06	0.0E+00	8.2E-04	0.4%
14	M-01	Propane Ship Loading	Propane Loading Line	1.9E-03	1.6E-04	2.3E-04	2.5E-05	0.0E+00	2.3E-03	1.1%
15	M-03	Propane Ship Loading	Propane Recirculation Line	1.1E-04	9.0E-06	1.4E-05	1.6E-06	0.0E+00	1.4E-04	0.1%
16	M-04	Propane Ship Loading	Loading Vapor Return Line to Tank	1.8E-04	1.5E-05	2.4E-05	2.7E-06	0.0E+00	2.3E-04	0.1%
17	M-05	Propane Ship Loading	Jetty Loading Pipe	4.1E-04	4.9E-05	4.5E-05	5.0E-06	0.0E+00	5.1E-04	0.2%
18	M-06	Propane Ship Loading	Vapor Return Jetty Pipe	2.5E-04	2.1E-05	3.7E-05	4.1E-06	0.0E+00	3.2E-04	0.2%
19	M-07	Propane Ship Loading	Liquid Loading Arm	1.3E-03	4.5E-04	0.0E+00	2.6E-04	0.0E+00	2.0E-03	0.9%

#	ISO-Segment ID	Unit Name	ISO-Segment Name	Small (3mm~ 25mm)	Medium (25mm~ 75mm)	Large (75mm~ 125mm)	Full Bore Rupture (>125mm)	BLEVE/ Tank Rupture	Total	%
20	M-08	Propane Ship Loading	Vapor Recovery Arm	6.3E-04	2.3E-04	0.0E+00	1.3E-04	0.0E+00	9.9E-04	0.5%
21	F-01	Propane Refrigeration	C3 Feed & Comp. 3rd	2.5E-02	2.5E-03	3.7E-03	4.2E-04	0.0E+00	3.1E-02	15.1%
22	F-02	Propane Refrigeration	BOG Compressor	1.3E-02	1.5E-03	1.0E-03	1.1E-04	0.0E+00	1.6E-02	7.5%
23	F-03	Propane Refrigeration	C3 Comp. 2nd	5.6E-03	6.6E-04	8.1E-04	9.0E-05	0.0E+00	7.2E-03	3.4%
24	F-04	Propane Refrigeration	C3 Comp. 1st	5.6E-03	6.6E-04	8.1E-04	9.0E-05	0.0E+00	7.2E-03	3.4%
25	F-05	Propane Refrigeration	C3 Accumulator	1.1E-02	1.5E-03	1.9E-03	2.1E-04	0.0E+00	1.5E-02	7.2%
Total				**1.7E-01**	**1.8E-02**	**1.6E-02**	**2.2E-03**	**2.0E-04**	**2.1E-01**	**100.0%**

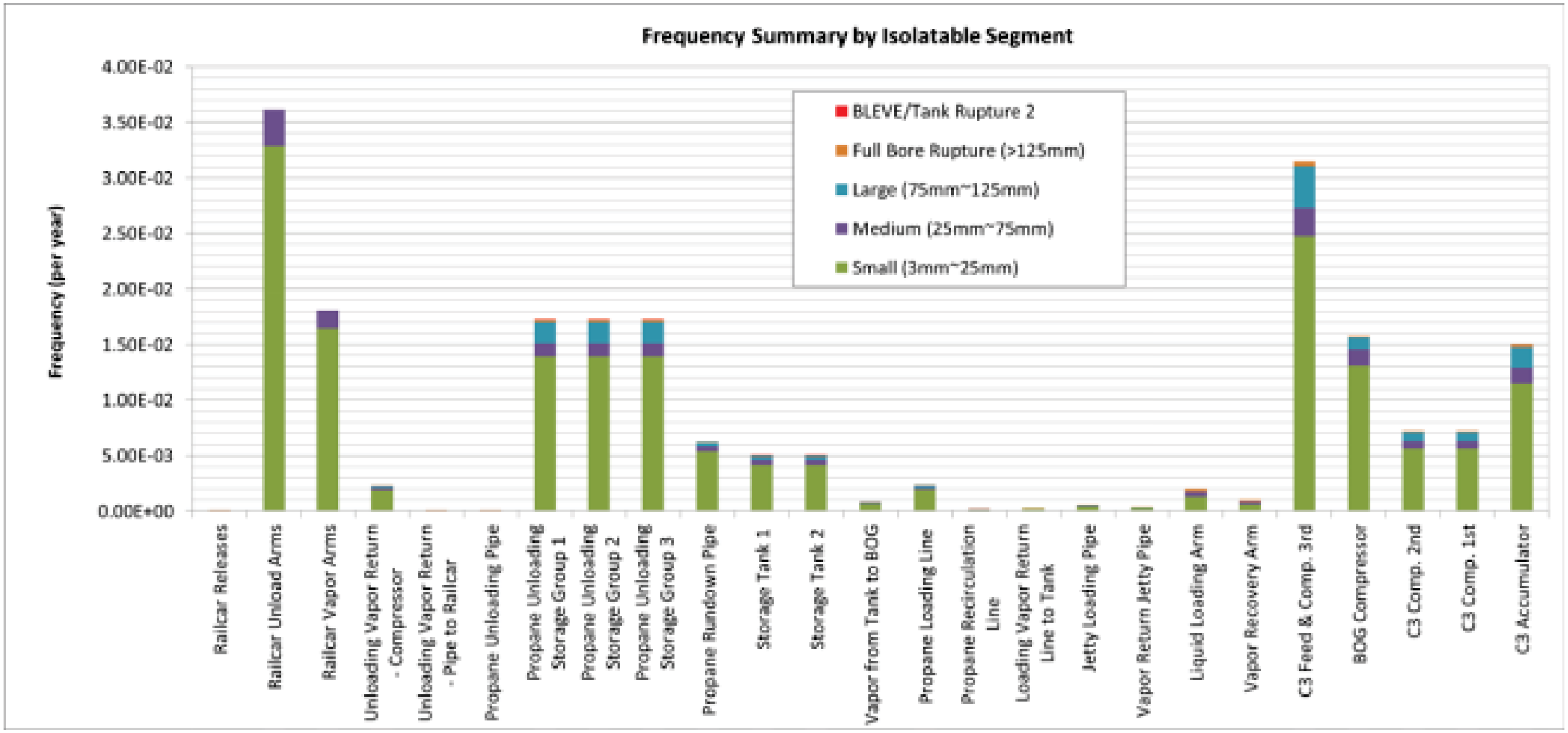

Figure III-4: Leak Frequency (per year), by Isolatable Segment

III.3.3 Frequency by Release Events

The isolatable sections may be split into several sub-release events depending on the variable process conditions. Table III-6 and Figure III-5 present the release frequency corresponding to the release events defined for the railcar unloading, common area and marine loading.

There are 50 release events defined for the facility, each with up to four hole sizes modeled. In addition, propane bullets BLEVE, refrigerated tank rupture scenarios, and railcar derailment scenarios are modeled as well.

The Railcar Unloading Arms (R01-01Z), Railcar Vapor Return Arms (R01-02Z) and BOG Compressor (F02-02Z) are the top three events, contributing approximately 34% of the total frequencies across the facility.

The top 10 contributors to the frequency are indicated in Table III-6 in red text color.

Table III-6: Release Frequency (per year) by Release Event Scenario

#	Event Description	Event ID	Small (3mm~ 25mm)	Medium (25mm~ 75mm)	Large (75mm~ 125mm)	Full Bore Rupture (>125mm)	BLEVE/ Tank Rupture	Total Frequency (per year)	%
1	Railcar Release	R01-00Z	0.0E+00	0.0E+00	1.2E-05	0.0E+00	5.6E-05	6.8E-05	0.03%
2	Railcar Unloading Arm	R01-01Z	3.3E-02	3.3E-03	0.0E+00	0.0E+00	0.0E+00	3.6E-02	17.3%
3	Railcar Vapor Return Arm	R01-02Z	1.6E-02	1.6E-03	0.0E+00	0.0E+00	0.0E+00	1.8E-02	8.7%
4	Unloading Vapor Return - Compressor	R01-03Z	1.9E-03	2.1E-04	1.5E-04	1.6E-05	0.0E+00	2.3E-03	1.1%
5	Unloading Vapor Return - Pipe to Railcar	R01-04Z	3.3E-05	3.0E-06	6.5E-06	7.2E-07	0.0E+00	4.3E-05	0.02%
6	Propane Unloading Pipe	R01-05Z	3.9E-05	3.6E-06	8.4E-06	9.3E-07	0.0E+00	5.2E-05	0.03%
7	Propane Unloading Storage Group1 (Connections) - Liquid	B01-06A	7.7E-03	6.4E-04	8.3E-04	9.2E-05	0.0E+00	9.3E-03	4.4%
8	Propane Unloading Storage Group1 (Connections) - Gas	B01-06B	6.1E-03	5.4E-04	1.1E-03	1.2E-04	0.0E+00	7.9E-03	3.8%
9	Propane Unloading Storage Group2 (Connections) - Liquid	B01-07A	7.7E-03	6.4E-04	8.3E-04	9.2E-05	0.0E+00	9.3E-03	4.4%
10	Propane Unloading Storage Group2 (Connections) - Gas	B01-07B	6.1E-03	5.4E-04	1.1E-03	1.2E-04	0.0E+00	7.9E-03	3.8%
11	Propane Unloading Storage Group3 (Connections) - Liquid	B01-08A	7.7E-03	6.4E-04	8.3E-04	9.2E-05	0.0E+00	9.3E-03	4.4%
12	Propane Unloading Storage Group3 (Connections) - Gas	B01-08B	6.1E-03	5.4E-04	1.1E-03	1.2E-04	0.0E+00	7.9E-03	3.8%
13	Propane Unloading Storage Group1 - Bullets	B01-06C	4.0E-05	2.0E-05	2.0E-05	8.0E-06	4.0E-05	1.3E-04	0.1%
14	Propane Unloading Storage Group2 - Bullets	B01-07C	4.0E-05	2.0E-05	2.0E-05	8.0E-06	4.0E-05	1.3E-04	0.1%
15	Propane Unloading Storage Group3 - Bullets	B01-08C	4.0E-05	2.0E-05	2.0E-05	8.0E-06	4.0E-05	1.3E-04	0.1%
16	Propane Rundown Pumps	F02-06A	4.1E-03	3.7E-04	2.1E-04	2.4E-05	0.0E+00	4.7E-03	2.2%
17	Propane Rundown Pipe to Storage Tank	F02-06B	1.3E-03	1.0E-04	1.4E-04	1.5E-05	0.0E+00	1.6E-03	0.8%
18	Storage Tank 1 - Connections Gas	S04-01A	1.5E-03	2.4E-04	9.9E-05	1.1E-05	0.0E+00	1.9E-03	0.9%
19	Storage Tank 1 - Connections Liquid	S04-01B	2.6E-03	2.1E-04	2.8E-04	3.1E-05	0.0E+00	3.1E-03	1.5%
20	Storage Tank 1	S04-01C	0.0E+00	0.0E+00	0.0E+00	3.0E-05	1.1E-05	4.1E-05	0.02%
21	Storage Tank 2 - Connections Gas	S04-02A	1.5E-03	2.4E-04	9.9E-05	1.1E-05	0.0E+00	1.9E-03	0.9%
22	Storage Tank 2 - Connections Liquid	S04-02B	2.6E-03	2.1E-04	2.8E-04	3.1E-05	0.0E+00	3.1E-03	1.5%
23	Storage Tank 2	S04-02C	0.0E+00	0.0E+00	0.0E+00	3.0E-05	1.1E-05	4.1E-05	0.02%
24	Vapor from Tank to BOG - Pipe	S04-03Z	6.8E-04	5.5E-05	6.8E-05	7.5E-06	0.0E+00	8.2E-04	0.4%
25	Marine Propane Loading Line - Loading Mode	M03-01L	2.2E-04	1.8E-05	2.6E-05	2.8E-06	0.0E+00	2.6E-04	0.1%
26	Marine Propane Loading Line - Holding Mode	M03-01H	1.6E-03	1.3E-04	1.9E-04	2.1E-05	0.0E+00	1.9E-03	0.9%
27	Marine Propane Loading Line – Recirculation Mode	M03-01R	1.4E-04	1.1E-05	1.6E-05	1.8E-06	0.0E+00	1.7E-04	0.1%
28	Propane Recirculation	M03-03Z	1.1E-04	9.0E-06	1.4E-05	1.6E-06	0.0E+00	1.4E-04	0.1%
29	Loading Vapor Return Line to Tank	M03-04Z	1.8E-04	1.5E-05	2.4E-05	2.7E-06	0.0E+00	2.3E-04	0.1%

#	Event Description	Event ID	Small (3mm~ 25mm)	Medium (25mm~ 75mm)	Large (75mm~ 125mm)	Full Bore Rupture (>125mm)	BLEVE/ Tank Rupture	Total Frequency (per year)	%
30	Jetty Loading Pipe	M03-05Z	4.1E-04	4.9E-05	4.5E-05	5.0E-06	0.0E+00	5.1E-04	0.2%
31	Vapor Return Jetty Pipe	M03-06Z	2.5E-04	2.1E-05	3.7E-05	4.1E-06	0.0E+00	3.2E-04	0.2%
32	Liquid Loading Arm	M03-07Z	1.3E-03	4.5E-04	0.0E+00	2.6E-04	0.0E+00	2.0E-03	0.9%
33	Vapor Recovery Arm	M03-08Z	6.3E-04	2.3E-04	0.0E+00	1.3E-04	0.0E+00	9.9E-04	0.5%
34	Propane Feeding Pumps	F02-01A	7.8E-03	7.1E-04	9.6E-04	1.1E-04	0.0E+00	9.6E-03	4.6%
35	Propane Subcooler	F02-01B	5.2E-03	5.3E-04	9.4E-04	1.0E-04	0.0E+00	6.8E-03	3.3%
36	HP Suction Drum - Liquid	F02-01C	1.7E-03	1.9E-04	2.4E-04	2.7E-05	0.0E+00	2.1E-03	1.0%
37	HP Suction Drum - Gas	F02-01D	1.9E-03	2.2E-04	3.6E-04	4.1E-05	0.0E+00	2.6E-03	1.2%
38	HP Propane Compression	F02-01E	2.5E-03	2.8E-04	2.3E-04	2.6E-05	0.0E+00	3.0E-03	1.4%
39	BOG Air Cooler	F02-01F	5.7E-03	5.7E-04	1.0E-03	1.1E-04	0.0E+00	7.4E-03	3.5%
40	BOG Compressor	F02-02Z	1.3E-02	1.5E-03	1.0E-03	1.1E-04	0.0E+00	1.6E-02	7.5%
41	MP Suction Drum - Liquid	F02-03A	1.2E-03	1.6E-04	2.1E-04	2.3E-05	0.0E+00	1.6E-03	0.8%
42	MP Suction Drum - Gas	F02-03B	1.9E-03	2.2E-04	3.6E-04	4.1E-05	0.0E+00	2.6E-03	1.2%
43	MP Propane Compression	F02-03C	2.5E-03	2.8E-04	2.3E-04	2.6E-05	0.0E+00	3.0E-03	1.4%
44	LP Suction Drum - Liquid	F02-04A	1.2E-03	1.6E-04	2.1E-04	2.3E-05	0.0E+00	1.6E-03	0.8%
45	LP Suction Drum - Gas	F02-04B	1.9E-03	2.2E-04	3.6E-04	4.1E-05	0.0E+00	2.6E-03	1.2%
46	LP Propane Compression	F02-04C	2.5E-03	2.8E-04	2.3E-04	2.6E-05	0.0E+00	3.0E-03	1.4%
47	Propane Air Cooler Liquid	F02-05A	2.5E-03	2.5E-04	4.6E-04	5.1E-05	0.0E+00	3.2E-03	1.5%
48	Propane Air Cooler Gas	F02-05B	1.7E-03	1.8E-04	2.9E-04	3.2E-05	0.0E+00	2.2E-03	1.0%
49	Propane Accumulator & Condenser - Liquid	F02-05C	2.1E-03	3.2E-04	2.7E-04	3.0E-05	0.0E+00	2.8E-03	1.3%
50	Propane Accumulator & Condenser - Gas	F02-05D	5.2E-03	7.1E-04	8.6E-04	9.5E-05	0.0E+00	6.8E-03	3.3%
	Total		**1.7E-01**	**1.8E-02**	**1.6E-02**	**2.2E-03**	**2.0E-04**	**2.1E-01**	**100.0%**

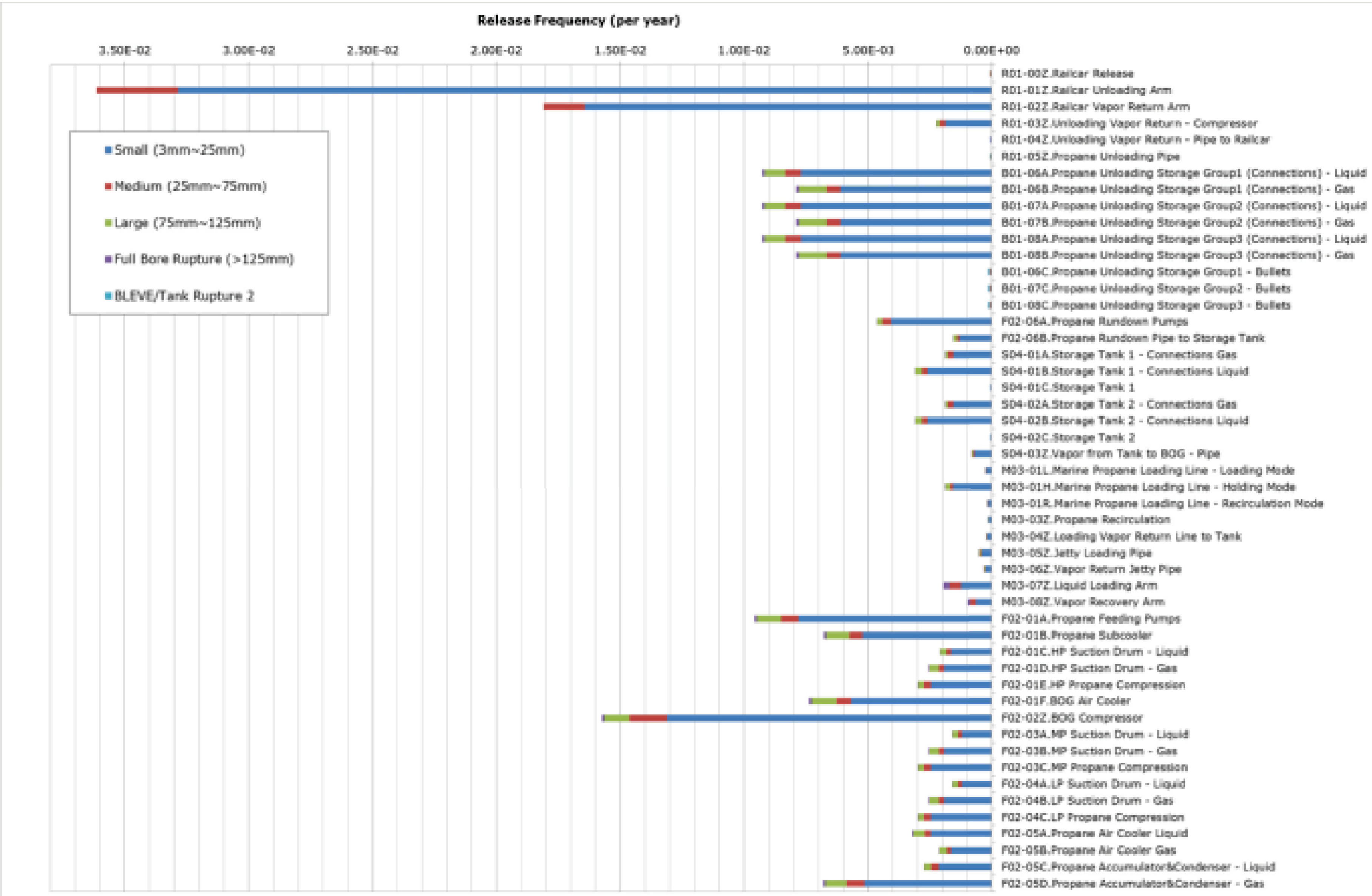

Figure III-5: Release Frequency by Release Event

III.4 References

1. *Pembina Propane Facility QRA Study - Study Basis, Rev. 0, DNV GL 2015-02-24.*

2. *Hydrocarbon Release Database (HCRD), UK Health and Safety Executive (HSE), October 1992 - March 2010.*

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7. *Pembina LPG Project Protland, Oregon Overall Plot Plan, Rev. B.* s.l. : SK E&C USA, 01-12-2015. 14088D-PI-PP-00000-01.

APPENDIX IV: CONSEQUENCE ASSESSMENT

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IV CONSEQUENCE ASSESSMENT

IV.1 Introduction

This appendix presents the consequence analysis of major accident hazards identified and modeled for the Pembina Propane Terminal, which includes all sections from the propane railcar up to the marine loading arms at the jetty. All representative release scenarios identified from the propane rail car release, refrigeration compression, transfer pipelines, propane storage, and propane loading and vapor return arms at the jetty are included in this appendix.

IV.2 Scenario Development

The scenario selection is conducted on a sectional basis. Failure cases (i.e., specific release scenarios to be modeled in the QRA) are defined by dividing the facility and systems into sections with similar characteristics. The scenario development is documented in Appendix II: Scenario Development Ref. (1).

IV.3 Release Rate

The key parameters determining the behavior of each release, and the subsequent consequences, are: the representative release rate, the duration of the release (which is related to the inventory available for release), and the release velocity. The temperature of the release and additional liquid and vapor properties are also relevant parameters. The general approach adopted in deriving each of these parameters is described in Appendix I: Study Basis Ref. (2). Release rate is discussed in more detail in the current appendix.

The actual mass flow rate from any release scenario varies with time as the inventory and pressure in the isolatable section decreases following emergency shutdown (ESD) and isolation. However, any impacts to personnel from immediate ignition events are rapid, and if not immediately ignited, the subsequent dispersion (relevant to delayed ignition events) is largely determined by the release rate within the initial moments.

The representative release rate, Q (lb/hr), selected in each case is generally taken as the initial maximum release rate, Q_0 (lb/hr), which is calculated within the Phast discharge model. However, certain key scenarios are considered where the representative release rate is adjusted from the initial maximum Q_0:

- If the initial maximum release rate, Q_0, is very large, greater than 2 × NFR (normal flow rate), the initial release rate is of very short duration:

    a) For vapor releases, the representative release rate (to be considered in Phast) is based on the average rate over the first minute. This typically results in Q being between ¼ and ⅔ of Q_0, where any residual release at the inflow rate (after depletion of the segment inventory, before isolation occurs) has a negligible impact in comparison to this initial release.

    b) For liquid releases, the representative release rate is the average of (0.1 × Q_0) and NFR. This approach is from the DNV GL's internal practice applied on previous projects.

- For less substantial releases (i.e. Q_0 lower than 2 × NFR) the representative release rate is taken as the initial release rate (i.e. $Q = Q_0$). Where Q_0 is greater than the inflow rate, this assumption is conservative resulting in larger consequence zones, and compensates for the likelihood of a longer duration residual release at NFR.

- The above considerations apply where the initial release is driven by the inventory of the segment, or by that of a specific vessel. Where releases occur downstream of a pump or compressor, the release rate is typically driven by the normal flow rate of the section in forward flow. Therefore, where back-flow from the upstream inventory is not credible, the release rate (Q) is capped at a maximum of 125% of the inflow rate, i.e. Q = 1.25 × NFR.

Table IV-1 summarizes the release parameters applied for this study.

Table IV-1: Release Parameters

Type	Description	Release Rate, Q (kg/s)
Inventory	Liquid/vapor releases downstream of a vessel (or significant inventory), i.e. inventory-driven releases. Influenced by the available mass, which includes consideration of connected / linked inventories.	If Q_0 > 2 × NFR: apply average rate over the first minute for vapor releases; Apply Q = (0.1 Q_0 + NFR)/2 for liquid release. If Q_0 < 2 x NFR, apply initial rate calculated by Phast, Q_0
Pumped/ Compressed	Liquid/vapor releases restricted by flow rate (with allowance for pump/ compressor overrun to compensate for release).	Restricted to a maximum of 125% of NFR: If Q_0 > 1.25 x NFR, apply Q = 1.25 x NFR. If Q_0 < 1.25 x NFR, apply Q = Q_0

IV.4 Consequence modeling

This section summarizes the methods adopted in deriving the consequences associated with the defined release scenarios. The following descriptions are based on the potential different hazard types modeled, which include jet fires, pool fires, and vapor cloud dispersion which may lead to flash fires or vapor cloud explosions (VCE).

IV.4.1 Meteorology

The dispersion of a cloud of hazardous material is governed by the wind speed, wind direction and the atmospheric stability. Factors, which increase the dilution of a hazardous cloud with respect to distance traveled, are increasing wind speeds and decreasing stability of the atmosphere. However, high winds may transport hazardous materials far downwind before they become sufficiently diluted to no longer pose a hazard. An unstable atmosphere, typically experienced on a sunny day, causes increased vertical mixing, which further dilutes the hazardous clouds as they disperse downwind. The effect of wind direction is obvious in that only receptors downwind of the release are affected.

The meteorological data used in the Phast model consist of wind speed, humidity, solar radiation flux and ambient temperature. The temperature and humidity used for this study are 82°F and 0.4 for summer condition, 35°F and 0.69 for winter condition. The general meteorological data applied in the analysis are documented in the Study Basis Assumption 5 Ref. (2). The weather stability classes used in the study are

- B1.8 (B stability and 1.8 m/s or 4.0 mph wind speed)
- C/D2.2 (C/D stability and 2.2 m/s or 4.9 mph wind speed)
- D7.2 (D stability and 7.2 m/s or 16.1 mph wind speed)
- D2.9 (D stability and 2.9 m/s or 6.5 mph wind speed)
- F1.8 (F stability and 1.8 m/s or 4.0 mph wind speed)

IV.4.2 General Approach

For each release event defined, the magnitude of the potential consequences / hazard zones is estimated using DNV GL's proprietary software package Phast v6.7. These consequence results are used as input to the risk model within Phast Risk to calculate risk to personnel.

Each release event may pose several different types of hazards as described in Table IV-2.

Table IV-2: Summary of Potential Hazard Types

Release Type	Hazard Type (Consequence)		
	Immediate Ignition	**Delayed Ignition**	**Toxic (no ignition)**
Vapor release – leak	Jet fire	VCE / flash fire	-
Vapor release – instantaneous release	Fireball	VCE / flash fire	-
Flashing (2-phase) liquid	Jet fire	VCE / flash fire / jet or pool fire	-
Liquid release	Pool fire	Pool fire + VCE / flash fire of vaporized cloud Possible BLEVE (due to escalation)	-
Toxic gas release	-	-	Toxic gas dispersion

When a release occurs in an open field, free of obstructions in the downwind direction, the vapor plume tends to have a longer dispersion distance but smaller cross-sectional width. If the release occurs in a congested area, it is expected that the release jet likely impinges on the surrounding obstructions. This impingement alters the jet's momentum, resulting in a wider plume width as forward momentum is transferred laterally, thus increasing plume-air mixing and reducing the downwind dispersion distance. An impinged release may also divert the dispersion direction depending on the geometry of the obstruction and release condition. The Pembina Propane Terminal generally has a low congestion level; hence the releases are modeled as unobstructed, horizontal releases.

If delayed ignition occurs, this can result in either a Vapor Cloud Explosion (VCE) if ignition occurs in a congested area, or a flash fire if ignition occurs in an unconfined area. Liquid releases may result in different consequences according to the release conditions. These are generally determined by whether there is a significant initial flash (if the liquid is pressurized or the temperature is above the boiling point of the liquid) or whether the release is predominantly liquid upon release (if the liquid is stabilized or cryogenic). Flashing liquid releases may or may not have rainout. If no rainout occurs, pool fire hazards are not credible. Where rainout occurs, pool fire and pool vaporization consequences are modeled.

The general release schematics from any stream follow the flowchart shown in Figure IV-1 Ref. (3). In this study most of the releases falls into the area marked in red in the figure.

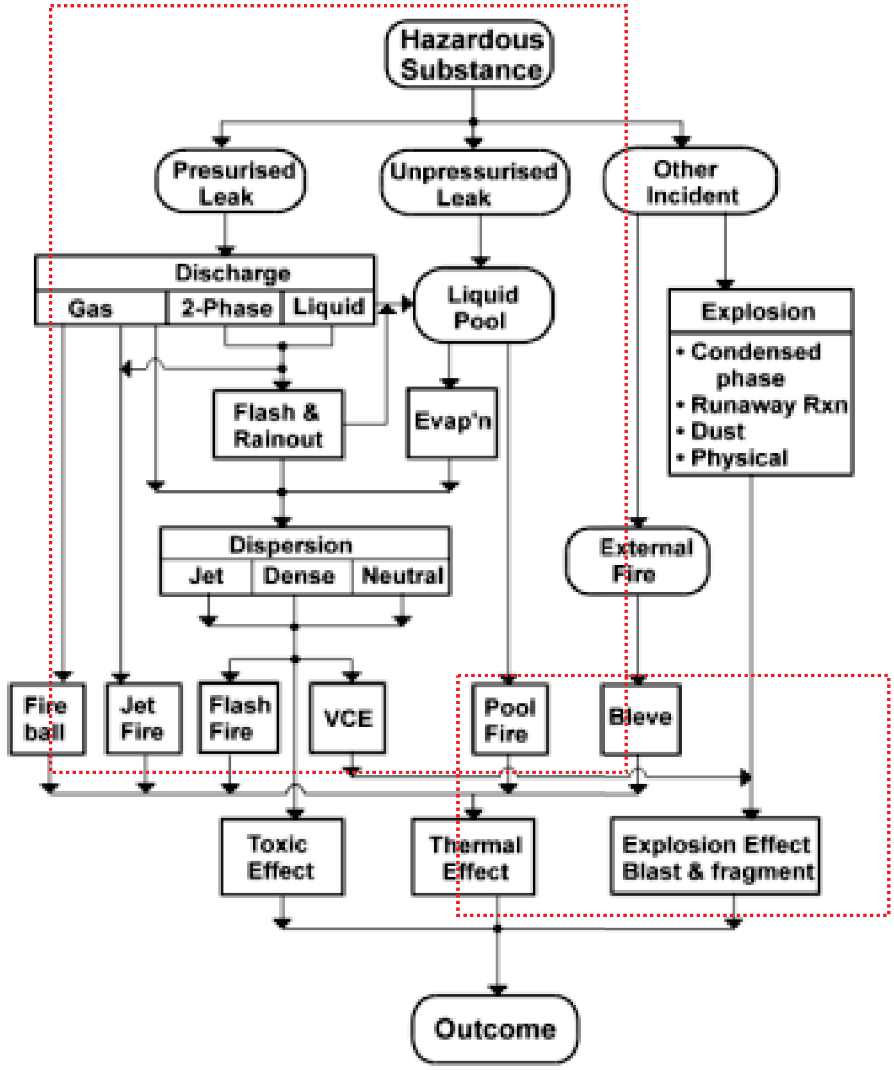

Figure IV-1: Consequence Release model

IV.4.3 Flammable Scenarios

All immediately ignited releases are modeled as either jet or pool fires, unless the release is instantaneous or very rapid (less than 20 seconds) in which case a fireball is applied. All delayed ignition events are modeled as flash fires or VCEs, where pool fires will accompany the flash fires/VCEs for liquid spills.

Most delayed ignition events also burn-back to form jet or pool fires that follow the initial flash fire or VCE, although the impacts to personnel are dominated by the initial flash fire/VCE effects. The jet or pool fire, however, is important to the escalation potential.

IV.4.3.1 Jet fires

The widely used Cone (Shell) model is applied as the basis for the jet fire modeling within Phast, which describes the shape of a jet flame as a frustum of a cone. The parameters describing the frustum, accounting for choked flow, are derived from comparisons with experimental data from laboratory and field tests. The key input parameters in defining jet fires are release rate, velocity, material, and release elevation. For the purpose of the risk calculations, immediate fatality is assumed for all personnel within the 35 kW/m^2 radiation contour of a jet fire or a pool fire.

A horizontal jet fire typically results in a larger hazard zone than a vertical or angled release and is generally more hazardous for personnel and equipment. The jet flame lengths and the subsequent radiation hazard ranges are primarily driven by the release rate and the material.

IV.4.3.2 Pool fires

The pool fire model in Phast calculates the shape and intensity of the flame, and a range of radiation results. A pool fire flame is modeled as a cylinder sheared in the direction of the wind, with diameter, height, and tilt angle (measured from the vertical). The flame shape gives input to the radiation calculations. The pool diameter is calculated by

- Continuous liquid leak - The stable burning size is calculated, where the mass burning rate balances the mass release rate of liquid; the pool diameter is, then, the lesser of the stable burning size or the bund diameter if a bund is defined.
- Unbunded leak - If a bund area is not defined, the pool fire model takes into account any physical barriers to the spread of the liquid pool. As such, the pool is allowed to spread at a uniform depth until it attains a minimum thickness at a steady state. Factors such as sloping, drainage, and curbing in the immediate area are therefore not taken into account in determining the pool diameter.

The surface area of a pool is a critical parameter for fire calculations. Models are available for spills onto flat ground for both continuous spills (Mudan and Croce) Ref. (4) and instantaneous spills (Raj and Kalelkar) Ref. (5).

The simplest calculation Ref. (6) is for continuous spills, where the steady state pool diameter is calculated when the (burning rate x surface area) = (leak rate). This assumes no confinement by a dike or curb.

$$D_{max} = 2 \times (V_L / \pi y)$$

where (all in common units),

D_{max} = maximum pool diameter

V_L = Volumetric discharge rate

y = burning rate

Consequences from ignition of an “infinite” spreading pool are overly conservative. Phast model tends to overpredict pool vaporization effects due to the increased surface area as the pool spreads when there is no bund present. To reduce some conservatism in the model, a bund is specified for all liquid releases with an area of 360,000 m^2 (3,875,010 ft^2). This reduces the potential for overly conservative and unrealistic rainout distances from the source and limits pool diameter.

IV.4.3.3 Fireballs

All immediately ignited releases are modeled as either jet or pool fires, unless the release is instantaneous or very rapid (less than 20 seconds) in which case a fireball is applied.

IV.4.3.4 Flash fires

A flash fire is effectively the advancing flame front of an ignited vapor cloud. Although it presents significant personnel hazards (any outdoor personnel caught within the flash fire envelope are considered immediate fatalities), flash fires do not cause significant structural damage. There is little radiation outside of the LFL contour, and damage done by the flash fire should be restricted to ignition of easily ignitable materials such as flammable vapor vents, cabling and plastic. Furthermore, flash fires do not generally create overpressures and as such their damage is limited to thermal impacts only.

The consequence results for potential flash fire events are presented in the form of flash fire effect zones represented by LFL and ½LFL contours. Wind speed and atmospheric stability may have a significant effect on the dispersion of a vapor cloud, which ultimately determines distances to LFL and ½LFL concentrations. It should be noted that the results relate to worst-case hazard ranges, i.e. maximum downwind distance reached.

IV.4.3.5 Vapor Clouds

The gas dispersion model within Phast requires as inputs: material, phase, release rate, duration, and velocity. Where the cloud is ignited without being in contact with any area of congestion, a *flash fire* is assumed to occur. The flammable cloud envelope defining the flash fire envelope is taken as the distance to lower flammable limit (LFL), i.e. is equivalent to the cloud dimensions.

The TNO or Multi-Energy (ME) model Ref. (7) is applied for the VCE assessment. The TNO model predicts explosion effects in terms of peak overpressure in the vicinity around an explosion, for an explosion occurring at the stoichiometric concentration within a congested region. The congested regions are defined in terms of location, geometry, and the degree of congestion/confinement. Each congested region is given a corresponding ME curve number. The correlation of the TNO's ME curve number to peak side-on-overpressure is displayed as curves in Figure IV-2.

Curves 6 to 10 converge in the far field, i.e., the overpressure predicted in the far field is the same for Curve 6 to 10, and only in the near field is the predicted overpressure different. Therefore, the impact of vapor cloud explosion on offsite populations (more likely located in the far field) is not sensitive to the TNO curve selection if curve 6 or above is used. However, as indicated in Figure IV-2 impact on the near field working personnel is very sensitive to the TNO curve used for explosion modeling. Selection of the TNO curve is mainly based on the congested level of the obstructed areas on the facility Note that all of the congested areas, to which the TNO curve 5 or 5.5 are generally suitable, are defined in the in Appendix I Study Basis Assumption 22 Ref. (2).

The predicted overpressure caused by a VCE is associated with the volume (mass) of the flammable cloud confined within the obstructed region(s), which needs to be differentiated from the entire volume of the vapor cloud or the total released inventory. In this study, the amount of the flammable cloud confined within the congested region(s) with the concentration between LFL and UFL is used for the overpressure calculation.

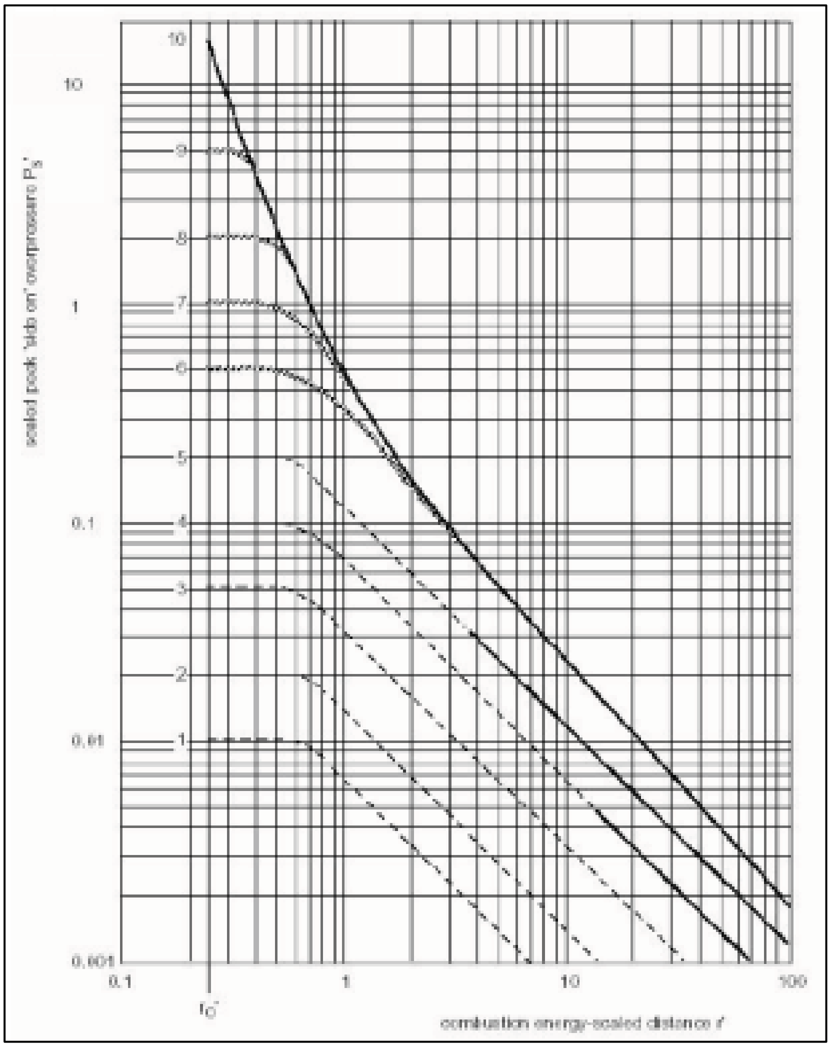

Figure IV-2: TNO Multi-Energy Curves

IV.4.4 Fragments

An analytical assessment of the potential theoretical hazard zones due to projectiles launched by a BLEVE of the propane bullet tanks was carried out using the methods provided in the CCPS guidelines Ref. (8). The following assumptions were made:

1. Brittle tank failure (sudden, complete failure that results in fragments)
2. The empty tank mass is 161,500 kg (178 short tons).
3. The ambient air conditions were 1 atm and 82 F.
4. The tank is liquid filled
5. The propane is a superheated liquid at release
6. All liquid vaporizes instantly upon tank rupture
7. Adiabatic expansion
8. Tank failure due to thermal weakening of the steel (failure due to external fire)
9. Tank failure at 14.3 bar (1.21 times the operating pressure to account for pressure relief devices and tank strength loss due to thermal damage as per CCPS Ref. (8))
10. Fragments are “chunky” with a coefficient of lift = 0

The three major steps in the process of determining the theoretical hazard zones can be described as calculating blast energy, determining initial velocity, and estimating the fragment range.

IV.4.4.1 Step 1: Calculating Blast Energy

The total energy associated with the BLEVE can be determined by accounting for the difference in internal energy of the propane at its initial state (at rupture) at its final state (at ambient conditions). The internal energy of a substance can be calculated using the following equation:

$$u = h - pv \qquad (1)$$

where

u	Specific Internal Energy	kJ/kg
h	Specific Enthalpy	kJ/kg
p	Pressure	kPa
v	Specific Volume	m^3/kg

The values for enthalpy and specific volume are gathered from thermodynamic property tables for temperature values between 50 and 160 C, and extrapolated to 550 C. Once internal energies are determined for the initial and final states, the BLEVE energy is calculated by taking the difference of these energies as shown below.

$$E_{BLEVE} = -\Delta u \qquad (2)$$

This represents the total energy involved in the BLEVE, but only a portion of this is imparted into tank fragments as kinetic energy. Large portions of energy will be diverted into moving the surrounding air and creating the shockwave. The portion assumed to become kinetic energy is 20% for liquid vaporization cases Ref. (8). However, another factor of 2 must be applied to this energy to account for the reflection of the shock off of the ground. This process is repeated for a range of temperatures to establish a relationship between the temperature of the propane at failure and the explosion energy.

IV.4.4.2 Step 2: Determining Initial Velocity

The CCPS guideline (8) presents three different methods for calculating the velocity of fragments. Method 1 is the simplest method that uses the theoretical correlation between kinetic energy and velocity; Method 2 is only appropriate for ideal gases; and Method 3 employs an empirical formula derived by Moore in 1967. While method 1 and 3 both appear to be valid for this scenario, the former results in gross overestimations for explosions with scaled energies with larger than 0.8. To calculate the scaled energy, the following equation is utilized:

$$E_{Scaled} = \left(\frac{2 * E}{M * a_0^2}\right)^{0.5} \qquad (3)$$

where

E_{Scaled}	Scaled Energy	-
E	Total Explosion Energy	J

M	Vessel Mass	kg
a_0	Speed of Sound in the Gas	m/s

For every temperature being studied, the scaled energy is above 0.8. Therefore, method 3 is utilized for all scenarios in this analysis. The empirical equation to estimate the initial velocity is

$$v_i = 1.092 * \left(\frac{E_k * G}{M}\right)^{0.5} \quad (4)$$

where

$$G = \frac{1}{1 + \left(\frac{C}{2M}\right)} \quad (5)$$

and

v_i	Initial Velocity	m/s
E_k	Kinetic Energy	J
C	Total Mass of Gas	kg
M	Mass of Vessel	kg

IV.4.4.3 Step 3: Estimating Fragment Range

Once the initial velocity has been calculated, the range for free-flying fragments is easily determined with 2D particle mechanics. It should be noted that "free-flying" indicates that the drag forces from air resistance are not accounted for and the only force acting on the fragment during its flight is gravity. Since the primary concern in this case is the horizontal range of fragments, the vertical range is not calculated. The horizontal range is calculated as follows:

$$R = \frac{v_i^2 * \sin(2 * \alpha_i)}{g} \quad (6)$$

where

R	Horizontal Range	m
v_i	Initial Velocity	m/s
α_i	Initial Trajectory Angle	rad
g	Gravitational Acceleration	m/s^2

As shown above, the range is dependent on the initial angle of the fragment. The CCPS guideline (8) reports that for horizontally positioned vessels, this angle will range from 5 to 10 degrees. The largest value of 10 degrees is used in calculations for each case to achieve a "worst case" result.

While the free-flying distance can be a useful result, it is too conservative to use as a representation of an actual BLEVE event. The CCPS guideline (8) provides a method to account for the effects of drag and lift on the fragment range. This method depends on the value of the scaled velocity and scaled range, as well as the coefficients of drag and lift. Once the scaled velocity is calculated, it is related to the scaled range via Figure IV-3 (Ref. (8)). Once the scaled range is obtained, the actual range can be calculated. The equations are as follows:

$$R_{Scaled} = \frac{\rho_0 C_D A_D R}{M_f} \qquad 7$$

And

$$v_{Scaled} = \frac{\rho_0 C_D A_D V_i^2}{M_f g} \qquad 8$$

where

R_{Scaled}	Scaled Range	-
v_{Scaled}	Scaled Velocity	-
V_i	Actual Velocity	m/s
R	Actual Range	m
ρ_0	Density of Ambient Air	kg/m^3
C_D	Drag Coefficient	-
A_D	Effective Drag Area	m^2
M_f	Mass of Fragment	kg
g	Gravitational Acceleration	m/s^2

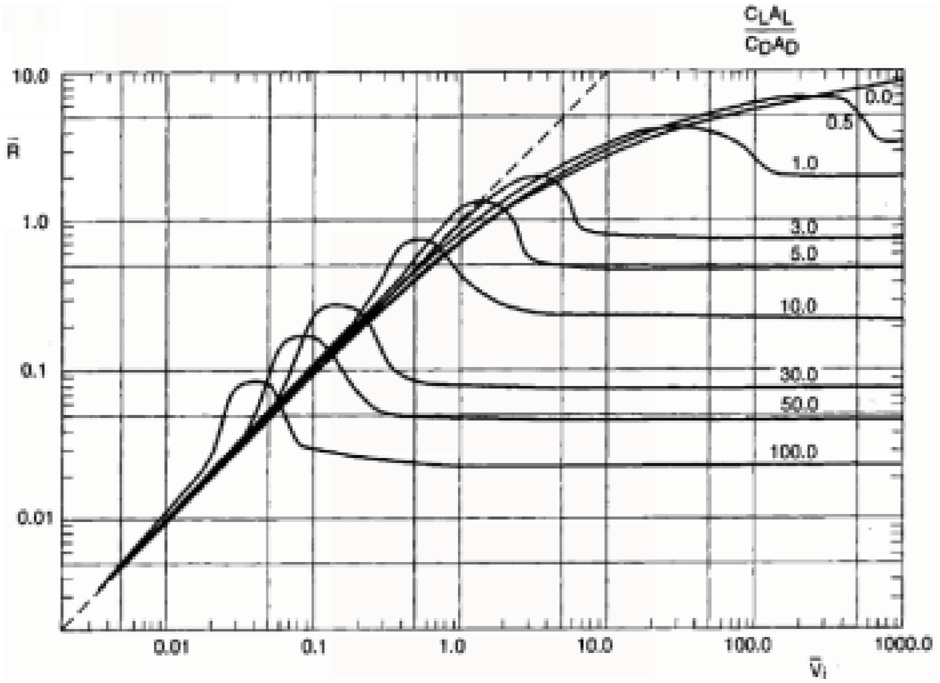

Figure IV-3: Correlation between scaled velocity and scaled range (Ref. (8))

It should be noted that the range represented here is the maximum range achieved by varying the initial angle. While the "free-flying" calculations limited the angle to 10 degrees, the angle used here is likely to be closer to 45 degrees. Thus, these results represent a more realistic, but still very conservative, worst case scenario.

Another BLEVE guidance document (Ref. (9)) provides a rough estimate of projectile ranges based on fireball radius (R). The following rough estimates are presented in the guidance document for approximations:

- 80-90% of projectiles fall within 4 R from the tank
- Severe rockets can go 15 R
- In very severe, very rare cases it may be possible to see rockets travel 22-30 R

IV.4.4.4 Results

The results of this analysis are presented below in Figure IV-4.

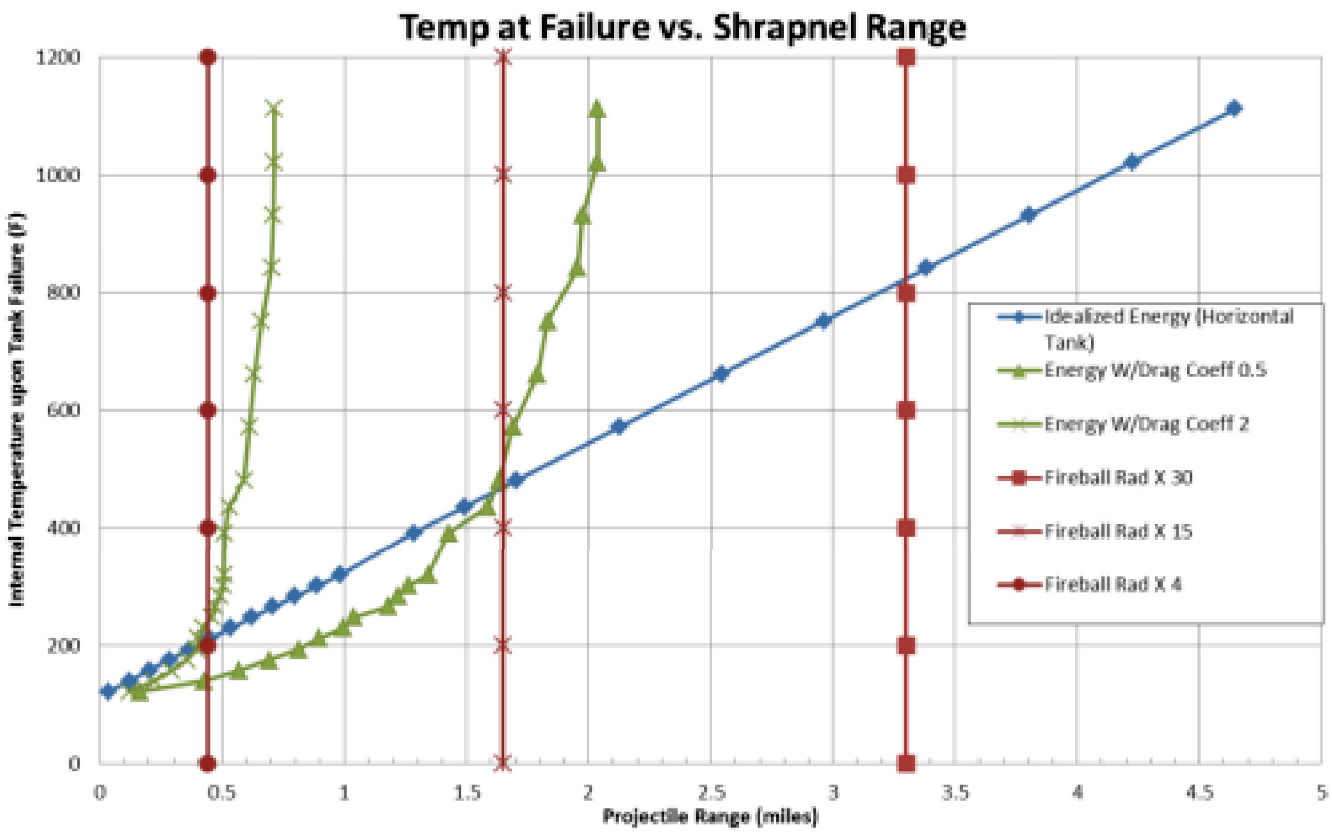

Figure IV-4: Results of shrapnel range analysis

As shown above, the results for the idealized free-flying method can provide good estimates at lower temperature (which translates to lower velocity where drag forces are less dominate) release scenarios, but results in extremely large over-estimations for higher temperatures where the steel tanks are more likely to actually fail. The resulting distance from assuming a drag coefficient of 0.5 seems to plateau around the 3200 m (~ 2 mile) range. This is slightly more than 0.5 miles past the 15X fireball distance (~ 2655 m / 1.65 miles). It should be noted that 0.5 is a very low drag coefficient; a perfect sphere has a coefficient of 0.47. It is highly unlikely that any fragment created in a BLEVE would have such a low coefficient for the duration of its flight and travel this distance. The more realistic drag coefficient of 2 yields results that appear to plateau near the 1150 m (~ 0.7 miles) range. This is approximately 450 m (~ 0.45 miles) further than 4X fireball distance (approx. 710 meters / 0.44 miles). These results are still quite conservative, but are much more in line with historical accounts of extreme fragment ranges. Note that not all fragments are expected to reach these distances, rather the calculations represent the maximum distance that could be traveled by a fragment with optimal conditions.

Based on the assessment calculations, conservatively 2 miles is the potential distance for fragment missiles from a BLEVE scenario of the pressurized storage tanks; and the majority of the fragments would be expected to be within 0.7 miles.

IV.4.5 Toxic Scenarios

Toxic hazards are not considered in this QRA study.

IV.5 Fire Consequence Results

Table III-3 and Table III-4 summarize hazard zones for jet fire and pool fire downwind distance to the following thermal radiation levels at 1 m height: 5 kW/m^2, 12.5 kW/m^2 and 35 kW/m^2.

Table III-5 summarizes hazard zones for flammable cloud downwind dispersion distance to LFL and 0.5 LFL concentrations, at 1 m (3.3 ft) height for each release event.

The downwind distances are reported at 1 m (3.3 ft) height as this is typically where personnel are generally located. In most cases, the radiation received downwind from the jet fire radiation is worse than the pool fire radiation.

Note that although 12 different weather conditions (six for both summer and winter each) are modeled, only the worst distances are reported for each scenario and hazard.

IV.5.1 Jet Fire Events

Significant jet fire hazards occur from several sections due to high pressure releases from rupture or large events. The largest jet fire thermal impact distance is found to be generated by the rupture of derailment of 14 railcars (R00-01Z-14C), which has a release rate of 30,148,911 lb/hr at -35°F / 70 psia. The 5 kW/m^2, 12.5 kW/m^2 and 35 kW/m^2 thermal radiation levels can reach 1,079 m (3,538 ft), 874 m (2,867 ft) and 724 m (2,374 ft), respectively, at B 1.8 m/s (4.0 mph) winter-night weather condition. However, this particular event is a theoretical event with an assumed large release rate (the release rate for the scenario is defined as the total inventory of 14 railcars released in 10 min). A jet fire would likely result from the derailment but may be several individual jets from the different rail cars in addition to pool fire; and this is meant to be represented by the assumed large release rate.

The next largest hazard zone for jet fire is from the 1000 mm (40 inch) rupture release from the refrigerated storage tank 1 (S04-01C-R2), which has a release rate of 22,552,398 lb/hr at -44°F / 19 psia. The 5 kW/m^2, 12.5 kW/m^2 and 35 kW/m^2 thermal radiation levels can reach 528 m (1,732 ft), 429 m (1,407 ft) and 354 m (1,160 ft), respectively, at F 1.8 m/s (4.0 mph) winter-night weather condition. Again note this is a theoretical case as the refrigerated storage tank is not under high pressure and the large jet is modeled given the high release rate from the large hole size.

IV.5.2 Pool Fire Events

For pool fires, the largest hazard distance from a steady state pool fire event is caused by the rupture release with 1000 mm (40 inch) hole size from the refrigerated storage tank 1 (S04-01C-R2), which has a release rate of 22,552,398 lb/hr at -44°F / 19 psia. The 5 kW/m^2, 12.5 kW/m^2 and 35 kW/m^2 thermal radiation levels can reach 400 m (1,313 ft), 282 m (925 ft) and 191 m (625 ft), respectively, at D 7.2 m/s (16.1 mph) winter-day weather condition.

IV.5.3 Flash Fire Events

For the flash fire, the largest hazard distance is also caused by the catastrophic rupture release from the refrigerated storage tank 1 (S04-01C-R3). The ½LFL and LFL can travel as far as 2,387 m (7,831 ft / 1.5 mi) and 1,910 m (6,267 ft / 1.2 mi), respectively, at F1.8 m/s (4.0 mph) summer-night weather condition.

Table IV-3: Jet Fire Hazard Zones (1m [3.3 ft] above ground level) by Weather Category

Event Description	Event Name	Release Rate	Distance to 5 kW/m²			Distance to 12.5 kW/m²			Distance to 35 kW/m²		
			Max Distance		Weather Condition	Max Distance		Weather Condition	Max Distance		Weather Condition
		lb/hour	(m)	(ft)		(m)	(ft)		(m)	(ft)	
Railcar Transit - Summer	R00-01Z-S-3H	684,582	181	592	B 1.8m/s (4.0 mph) S-D	150	492	B 1.8m/s (4.0 mph) S-D	127	418	B 1.8m/s (4.0 mph) S-D
	R00-01Z-S-2C	4,307,214	412	1,350	B 1.8m/s (4.0 mph) S-D	340	1,114	B 1.8m/s (4.0 mph) S-D	287	940	B 1.8m/s (4.0 mph) S-D
	R00-01Z-S-6C	12,920,849	671	2,202	B 1.8m/s (4.0 mph) S-D	552	1,811	B 1.8m/s (4.0 mph) S-D	464	1,523	B 1.8m/s (4.0 mph) S-D
	R00-01Z-S-14C	30,148,911	967	3,174	B 1.8m/s (4.0 mph) S-D	796	2,610	B 1.8m/s (4.0 mph) S-D	668	2,193	B 1.8m/s (4.0 mph) S-D
Railcar Transit - Winter	R00-01Z-W-3H	470,259	167	549	B 1.8m/s (4.0 mph) W-D	138	453	B 1.8m/s (4.0 mph) W-D	116	381	B 1.8m/s (4.0 mph) W-D
	R00-01Z-W-2C	4,307,214	453	1,485	B 1.8m/s (4.0 mph) W-D	369	1,212	B 1.8m/s (4.0 mph) W-D	308	1,012	B 1.8m/s (4.0 mph) W-D
	R00-01Z-W-6C	12,920,849	740	2,426	B 1.8m/s (4.0 mph) W-D	601	1,972	B 1.8m/s (4.0 mph) W-D	499	1,639	B 1.8m/s (4.0 mph) W-D
	R00-01Z-W-14C	30,148,911	1,079	3,538	B 1.8m/s (4.0 mph) W-D	874	2,867	B 1.8m/s (4.0 mph) W-D	724	2,374	B 1.8m/s (4.0 mph) W-D
Railcar Unloading Arm	R01-01Z-S	26,528	41	135	B 1.8m/s (4.0 mph) W-D	34	111	B 1.8m/s (4.0 mph) W-D	28	92	B 1.8m/s (4.0 mph) W-D
	R01-01Z-M	294,751	125	412	B 1.8m/s (4.0 mph) W-D	104	341	B 1.8m/s (4.0 mph) W-D	88	288	B 1.8m/s (4.0 mph) W-D
Railcar Vapor Return Arm	R01-02Z-S	3,534	7.3	24	B 1.8m/s (4.0 mph) W-D						
	R01-02Z-M	39,263	39	127	D 7.2m/s (16.1 mph) S-D	33	107	D 7.2m/s (16.1 mph) S-D	25	83	D 7.2m/s (16.1 mph) S-D
Unloading Vapor Return - Compressor	R01-03Z-S	2,063	8.0	26	B 1.8m/s (4.0 mph) S-D	7.3	24	D 7.2m/s (16.1 mph) S-D	6.6	22	D 7.2m/s (16.1 mph) S-D
	R01-03Z-M	51,579	44	144	D 7.2m/s (16.1 mph) S-D	38	125	D 7.2m/s (16.1 mph) S-D	34	111	D 7.2m/s (16.1 mph) S-D
	R01-03Z-L	97,092	59	195	D 7.2m/s (16.1 mph) S-D	51	168	D 7.2m/s (16.1 mph) S-D	45	147	D 7.2m/s (16.1 mph) S-D
	R01-03Z-R	97,092	59	195	D 7.2m/s (16.1 mph) S-D	51	168	D 7.2m/s (16.1 mph) S-D	45	147	D 7.2m/s (16.1 mph) S-D
Unloading Vapor Return - Piping to Railcar	R01-04Z-S	1,571	7.0	23	B 1.8m/s (4.0 mph) S-D	6.4	21	D 7.2m/s (16.1 mph) S-D	5.2	17	D 2.9m/s (6.5 mph) W-N
	R01-04Z-M	39,263	39	126	D 7.2m/s (16.1 mph) S-D	34	111	D 7.2m/s (16.1 mph) S-D	30	98	D 7.2m/s (16.1 mph) S-D
	R01-04Z-L	97,075	60	195	D 7.2m/s (16.1 mph) S-D	51	169	D 7.2m/s (16.1 mph) S-D	45	148	D 7.2m/s (16.1 mph) S-D
	R01-04Z-R-LP	148,425	75	245	B 1.8m/s (4.0 mph) W-D	59	193	D 7.2m/s (16.1 mph) S-D	55	180	D 7.2m/s (16.1 mph) S-D
Propane Unloading Pipe	R01-05Z-S	13,344	30	100	B 1.8m/s (4.0 mph) W-D	25	84	B 1.8m/s (4.0 mph) W-D	22	72	B 1.8m/s (4.0 mph) W-D
	R01-05Z-M	333,599	132	432	B 1.8m/s (4.0 mph) W-D	109	358	B 1.8m/s (4.0 mph) W-D	92	303	B 1.8m/s (4.0 mph) W-D
	R01-05Z-L	1,334,398	247	809	B 1.8m/s (4.0 mph) W-D	203	666	B 1.8m/s (4.0 mph) W-D	171	562	B 1.8m/s (4.0 mph) W-D
	R01-05Z-R-LP	4,717,779	462	1,515	B 1.8m/s (4.0 mph) W-D	377	1,238	B 1.8m/s (4.0 mph) W-D	316	1,035	B 1.8m/s (4.0 mph) W-D
Propane Unloading Storage Group1 (Connections) –	B01-06A-S	12,729	30	97	B 1.8m/s (4.0 mph) W-D	25	81	B 1.8m/s (4.0 mph) W-D	21	70	B 1.8m/s (4.0 mph) W-D
	B01-06A-M	318,220	128	421	B 1.8m/s (4.0 mph) W-D	106	349	B 1.8m/s (4.0 mph) W-D	90	296	B 1.8m/s (4.0 mph) W-D

Event Description	Event Name	Release Rate	Distance to 5 kW/m²			Distance to 12.5 kW/m²			Distance to 35 kW/m²		
			Max Distance		Weather Condition	Max Distance		Weather Condition	Max Distance		Weather Condition
		lb/hour	(m)	(ft)		(m)	(ft)		(m)	(ft)	
Liquid*	B01-06A-L	1,272,879	241	789	B 1.8m/s (4.0 mph) W-D	198	650	B 1.8m/s (4.0 mph) W-D	167	549	B 1.8m/s (4.0 mph) W-D
	B01-06A-R	2,150,503	305	1,000	B 1.8m/s (4.0 mph) W-D	251	822	B 1.8m/s (4.0 mph) W-D	211	692	B 1.8m/s (4.0 mph) W-D
Propane Unloading Storage Group1 (Connections) – Gas*	B01-06B-S	1,571	7.0	23	B 1.8m/s (4.0 mph) S-D	6.4	21	D 7.2m/s (16.1 mph) S-D	5.2	17	D 2.9m/s (6.5 mph) W-N
	B01-06B-M	39,263	39	126	D 7.2m/s (16.1 mph) S-D	34	111	D 7.2m/s (16.1 mph) S-D	30	98	D 7.2m/s (16.1 mph) S-D
	B01-06B-L	156,641	74	242	D 7.2m/s (16.1 mph) S-D	63	207	D 7.2m/s (16.1 mph) S-D	55	180	D 7.2m/s (16.1 mph) S-D
	B01-06B-R	963,649	171	561	B 1.8m/s (4.0 mph) W-D	133	436	D 7.2m/s (16.1 mph) S-D	111	364	D 7.2m/s (16.1 mph) S-D
Propane Unloading Storage Group2 (Connections) – Liquid*	B01-07A-S	12,729	30	97	B 1.8m/s (4.0 mph) W-D	25	81	B 1.8m/s (4.0 mph) W-D	21	70	B 1.8m/s (4.0 mph) W-D
	B01-07A-M	318,220	128	421	B 1.8m/s (4.0 mph) W-D	106	349	B 1.8m/s (4.0 mph) W-D	90	296	B 1.8m/s (4.0 mph) W-D
	B01-07A-L	1,272,879	241	789	B 1.8m/s (4.0 mph) W-D	198	650	B 1.8m/s (4.0 mph) W-D	167	549	B 1.8m/s (4.0 mph) W-D
	B01-07A-R	2,150,503	305	1,000	B 1.8m/s (4.0 mph) W-D	251	822	B 1.8m/s (4.0 mph) W-D	211	692	B 1.8m/s (4.0 mph) W-D
Propane Unloading Storage Group2 (Connections) – Gas*	B01-07B-S	1,571	7.0	23	B 1.8m/s (4.0 mph) S-D	6.4	21	D 7.2m/s (16.1 mph) S-D	5.2	17	D 2.9m/s (6.5 mph) W-N
	B01-07B-M	39,263	39	126	D 7.2m/s (16.1 mph) S-D	34	111	D 7.2m/s (16.1 mph) S-D	30	98	D 7.2m/s (16.1 mph) S-D
	B01-07B-L	156,641	74	242	D 7.2m/s (16.1 mph) S-D	63	207	D 7.2m/s (16.1 mph) S-D	55	180	D 7.2m/s (16.1 mph) S-D
	B01-07B-R	963,649	171	561	B 1.8m/s (4.0 mph) W-D	133	436	D 7.2m/s (16.1 mph) S-D	111	364	D 7.2m/s (16.1 mph) S-D
Propane Unloading Storage Group3 (Connections) – Liquid*	B01-08A-S	12,729	30	97	B 1.8m/s (4.0 mph) W-D	25	81	B 1.8m/s (4.0 mph) W-D	21	70	B 1.8m/s (4.0 mph) W-D
	B01-08A-M	318,220	128	421	B 1.8m/s (4.0 mph) W-D	106	349	B 1.8m/s (4.0 mph) W-D	90	296	B 1.8m/s (4.0 mph) W-D
	B01-08A-L	1,272,879	241	789	B 1.8m/s (4.0 mph) W-D	198	650	B 1.8m/s (4.0 mph) W-D	167	549	B 1.8m/s (4.0 mph) W-D
	B01-08A-R	2,150,503	305	1,000	B 1.8m/s (4.0 mph) W-D	251	822	B 1.8m/s (4.0 mph) W-D	211	692	B 1.8m/s (4.0 mph) W-D
Propane Unloading Storage Group3 (Connections) – Gas*	B01-08B-S	1,571	7.0	23	B 1.8m/s (4.0 mph) S-D	6.4	21	D 7.2m/s (16.1 mph) S-D	5.2	17	D 2.9m/s (6.5 mph) W-N
	B01-08B-M	39,263	39	126	D 7.2m/s (16.1 mph) S-D	34	111	D 7.2m/s (16.1 mph) S-D	30	98	D 7.2m/s (16.1 mph) S-D
	B01-08B-L	156,641	74	242	D 7.2m/s (16.1 mph) S-D	63	207	D 7.2m/s (16.1 mph) S-D	55	180	D 7.2m/s (16.1 mph) S-D
	B01-08B-R	963,649	171	561	B 1.8m/s (4.0 mph) W-D	133	436	D 7.2m/s (16.1 mph) S-D	111	364	D 7.2m/s (16.1 mph) S-D
Propane Unloading Storage Group1 – Bullets	B01-06C-S	21,512	38	123	B 1.8m/s (4.0 mph) W-D	32	103	B 1.8m/s (4.0 mph) W-D	27	89	B 1.8m/s (4.0 mph) W-D
	B01-06C-M	79,555	68	224	B 1.8m/s (4.0 mph) W-D	57	187	B 1.8m/s (4.0 mph) W-D	49	159	B 1.8m/s (4.0 mph) W-D
	B01-06C-L	318,220	128	421	B 1.8m/s (4.0 mph) W-D	106	349	B 1.8m/s (4.0 mph) W-D	90	296	B 1.8m/s (4.0 mph) W-D
	B01-06C-R	2,153,813	305	1,001	B 1.8m/s (4.0 mph) W-D	251	823	B 1.8m/s (4.0 mph) W-D	211	693	B 1.8m/s (4.0 mph) W-D

Event Description	Event Name	Release Rate	Distance to 5 kW/m²			Distance to 12.5 kW/m²			Distance to 35 kW/m²		
			Max Distance		Weather Condition	Max Distance		Weather Condition	Max Distance		Weather Condition
		lb/hour	(m)	(ft)		(m)	(ft)		(m)	(ft)	
Propane Unloading Storage Group2 – Bullets	B01-07C-S	21,512	38	123	B 1.8m/s (4.0 mph) W-D	32	103	B 1.8m/s (4.0 mph) W-D	27	89	B 1.8m/s (4.0 mph) W-D
	B01-07C-M	79,555	68	224	B 1.8m/s (4.0 mph) W-D	57	187	B 1.8m/s (4.0 mph) W-D	49	159	B 1.8m/s (4.0 mph) W-D
	B01-07C-L	318,220	128	421	B 1.8m/s (4.0 mph) W-D	106	349	B 1.8m/s (4.0 mph) W-D	90	296	B 1.8m/s (4.0 mph) W-D
	B01-07C-R	2,153,813	305	1,001	B 1.8m/s (4.0 mph) W-D	251	823	B 1.8m/s (4.0 mph) W-D	211	693	B 1.8m/s (4.0 mph) W-D
Propane Unloading Storage Group3 – Bullets	B01-08C-S	21,512	38	123	B 1.8m/s (4.0 mph) W-D	32	103	B 1.8m/s (4.0 mph) W-D	27	89	B 1.8m/s (4.0 mph) W-D
	B01-08C-M	79,555	68	224	B 1.8m/s (4.0 mph) W-D	57	187	B 1.8m/s (4.0 mph) W-D	49	159	B 1.8m/s (4.0 mph) W-D
	B01-08C-L	318,220	128	421	B 1.8m/s (4.0 mph) W-D	106	349	B 1.8m/s (4.0 mph) W-D	90	296	B 1.8m/s (4.0 mph) W-D
	B01-08C-R	2,153,595	305	1,001	B 1.8m/s (4.0 mph) W-D	251	823	B 1.8m/s (4.0 mph) W-D	211	693	B 1.8m/s (4.0 mph) W-D
Propane Rundown Pumps	F02-06A-S	2,119	15	50	B 1.8m/s (4.0 mph) W-D	13	42	B 1.8m/s (4.0 mph) W-D	11	35	B 1.8m/s (4.0 mph) W-D
	F02-06A-M	52,987	58	192	B 1.8m/s (4.0 mph) W-D	49	160	B 1.8m/s (4.0 mph) W-D	41	133	B 1.8m/s (4.0 mph) W-D
	F02-06A-L	211,948	101	331	B 1.8m/s (4.0 mph) W-D	83	273	B 1.8m/s (4.0 mph) W-D	69	228	B 1.8m/s (4.0 mph) W-D
	F02-06A-R	434,990	131	431	B 1.8m/s (4.0 mph) W-D	108	355	B 1.8m/s (4.0 mph) W-D	90	296	B 1.8m/s (4.0 mph) W-D
Propane Rundown Pipe to Storage Tank	F02-06B-S	1,463	11	36	B 1.8m/s (4.0 mph) W-D	9.2	30	B 1.8m/s (4.0 mph) W-D	8.2	27	B 1.8m/s (4.0 mph) W-D
	F02-06B-M	36,580	43	140	B 1.8m/s (4.0 mph) W-D	36	117	B 1.8m/s (4.0 mph) W-D	30	98	B 1.8m/s (4.0 mph) W-D
	F02-06B-L	146,321	75	246	B 1.8m/s (4.0 mph) W-D	62	205	B 1.8m/s (4.0 mph) W-D	52	172	B 1.8m/s (4.0 mph) W-D
	F02-06B-R	1,397,740	174	572	B 1.8m/s (4.0 mph) W-D	144	472	B 1.8m/s (4.0 mph) W-D	120	394	B 1.8m/s (4.0 mph) W-D
Storage Tank 1 - Connections – Liquid*	S04-01B-M	56,381	43	142	B 1.8m/s (4.0 mph) W-D						
	S04-01B-L	225,524	130	426	B 1.8m/s (4.0 mph) W-D	90	296	B 1.8m/s (4.0 mph) W-D			
	S04-01B-R	434,858	181	595	B 1.8m/s (4.0 mph) W-D	138	453	B 1.8m/s (4.0 mph) W-D	94	310	B 1.8m/s (4.0 mph) W-D
Storage Tank 2 - Connections – Liquid*	S04-02B-M	56,381	63	207	B 1.8m/s (4.0 mph) W-D						
	S04-02B-L	225,524	136	445	B 1.8m/s (4.0 mph) W-D	103	339	B 1.8m/s (4.0 mph) W-D	71	231	B 1.8m/s (4.0 mph) W-D
	S04-02B-R	434,858	188	616	B 1.8m/s (4.0 mph) W-D	147	482	B 1.8m/s (4.0 mph) W-D	110	361	B 1.8m/s (4.0 mph) W-D
Earthquake	EQ-L	202,979	100	329	B 1.8m/s (4.0 mph) W-D	83	272	B 1.8m/s (4.0 mph) W-D	69	227	B 1.8m/s (4.0 mph) W-D
	EQ-R	2,029,716	228	746	B 1.8m/s (4.0 mph) W-D	186	612	B 1.8m/s (4.0 mph) W-D	155	508	B 1.8m/s (4.0 mph) W-D
Storage Tank 1	S04-01C-R1	2,029,716	228	746	B 1.8m/s (4.0 mph) W-D	186	612	B 1.8m/s (4.0 mph) W-D	155	508	B 1.8m/s (4.0 mph) W-D
	S04-01C-R2	22,552,398	528	1,732	F 1.8m/s (4.0 mph) W-N	429	1,407	F 1.8m/s (4.0 mph) W-N	354	1,160	F 1.8m/s (4.0 mph) W-N

Event Description	Event Name	Release Rate	Distance to 5 kW/m²			Distance to 12.5 kW/m²			Distance to 35 kW/m²		
			Max Distance		Weather Condition	Max Distance		Weather Condition	Max Distance		Weather Condition
		lb/hour	(m)	(ft)		(m)	(ft)		(m)	(ft)	
Storage Tank 2	S04-02C-R1	2,029,716	228	746	B 1.8m/s (4.0 mph) W-D	186	612	B 1.8m/s (4.0 mph) W-D	155	508	B 1.8m/s (4.0 mph) W-D
	S04-02C-R2	22,552,398	528	1,732	F 1.8m/s (4.0 mph) W-N	429	1,407	F 1.8m/s (4.0 mph) W-N	354	1,160	F 1.8m/s (4.0 mph) W-N
Vapor from Tank to BOG – Pipe	S04-03Z-S	67	3.6	12	D 7.2m/s (16.1 mph) S-D						
	S04-03Z-M	1,679	11	37	D 7.2m/s (16.1 mph) S-D	11	37	D 7.2m/s (16.1 mph) S-D	11	37	D 7.2m/s (16.1 mph) S-D
	S04-03Z-L	6,716	20	65	D 7.2m/s (16.1 mph) S-D	20	64	D 7.2m/s (16.1 mph) S-D	20	64	D 7.2m/s (16.1 mph) S-D
	S04-03Z-R	53,053	57	186	D 7.2m/s (16.1 mph) S-D	54	178	D 7.2m/s (16.1 mph) S-D	52	172	D 7.2m/s (16.1 mph) S-D
Propane Feed Pumps	F02-01A-S	12,220	29	96	B 1.8m/s (4.0 mph) W-D	25	80	B 1.8m/s (4.0 mph) W-D	21	69	B 1.8m/s (4.0 mph) W-D
	F02-01A-M	305,492	127	416	B 1.8m/s (4.0 mph) W-D	105	345	B 1.8m/s (4.0 mph) W-D	89	292	B 1.8m/s (4.0 mph) W-D
	F02-01A-L	370,183	138	454	B 1.8m/s (4.0 mph) W-D	115	376	B 1.8m/s (4.0 mph) W-D	97	319	B 1.8m/s (4.0 mph) W-D
	F02-01A-R	369,780	138	454	B 1.8m/s (4.0 mph) W-D	114	376	B 1.8m/s (4.0 mph) W-D	97	318	B 1.8m/s (4.0 mph) W-D
Propane Subcooler	F02-01B-S	1,029	8.3	27	B 1.8m/s (4.0 mph) W-D	7.1	23	B 1.8m/s (4.0 mph) W-D	6.1	20	B 1.8m/s (4.0 mph) W-D
	F02-01B-M	25,725	37	121	B 1.8m/s (4.0 mph) W-D	31	102	B 1.8m/s (4.0 mph) W-D	27	87	B 1.8m/s (4.0 mph) W-D
	F02-01B-L	102,899	70	229	B 1.8m/s (4.0 mph) W-D	58	192	B 1.8m/s (4.0 mph) W-D	50	164	B 1.8m/s (4.0 mph) W-D
	F02-01B-R	386,032	131	430	B 1.8m/s (4.0 mph) W-D	109	357	B 1.8m/s (4.0 mph) W-D	93	304	B 1.8m/s (4.0 mph) W-D
HP Suction Drum – Liquid	F02-01C-S	9,316	28	91	B 1.8m/s (4.0 mph) W-D	23	76	B 1.8m/s (4.0 mph) W-D	20	65	B 1.8m/s (4.0 mph) W-D
	F02-01C-M	232,894	120	392	B 1.8m/s (4.0 mph) W-D	99	324	B 1.8m/s (4.0 mph) W-D	84	275	B 1.8m/s (4.0 mph) W-D
	F02-01C-L	279,041	130	426	B 1.8m/s (4.0 mph) W-D	107	352	B 1.8m/s (4.0 mph) W-D	91	297	B 1.8m/s (4.0 mph) W-D
	F02-01C-R	520,523	172	564	B 1.8m/s (4.0 mph) W-D	142	465	B 1.8m/s (4.0 mph) W-D	119	392	B 1.8m/s (4.0 mph) W-D
HP Suction Drum – Gas	F02-01D-S	1,003	5.6	18	B 1.8m/s (4.0 mph) S-D	5.0	17	D 7.2m/s (16.1 mph) S-D	3.1	10	D 7.2m/s (16.1 mph) W-D
	F02-01D-M	25,083	31	102	D 7.2m/s (16.1 mph) S-D	28	91	D 7.2m/s (16.1 mph) S-D	25	81	D 7.2m/s (16.1 mph) S-D
	F02-01D-L	100,330	61	199	D 7.2m/s (16.1 mph) S-D	52	172	D 7.2m/s (16.1 mph) S-D	46	151	D 7.2m/s (16.1 mph) S-D
	F02-01D-R	477,567	125	409	B 1.8m/s (4.0 mph) W-D	99	326	D 7.2m/s (16.1 mph) S-D	85	278	D 7.2m/s (16.1 mph) S-D
HP Propane Compression	F02-01E-S	3,352	10	33	B 1.8m/s (4.0 mph) S-D	9.0	30	D 7.2m/s (16.1 mph) S-D	8.2	27	D 7.2m/s (16.1 mph) S-D
	F02-01E-M	83,797	54	178	D 7.2m/s (16.1 mph) S-D	47	153	D 7.2m/s (16.1 mph) S-D	41	134	D 7.2m/s (16.1 mph) S-D
	F02-01E-L	335,188	104	342	B 1.8m/s (4.0 mph) W-D	87	284	D 7.2m/s (16.1 mph) S-D	74	242	D 7.2m/s (16.1 mph) S-D
	F02-01E-R	431,950	117	385	B 1.8m/s (4.0 mph) W-D	96	315	D 7.2m/s (16.1 mph) S-D	81	267	D 7.2m/s (16.1 mph) S-D

Event Description	Event Name	Release Rate	Distance to 5 kW/m²			Distance to 12.5 kW/m²			Distance to 35 kW/m²		
			Max Distance		Weather Condition	Max Distance		Weather Condition	Max Distance		Weather Condition
		lb/hour	(m)	(ft)		(m)	(ft)		(m)	(ft)	
BOG Air Cooler	F02-01F-S	939	5.3	17	B 1.8m/s (4.0 mph) S-D	4.7	16	C/D 2.2m/s (4.9 mph) S-D	3.0	10	D 7.2m/s (16.1 mph) W-D
	F02-01F-M	23,480	29	96	D 7.2m/s (16.1 mph) S-D	26	85	D 7.2m/s (16.1 mph) S-D	23	76	D 7.2m/s (16.1 mph) S-D
	F02-01F-L	65,169	49	161	D 7.2m/s (16.1 mph) S-D	43	140	D 7.2m/s (16.1 mph) S-D	38	123	D 7.2m/s (16.1 mph) S-D
	F02-01F-R	65,169	49	161	D 7.2m/s (16.1 mph) S-D	43	140	D 7.2m/s (16.1 mph) S-D	38	123	D 7.2m/s (16.1 mph) S-D
BOG Compressor	F02-02Z-S	1,099	5.7	19	B 1.8m/s (4.0 mph) S-D	5.2	17	B 1.8m/s (4.0 mph) S-D	3.6	12	B 1.8m/s (4.0 mph) W-D
	F02-02Z-M	27,479	32	103	D 7.2m/s (16.1 mph) S-D	28	91	D 7.2m/s (16.1 mph) S-D	25	81	D 7.2m/s (16.1 mph) S-D
	F02-02Z-L	65,136	49	160	D 7.2m/s (16.1 mph) S-D	42	139	D 7.2m/s (16.1 mph) S-D	37	122	D 7.2m/s (16.1 mph) S-D
	F02-02Z-R	65,136	49	160	D 7.2m/s (16.1 mph) S-D	42	139	D 7.2m/s (16.1 mph) S-D	37	122	D 7.2m/s (16.1 mph) S-D
MP Suction Drum – Liquid	F02-03A-S	5,358	24	80	B 1.8m/s (4.0 mph) W-D	20	67	B 1.8m/s (4.0 mph) W-D	17	57	B 1.8m/s (4.0 mph) W-D
	F02-03A-M	133,954	104	340	B 1.8m/s (4.0 mph) W-D	86	281	B 1.8m/s (4.0 mph) W-D	72	236	B 1.8m/s (4.0 mph) W-D
	F02-03A-L	535,817	193	634	B 1.8m/s (4.0 mph) W-D	158	520	B 1.8m/s (4.0 mph) W-D	133	435	B 1.8m/s (4.0 mph) W-D
	F02-03A-R	773,378	228	747	B 1.8m/s (4.0 mph) W-D	186	612	B 1.8m/s (4.0 mph) W-D	156	511	B 1.8m/s (4.0 mph) W-D
MP Suction Drum – Gas	F02-03B-S	410	3.9	13	D 7.2m/s (16.1 mph) S-D	3.7	12	D 7.2m/s (16.1 mph) S-D	2.1	7	D 2.9m/s (6.5 mph) W-N
	F02-03B-M	10,260	22	71	D 7.2m/s (16.1 mph) S-D	20	65	D 7.2m/s (16.1 mph) S-D	18	59	D 7.2m/s (16.1 mph) S-D
	F02-03B-L	41,042	41	136	D 7.2m/s (16.1 mph) S-D	37	120	D 7.2m/s (16.1 mph) S-D	33	108	D 7.2m/s (16.1 mph) S-D
	F02-03B-R	216,219	88	288	B 1.8m/s (4.0 mph) W-D	70	231	D 7.2m/s (16.1 mph) S-D	63	206	D 7.2m/s (16.1 mph) S-D
MP Propane Compression	F02-03C-S	959	5.4	18	B 1.8m/s (4.0 mph) S-D	4.8	16	B 1.8m/s (4.0 mph) S-D	3.0	10	D 7.2m/s (16.1 mph) W-D
	F02-03C-M	23,964	30	98	D 7.2m/s (16.1 mph) S-D	27	87	D 7.2m/s (16.1 mph) S-D	24	78	D 7.2m/s (16.1 mph) S-D
	F02-03C-L	95,857	59	194	D 7.2m/s (16.1 mph) S-D	51	168	D 7.2m/s (16.1 mph) S-D	45	147	D 7.2m/s (16.1 mph) S-D
	F02-03C-R	138,678	70	230	D 7.2m/s (16.1 mph) S-D	60	197	D 7.2m/s (16.1 mph) S-D	52	171	D 7.2m/s (16.1 mph) S-D
LP Suction Drum – Liquid	F02-04A-S	2,119	15	50	B 1.8m/s (4.0 mph) W-D	13	42	B 1.8m/s (4.0 mph) W-D	11	35	B 1.8m/s (4.0 mph) W-D
	F02-04A-M	52,987	58	192	B 1.8m/s (4.0 mph) W-D	49	160	B 1.8m/s (4.0 mph) W-D	41	133	B 1.8m/s (4.0 mph) W-D
	F02-04A-L	211,948	101	331	B 1.8m/s (4.0 mph) W-D	83	273	B 1.8m/s (4.0 mph) W-D	69	228	B 1.8m/s (4.0 mph) W-D
	F02-04A-R	240,216	106	347	B 1.8m/s (4.0 mph) W-D	87	286	B 1.8m/s (4.0 mph) W-D	73	239	B 1.8m/s (4.0 mph) W-D
LP Suction Drum – Gas	F02-04B-S	90	3.8	12	D 2.9m/s (6.5 mph) S-N	1.7	6	C/D 2.2m/s (4.9 mph) W-D			
	F02-04B-M	2,258	12	40	D 7.2m/s (16.1 mph) S-D	12	40	D 7.2m/s (16.1 mph) S-D	12	40	D 7.2m/s (16.1 mph) S-D

Event Description	Event Name	Release Rate	Distance to 5 kW/m²			Distance to 12.5 kW/m²			Distance to 35 kW/m²		
			Max Distance		Weather Condition	Max Distance		Weather Condition	Max Distance		Weather Condition
		lb/hour	(m)	(ft)		(m)	(ft)		(m)	(ft)	
	F02-04B-L	9,034	22	72	D 7.2m/s (16.1 mph) S-D	21	70	D 7.2m/s (16.1 mph) S-D	21	70	D 7.2m/s (16.1 mph) S-D
	F02-04B-R	56,461	52	170	D 7.2m/s (16.1 mph) S-D	49	161	D 7.2m/s (16.1 mph) S-D	47	154	D 7.2m/s (16.1 mph) S-D
LP Propane Compression	F02-04C-S	394	3.7	12	B 1.8m/s (4.0 mph) S-D	3.5	11	D 7.2m/s (16.1 mph) S-D	2.1	7	B 1.8m/s (4.0 mph) W-D
	F02-04C-M	9,853	21	69	D 7.2m/s (16.1 mph) S-D	19	62	D 7.2m/s (16.1 mph) S-D	17	57	D 7.2m/s (16.1 mph) S-D
	F02-04C-L	39,413	41	133	D 7.2m/s (16.1 mph) S-D	36	118	D 7.2m/s (16.1 mph) S-D	32	106	D 7.2m/s (16.1 mph) S-D
	F02-04C-R	48,482	44	146	D 7.2m/s (16.1 mph) S-D	39	129	D 7.2m/s (16.1 mph) S-D	35	115	D 7.2m/s (16.1 mph) S-D
Propane Air Cooler – Liquid	F02-05A-S	15,399	30	99	B 1.8m/s (4.0 mph) W-D	25	84	B 1.8m/s (4.0 mph) W-D	22	72	B 1.8m/s (4.0 mph) W-D
	F02-05A-M	384,975	132	434	B 1.8m/s (4.0 mph) W-D	110	360	B 1.8m/s (4.0 mph) W-D	93	306	B 1.8m/s (4.0 mph) W-D
	F02-05A-L	691,261	172	566	B 1.8m/s (4.0 mph) W-D	143	469	B 1.8m/s (4.0 mph) W-D	121	398	B 1.8m/s (4.0 mph) W-D
	F02-05A-R	691,261	172	566	B 1.8m/s (4.0 mph) W-D	143	469	B 1.8m/s (4.0 mph) W-D	121	398	B 1.8m/s (4.0 mph) W-D
Propane Air Cooler – Gas	F02-05B-S	3,352	10	33	B 1.8m/s (4.0 mph) S-D	9.0	30	D 7.2m/s (16.1 mph) S-D	8.2	27	D 7.2m/s (16.1 mph) S-D
	F02-05B-M	83,797	54	178	D 7.2m/s (16.1 mph) S-D	47	153	D 7.2m/s (16.1 mph) S-D	41	134	D 7.2m/s (16.1 mph) S-D
	F02-05B-L	335,188	104	342	B 1.8m/s (4.0 mph) W-D	87	284	D 7.2m/s (16.1 mph) S-D	74	242	D 7.2m/s (16.1 mph) S-D
	F02-05B-R	651,114	143	468	B 1.8m/s (4.0 mph) W-D	113	372	D 7.2m/s (16.1 mph) S-D	95	313	D 7.2m/s (16.1 mph) S-D
Propane Accumulator & Condenser - Liquid	F02-05C-S	15,399	30	99	B 1.8m/s (4.0 mph) W-D	25	84	B 1.8m/s (4.0 mph) W-D	22	72	B 1.8m/s (4.0 mph) W-D
	F02-05C-M	384,975	132	434	B 1.8m/s (4.0 mph) W-D	110	360	B 1.8m/s (4.0 mph) W-D	93	306	B 1.8m/s (4.0 mph) W-D
	F02-05C-L	691,261	172	566	B 1.8m/s (4.0 mph) W-D	143	469	B 1.8m/s (4.0 mph) W-D	121	398	B 1.8m/s (4.0 mph) W-D
	F02-05C-R	691,261	172	566	B 1.8m/s (4.0 mph) W-D	143	469	B 1.8m/s (4.0 mph) W-D	121	398	B 1.8m/s (4.0 mph) W-D
Propane Accumulator & Condenser - Gas	F02-05D-S	3,352	10	33	B 1.8m/s (4.0 mph) S-D	9.0	30	D 7.2m/s (16.1 mph) S-D	8.2	27	D 7.2m/s (16.1 mph) S-D
	F02-05D-M	83,797	54	178	D 7.2m/s (16.1 mph) S-D	47	153	D 7.2m/s (16.1 mph) S-D	41	134	D 7.2m/s (16.1 mph) S-D
	F02-05D-L	335,188	104	342	B 1.8m/s (4.0 mph) W-D	87	284	D 7.2m/s (16.1 mph) S-D	74	242	D 7.2m/s (16.1 mph) S-D
	F02-05D-R	1,025,548	176	576	B 1.8m/s (4.0 mph) W-D	137	451	D 7.2m/s (16.1 mph) W-D	114	374	D 7.2m/s (16.1 mph) S-D
Marine Propane Loading Line - Holding Mode**	M03-01H-S	2,256	16	52	B 1.8m/s (4.0 mph) W-D	13	44	B 1.8m/s (4.0 mph) W-D	11	36	B 1.8m/s (4.0 mph) W-D
	M03-01H-M	56,395	61	199	B 1.8m/s (4.0 mph) W-D	50	165	B 1.8m/s (4.0 mph) W-D	42	138	B 1.8m/s (4.0 mph) W-D
	M03-01H-L	225,579	104	341	B 1.8m/s (4.0 mph) W-D	86	281	B 1.8m/s (4.0 mph) W-D	72	235	B 1.8m/s (4.0 mph) W-D
	M03-01H-R	570,860	145	476	B 1.8m/s (4.0 mph) W-D	119	392	B 1.8m/s (4.0 mph) W-D	99	326	B 1.8m/s (4.0 mph) W-D

Event Description	Event Name	Release Rate	Distance to 5 kW/m²			Distance to 12.5 kW/m²			Distance to 35 kW/m²		
			Max Distance		Weather Condition	Max Distance		Weather Condition	Max Distance		Weather Condition
		lb/hour	(m)	(ft)		(m)	(ft)		(m)	(ft)	
Marine Propane Loading Line – Recirculation Mode	M03-01R-S	8,862	32	106	B 1.8m/s (4.0 mph) W-D	27	88	B 1.8m/s (4.0 mph) W-D	23	75	B 1.8m/s (4.0 mph) W-D
	M03-01R-M	124,893	106	347	B 1.8m/s (4.0 mph) W-D	87	286	B 1.8m/s (4.0 mph) W-D	73	239	B 1.8m/s (4.0 mph) W-D
	M03-01R-L	124,893	106	347	B 1.8m/s (4.0 mph) W-D	87	286	B 1.8m/s (4.0 mph) W-D	73	239	B 1.8m/s (4.0 mph) W-D
	M03-01R-R	124,893	106	347	B 1.8m/s (4.0 mph) W-D	87	286	B 1.8m/s (4.0 mph) W-D	73	239	B 1.8m/s (4.0 mph) W-D
Propane Recirculation	M03-03Z-S	8,862	32	106	B 1.8m/s (4.0 mph) W-D	27	88	B 1.8m/s (4.0 mph) W-D	23	75	B 1.8m/s (4.0 mph) W-D
	M03-03Z-M	124,893	106	347	B 1.8m/s (4.0 mph) W-D	87	286	B 1.8m/s (4.0 mph) W-D	73	239	B 1.8m/s (4.0 mph) W-D
	M03-03Z-L	124,893	106	347	B 1.8m/s (4.0 mph) W-D	87	286	B 1.8m/s (4.0 mph) W-D	73	239	B 1.8m/s (4.0 mph) W-D
	M03-03Z-R	124,893	106	347	B 1.8m/s (4.0 mph) W-D	87	286	B 1.8m/s (4.0 mph) W-D	73	239	B 1.8m/s (4.0 mph) W-D
Marine Propane Loading Line - Loading Mode	M03-01L-S	10,669	34	113	B 1.8m/s (4.0 mph) W-D	29	94	B 1.8m/s (4.0 mph) W-D	24	80	B 1.8m/s (4.0 mph) W-D
	M03-01L-M	266,719	146	479	B 1.8m/s (4.0 mph) W-D	120	394	B 1.8m/s (4.0 mph) W-D	100	329	B 1.8m/s (4.0 mph) W-D
	M03-01L-L	1,066,875	271	891	B 1.8m/s (4.0 mph) W-D	222	727	B 1.8m/s (4.0 mph) W-D	184	605	B 1.8m/s (4.0 mph) W-D
	M03-01L-R	5,319,009	233	766	B 1.8m/s (4.0 mph) W-D	193	635	B 1.8m/s (4.0 mph) W-D	163	535	B 1.8m/s (4.0 mph) W-D
Loading Vapor Return Line to Tank	M03-04Z-S	66	3.5	12	D 7.2m/s (16.1 mph) S-D						
	M03-04Z-M	1,646	11	37	D 7.2m/s (16.1 mph) S-D	11	37	D 7.2m/s (16.1 mph) S-D	11	37	D 7.2m/s (16.1 mph) S-D
	M03-04Z-L	6,583	20	64	D 7.2m/s (16.1 mph) S-D	19	63	D 7.2m/s (16.1 mph) S-D	19	63	D 7.2m/s (16.1 mph) S-D
	M03-04Z-R	25,769	43	142	B 1.8m/s (4.0 mph) S-D	42	138	B 1.8m/s (4.0 mph) S-D	41	134	B 1.8m/s (4.0 mph) S-D
Jetty Loading Pipe	M03-05Z-S	10,669	34	113	B 1.8m/s (4.0 mph) W-D	29	94	B 1.8m/s (4.0 mph) W-D	24	80	B 1.8m/s (4.0 mph) W-D
	M03-05Z-M	266,719	146	479	B 1.8m/s (4.0 mph) W-D	120	394	B 1.8m/s (4.0 mph) W-D	100	329	B 1.8m/s (4.0 mph) W-D
	M03-05Z-L	1,066,875	271	891	B 1.8m/s (4.0 mph) W-D	222	727	B 1.8m/s (4.0 mph) W-D	184	605	B 1.8m/s (4.0 mph) W-D
	M03-05Z-R	3,233,550	201	659	B 1.8m/s (4.0 mph) W-D	166	546	B 1.8m/s (4.0 mph) W-D	140	460	B 1.8m/s (4.0 mph) W-D
Vapor Return from Jetty Pipe	M03-06Z-S	66	3.5	12	D 7.2m/s (16.1 mph) S-D						
	M03-06Z-M	1,646	11	37	D 7.2m/s (16.1 mph) S-D	11	37	D 7.2m/s (16.1 mph) S-D	11	37	D 7.2m/s (16.1 mph) S-D
	M03-06Z-L	6,583	20	64	D 7.2m/s (16.1 mph) S-D	19	63	D 7.2m/s (16.1 mph) S-D	19	63	D 7.2m/s (16.1 mph) S-D
	M03-06Z-R	14,286	34	112	B 1.8m/s (4.0 mph) S-D	33	109	B 1.8m/s (4.0 mph) S-D	33	108	B 1.8m/s (4.0 mph) S-D
Liquid Loading Arm	M03-07Z-S	10,669	34	113	B 1.8m/s (4.0 mph) W-D	29	94	B 1.8m/s (4.0 mph) W-D	24	80	B 1.8m/s (4.0 mph) W-D
	M03-07Z-M	266,719	146	479	B 1.8m/s (4.0 mph) W-D	120	394	B 1.8m/s (4.0 mph) W-D	100	329	B 1.8m/s (4.0 mph) W-D

Event Description	Event Name	Release Rate	Distance to 5 kW/m²			Distance to 12.5 kW/m²			Distance to 35 kW/m²		
			Max Distance		Weather Condition	Max Distance		Weather Condition	Max Distance		Weather Condition
		lb/hour	(m)	(ft)		(m)	(ft)		(m)	(ft)	
	M03-07Z-R	3,666,395	458	1,502	B 1.8m/s (4.0 mph) S-D	374	1,228	B 1.8m/s (4.0 mph) S-D	311	1,022	B 1.8m/s (4.0 mph) S-D
Vapor Recovery Loading Arm	M03-08Z-S	66	3.5	12	D 7.2m/s (16.1 mph) S-D						
	M03-08Z-M	1,646	11	37	D 7.2m/s (16.1 mph) S-D	11	37	D 7.2m/s (16.1 mph) S-D	11	37	D 7.2m/s (16.1 mph) S-D
	M03-08Z-R	9,897	24	78	D 7.2m/s (16.1 mph) S-D	23	75	D 7.2m/s (16.1 mph) S-D	23	75	D 7.2m/s (16.1 mph) S-D

Note:

*: These events are not releases from the tanks but releases from the connections associated with the tanks.

**: This event reflects the marine loading pipe during the holding mode. Once the ship finishes loading, the marine loading pipe will be full of propane. The pipe will be left full, but open to the storage tank. Thus propane will slowly vaporize and go back to the tank. The pipe is expected to be empty by the time the next ship comes in. Hence the pipe is conservatively assumed to be 50% full and has no dynamic inventory.

Table IV-4: Pool Fire Hazard Zones (1m [3.3 ft] above ground level) by Weather Category

Event Description	Event Name	Release Rate	Distance to 5 kW/m²			Distance to 12.5 kW/m²			Distance to 35 kW/m²		
			Max Distance		Weather Condition	Max Distance		Weather Condition	Max Distance		Weather Condition
		lb/hour	(m)	(ft)		(m)	(ft)		(m)	(ft)	
Railcar Transit - Summer	R00-01Z-S-6C	12,920,849	203	668	D 7.2m/s (16.1 mph) S-D	157	516	D 7.2m/s (16.1 mph) S-D	120	392	D 7.2m/s (16.1 mph) S-D
	R00-01Z-S-14C	30,148,911	347	1,138	D 7.2m/s (16.1 mph) S-D	248	813	D 7.2m/s (16.1 mph) S-D	170	556	D 7.2m/s (16.1 mph) S-D
Railcar Transit - Winter	R00-01Z-W-2C	4,307,214	181	593	D 7.2m/s (16.1 mph) W-D	143	468	D 7.2m/s (16.1 mph) W-D	112	368	D 7.2m/s (16.1 mph) W-D
	R00-01Z-W-6C	12,920,849	309	1,015	D 7.2m/s (16.1 mph) W-D	225	737	D 7.2m/s (16.1 mph) W-D	159	522	D 7.2m/s (16.1 mph) W-D
	R00-01Z-W-14C	30,148,911	400	1,313	D 7.2m/s (16.1 mph) W-D	282	924	D 7.2m/s (16.1 mph) W-D	190	625	D 7.2m/s (16.1 mph) W-D
Propane Unloading Pipe	R01-05Z-R	4,717,779	179	587	D 7.2m/s (16.1 mph) W-D	141	463	D 7.2m/s (16.1 mph) W-D	111	365	D 7.2m/s (16.1 mph) W-D
Propane Rundown Pumps	F02-06A-S	2,119	9.9	32	D 7.2m/s (16.1 mph) W-D	8.7	28	D 7.2m/s (16.1 mph) W-D	7.2	24	D 7.2m/s (16.1 mph) W-D
	F02-06A-M	52,987	46	150	D 7.2m/s (16.1 mph) S-D	35	114	D 7.2m/s (16.1 mph) S-D	25	83	D 7.2m/s (16.1 mph) W-D
	F02-06A-L	211,948	79	261	D 7.2m/s (16.1 mph) S-D	59	193	D 7.2m/s (16.1 mph) S-D	42	137	D 7.2m/s (16.1 mph) W-D
	F02-06A-R	434,990	100	329	D 7.2m/s (16.1 mph) W-N	74	242	D 7.2m/s (16.1 mph) W-N	52	171	D 7.2m/s (16.1 mph) W-N
Propane Rundown Pipe to Storage Tank	F02-06B-S	1,463	8.1	27	D 7.2m/s (16.1 mph) W-N	7.2	24	D 7.2m/s (16.1 mph) W-N	6.6	22	D 7.2m/s (16.1 mph) W-N
	F02-06B-M	36,580	39	129	D 7.2m/s (16.1 mph) S-D	30	99	D 7.2m/s (16.1 mph) S-D	22	71	D 7.2m/s (16.1 mph) W-D
	F02-06B-L	146,321	69	228	D 7.2m/s (16.1 mph) S-D	51	169	D 7.2m/s (16.1 mph) S-D	36	119	D 7.2m/s (16.1 mph) W-D
	F02-06B-R	1,397,740	168	553	D 7.2m/s (16.1 mph) W-D	121	398	D 7.2m/s (16.1 mph) W-D	84	275	D 7.2m/s (16.1 mph) W-D
Storage Tank 1 - Connections – Liquid*	S04-01B-M	56,381	113	371	D 7.2m/s (16.1 mph) W-N	61	200	D 2.9m/s (6.5 mph) W-N	57	189	D 2.9m/s (6.5 mph) W-N
	S04-01B-L	225,524	115	377	D 7.2m/s (16.1 mph) W-D	108	355	D 7.2m/s (16.1 mph) W-D	102	334	D 7.2m/s (16.1 mph) W-D
	S04-01B-R	434,858	123	403	D 7.2m/s (16.1 mph) W-N	111	365	D 7.2m/s (16.1 mph) W-N	102	334	D 7.2m/s (16.1 mph) W-N
Storage Tank 2 - Connections – Liquid*	S04-02B-S	2,255									
	S04-02B-M	56,381	87	285	D 7.2m/s (16.1 mph) W-D	83	272	D 7.2m/s (16.1 mph) W-D	79	258	D 7.2m/s (16.1 mph) W-D
	S04-02B-L	225,524	102	334	D 7.2m/s (16.1 mph) W-D	90	296	D 7.2m/s (16.1 mph) W-D	81	265	D 7.2m/s (16.1 mph) W-D
	S04-02B-R	434,858	115	379	D 7.2m/s (16.1 mph) W-N	99	325	D 7.2m/s (16.1 mph) W-N	86	281	D 7.2m/s (16.1 mph) W-N
Earthquake	EQ-L	202,979	78	256	D 7.2m/s (16.1 mph) S-D	58	190	D 7.2m/s (16.1 mph) S-D	41	136	D 7.2m/s (16.1 mph) W-D
	EQ-R	2,029,716	195	641	D 7.2m/s (16.1 mph) W-D	141	461	D 7.2m/s (16.1 mph) W-D	97	320	D 7.2m/s (16.1 mph) W-D
Storage Tank 1	S04-01C-R1	2,029,716	195	641	D 7.2m/s (16.1 mph) W-D	141	461	D 7.2m/s (16.1 mph) W-D	97	320	D 7.2m/s (16.1 mph) W-D
	S04-01C-R2	22,552,398	400	1,313	D 7.2m/s (16.1 mph) W-D	282	925	D 7.2m/s (16.1 mph) W-D	191	625	D 7.2m/s (16.1 mph) W-D

Event Description	Event Name	Release Rate	Distance to 5 kW/m²			Distance to 12.5 kW/m²			Distance to 35 kW/m²		
			Max Distance		Weather Condition	Max Distance		Weather Condition	Max Distance		Weather Condition
		lb/hour	(m)	(ft)		(m)	(ft)		(m)	(ft)	
Storage Tank 2	S04-02C-R1	2,029,716	195	641	D 7.2m/s (16.1 mph) W-D	141	461	D 7.2m/s (16.1 mph) W-D	97	320	D 7.2m/s (16.1 mph) W-D
	S04-02C-R2	22,552,398	400	1,313	D 7.2m/s (16.1 mph) W-D	282	925	D 7.2m/s (16.1 mph) W-D	191	625	D 7.2m/s (16.1 mph) W-D
MP Suction Drum – Liquid	F02-03A-S	5,358	12	40	C/D 2.2m/s (4.9 mph) W-D	12	38	D 2.9m/s (6.5 mph) W-N	12	38	D 2.9m/s (6.5 mph) W-N
	F02-03A-M	133,954	56	182	D 2.9m/s (6.5 mph) W-N	45	147	D 7.2m/s (16.1 mph) W-D	37	122	D 7.2m/s (16.1 mph) W-D
	F02-03A-L	535,817	102	333	D 2.9m/s (6.5 mph) W-N	81	264	D 7.2m/s (16.1 mph) W-D	64	210	D 7.2m/s (16.1 mph) W-D
	F02-03A-R	773,378	119	390	D 7.2m/s (16.1 mph) W-D	94	308	D 7.2m/s (16.1 mph) W-D	73	241	D 7.2m/s (16.1 mph) W-D
LP Suction Drum – Liquid	F02-04A-S	2,119	9.9	32	D 7.2m/s (16.1 mph) W-D	8.7	28	D 7.2m/s (16.1 mph) W-D	7.2	24	D 7.2m/s (16.1 mph) W-D
	F02-04A-M	52,987	46	150	D 7.2m/s (16.1 mph) S-D	35	114	D 7.2m/s (16.1 mph) S-D	25	83	D 7.2m/s (16.1 mph) W-D
	F02-04A-L	211,948	79	261	D 7.2m/s (16.1 mph) S-D	59	193	D 7.2m/s (16.1 mph) S-D	42	137	D 7.2m/s (16.1 mph) W-D
	F02-04A-R	240,216	83	274	D 7.2m/s (16.1 mph) S-D	62	202	D 7.2m/s (16.1 mph) S-D	44	144	D 7.2m/s (16.1 mph) W-D
Marine Propane Loading Line - Holding Mode**	M03-01H-S	2,256	10	34	D 7.2m/s (16.1 mph) W-D	9.0	30	D 7.2m/s (16.1 mph) W-D	7.3	24	D 7.2m/s (16.1 mph) W-D
	M03-01H-M	56,395	47	154	D 7.2m/s (16.1 mph) S-D	36	117	D 7.2m/s (16.1 mph) S-D	26	85	D 7.2m/s (16.1 mph) W-D
	M03-01H-L	225,579	82	267	D 7.2m/s (16.1 mph) S-D	60	198	D 7.2m/s (16.1 mph) S-D	43	141	D 7.2m/s (16.1 mph) W-D
	M03-01H-R	570,860	117	385	D 7.2m/s (16.1 mph) S-D	86	281	D 7.2m/s (16.1 mph) S-D	60	198	D 7.2m/s (16.1 mph) W-D
Marine Propane Loading Line – Recirculation Mode	M03-01R-S	8,862	18	59	D 2.9m/s (6.5 mph) W-N	16	52	D 7.2m/s (16.1 mph) W-D	13	44	D 7.2m/s (16.1 mph) W-D
	M03-01R-M	124,893	62	204	D 2.9m/s (6.5 mph) W-N	49	160	D 7.2m/s (16.1 mph) W-D	38	125	D 7.2m/s (16.1 mph) W-D
	M03-01R-L	124,893	62	204	D 2.9m/s (6.5 mph) W-N	49	160	D 7.2m/s (16.1 mph) W-D	38	125	D 7.2m/s (16.1 mph) W-D
	M03-01R-R	124,893	62	204	D 2.9m/s (6.5 mph) W-N	49	160	D 7.2m/s (16.1 mph) W-D	38	125	D 7.2m/s (16.1 mph) W-D
Propane Recirculation	M03-03Z-S	8,862	18	59	D 2.9m/s (6.5 mph) W-N	16	52	D 7.2m/s (16.1 mph) W-D	13	44	D 7.2m/s (16.1 mph) W-D
	M03-03Z-M	124,893	62	204	D 2.9m/s (6.5 mph) W-N	49	160	D 7.2m/s (16.1 mph) W-D	38	125	D 7.2m/s (16.1 mph) W-D
	M03-03Z-L	124,893	62	204	D 2.9m/s (6.5 mph) W-N	49	160	D 7.2m/s (16.1 mph) W-D	38	125	D 7.2m/s (16.1 mph) W-D
	M03-03Z-R	124,893	62	204	D 2.9m/s (6.5 mph) W-N	49	160	D 7.2m/s (16.1 mph) W-D	38	125	D 7.2m/s (16.1 mph) W-D
Marine Propane Loading Line - Loading Mode	M03-01L-S	10,669	19	62	C/D 2.2m/s (4.9 mph) W-D	17	55	D 7.2m/s (16.1 mph) W-D	14	48	D 7.2m/s (16.1 mph) W-D
	M03-01L-M	266,719	84	275	D 2.9m/s (6.5 mph) W-N	66	215	D 7.2m/s (16.1 mph) W-D	51	168	D 7.2m/s (16.1 mph) W-D
	M03-01L-L	1,066,875	150	492	D 7.2m/s (16.1 mph) W-D	115	376	D 7.2m/s (16.1 mph) W-D	86	283	D 7.2m/s (16.1 mph) W-D
	M03-01L-R	5,319,009	289	947	D 7.2m/s (16.1 mph) W-D	205	671	D 7.2m/s (16.1 mph) W-D	139	457	D 7.2m/s (16.1 mph) W-D

Event Description	Event Name	Release Rate	Distance to 5 kW/m²			Distance to 12.5 kW/m²			Distance to 35 kW/m²		
			Max Distance		Weather Condition	Max Distance		Weather Condition	Max Distance		Weather Condition
		lb/hour	(m)	(ft)		(m)	(ft)		(m)	(ft)	
Jetty Loading Pipe	M03-05Z-S	10,669	19	62	C/D 2.2m/s (4.9 mph) W-D	17	55	D 7.2m/s (16.1 mph) W-D	14	48	D 7.2m/s (16.1 mph) W-D
	M03-05Z-M	266,719	84	275	D 2.9m/s (6.5 mph) W-N	66	215	D 7.2m/s (16.1 mph) W-D	51	168	D 7.2m/s (16.1 mph) W-D
	M03-05Z-L	1,066,875	150	492	D 7.2m/s (16.1 mph) W-D	115	376	D 7.2m/s (16.1 mph) W-D	86	283	D 7.2m/s (16.1 mph) W-D
	M03-05Z-R	3,233,550	236	776	D 7.2m/s (16.1 mph) W-D	168	552	D 7.2m/s (16.1 mph) W-D	115	377	D 7.2m/s (16.1 mph) W-D
Liquid Loading Arm	M03-07Z-S	10,669	19	62	C/D 2.2m/s (4.9 mph) W-D	17	55	D 7.2m/s (16.1 mph) W-D	14	48	D 7.2m/s (16.1 mph) W-D
	M03-07Z-M	266,719	84	275	D 2.9m/s (6.5 mph) W-N	66	215	D 7.2m/s (16.1 mph) W-D	51	168	D 7.2m/s (16.1 mph) W-D
	M03-07Z-R	3,666,395	241	790	D 7.2m/s (16.1 mph) W-N	181	592	D 7.2m/s (16.1 mph) W-N	133	437	D 7.2m/s (16.1 mph) W-N

Note:
*: These events are not releases from the tanks but releases from the connections associated with the tanks.
**: This event reflects the marine loading pipe during the holding mode. Once the ship finishes loading, the marine loading pipe will be full of propane. The pipe will be left full, but open to the storage tank. Thus propane will slowly vaporize and go back to the tank. The pipe is expected to be empty by the time the next ship comes in. Hence the pipe is conservatively assumed to be 50% full and has no dynamic inventory.

Table IV-5: Worst Flammable Vapor Dispersion Hazard Zones (1m [3.3 ft] above ground level) by Weather Category

Event Description	Event Name	Release Rate	Distance to ½LFL			Distance to LFL		
			Max Distance		Weather Condition	Max Distance		Weather Condition
		(lb/hr)	(m)	(ft)		(m)	(ft)	
Railcar Transit - Summer	R00-01Z-S-3H	684,582	373	1,224	D 2.9m/s (6.5 mph) S-N	191	627	D 7.2m/s (16.1 mph) S-D
	R00-01Z-S-2C	4,307,214	903	2,962	D 2.9m/s (6.5 mph) S-N	512	1,680	D 7.2m/s (16.1 mph) S-D
	R00-01Z-S-6C	12,920,849	1,419	4,656	B 1.8m/s (4.0 mph) S-D	860	2,823	D 7.2m/s (16.1 mph) S-N
	R00-01Z-S-14C	30,148,911	1,824	5,983	D 2.9m/s (6.5 mph) S-N	1,146	3,761	D 7.2m/s (16.1 mph) S-D
Railcar Transit - Winter	R00-01Z-W-3H	470,259	424	1,391	F 1.8m/s (4.0 mph) W-N	170	559	F 1.8m/s (4.0 mph) W-N
	R00-01Z-W-2C	4,307,214	1,048	3,437	B 1.8m/s (4.0 mph) W-D	487	1,598	D 2.9m/s (6.5 mph) W-N
	R00-01Z-W-6C	12,920,849	1,529	5,015	B 1.8m/s (4.0 mph) W-D	733	2,404	D 7.2m/s (16.1 mph) W-D
	R00-01Z-W-14C	30,148,911	1,910	6,266	B 1.8m/s (4.0 mph) W-D	990	3,249	D 7.2m/s (16.1 mph) W-D
Railcar Unloading Arm	R01-01Z-M	294,751	164	537	F 1.8m/s (4.0 mph) S-N	72	236	F 1.8m/s (4.0 mph) S-N
Unloading Vapor Return - Compressor	R01-03Z-S	2,063	7.5	24	F 1.8m/s (4.0 mph) S-N	4.2	14	F 1.8m/s (4.0 mph) S-N
	R01-03Z-M	51,579	60	197	F 1.8m/s (4.0 mph) S-N	25	81	F 1.8m/s (4.0 mph) S-N
	R01-03Z-L	97,092	94	310	D 7.2m/s (16.1 mph) S-D	37	123	F 1.8m/s (4.0 mph) S-N
	R01-03Z-R	97,092	94	310	D 7.2m/s (16.1 mph) S-D	37	123	F 1.8m/s (4.0 mph) S-N
Unloading Vapor Return - Piping to Railcar	R01-04Z-S	1,571	6.6	22	F 1.8m/s (4.0 mph) S-N	3.7	12	F 1.8m/s (4.0 mph) S-N
	R01-04Z-M	39,263	52	169	F 1.8m/s (4.0 mph) S-N	21	69	F 1.8m/s (4.0 mph) S-N
	R01-04Z-L	97,075	97	317	D 7.2m/s (16.1 mph) S-D	38	125	F 1.8m/s (4.0 mph) S-N
	R01-04Z-R-LP	148,425	168	551	D 2.9m/s (6.5 mph) S-N	71	232	D 7.2m/s (16.1 mph) S-D
Propane Unloading Pipe	R01-05Z-S	13,344	33	107	F 1.8m/s (4.0 mph) S-N	15	48	F 1.8m/s (4.0 mph) S-N
	R01-05Z-M	333,599	247	809	D 2.9m/s (6.5 mph) S-N	117	384	D 7.2m/s (16.1 mph) S-D
	R01-05Z-L	1,334,398	503	1,649	D 2.9m/s (6.5 mph) S-N	274	899	D 7.2m/s (16.1 mph) S-D
	R01-05Z-R-LP	4,717,779	1,152	3,780	B 1.8m/s (4.0 mph) S-D	552	1,811	D 7.2m/s (16.1 mph) S-D
Propane Unloading Storage Group1 (connections) – Liquid*	B01-06A-S	12,729	32	104	F 1.8m/s (4.0 mph) S-N	14	47	F 1.8m/s (4.0 mph) S-N
	B01-06A-M	318,220	239	783	D 2.9m/s (6.5 mph) S-N	112	367	D 7.2m/s (16.1 mph) S-D
	B01-06A-L	1,272,879	485	1,590	D 2.9m/s (6.5 mph) S-N	265	869	D 7.2m/s (16.1 mph) S-D
	B01-06A-R	2,150,503	622	2,040	D 2.9m/s (6.5 mph) S-N	351	1,152	D 7.2m/s (16.1 mph) S-D
Propane Unloading	B01-06B-S	1,571	6.6	22	F 1.8m/s (4.0 mph) S-N	3.7	12	F 1.8m/s (4.0 mph) S-N

Event Description	Event Name	Release Rate	Distance to ½LFL			Distance to LFL		
			Max Distance		Weather Condition	Max Distance		Weather Condition
		(lb/hr)	(m)	(ft)		(m)	(ft)	
Storage Group1 (connections) – Gas*	B01-06B-M	39,263	52	169	F 1.8m/s (4.0 mph) S-N	21	69	F 1.8m/s (4.0 mph) S-N
	B01-06B-L	156,641	133	436	D 7.2m/s (16.1 mph) S-D	52	170	F 1.8m/s (4.0 mph) S-N
	B01-06B-R	963,649	367	1,203	D 7.2m/s (16.1 mph) S-D	164	538	D 7.2m/s (16.1 mph) S-D
Propane Unloading Storage Group2 (connections) – Liquid*	B01-07A-S	12,729	32	104	F 1.8m/s (4.0 mph) S-N	14	47	F 1.8m/s (4.0 mph) S-N
	B01-07A-M	318,220	239	783	D 2.9m/s (6.5 mph) S-N	112	367	D 7.2m/s (16.1 mph) S-D
	B01-07A-L	1,272,879	485	1,590	D 2.9m/s (6.5 mph) S-N	265	869	D 7.2m/s (16.1 mph) S-D
	B01-07A-R	2,150,503	622	2,040	D 2.9m/s (6.5 mph) S-N	351	1,152	D 7.2m/s (16.1 mph) S-D
Propane Unloading Storage Group2 (connections) – Gas*	B01-07B-S	1,571	6.6	22	F 1.8m/s (4.0 mph) S-N	3.7	12	F 1.8m/s (4.0 mph) S-N
	B01-07B-M	39,263	52	169	F 1.8m/s (4.0 mph) S-N	21	69	F 1.8m/s (4.0 mph) S-N
	B01-07B-L	156,641	133	436	D 7.2m/s (16.1 mph) S-D	52	170	F 1.8m/s (4.0 mph) S-N
	B01-07B-R	963,649	367	1,203	D 7.2m/s (16.1 mph) S-D	164	538	D 7.2m/s (16.1 mph) S-D
Propane Unloading Storage Group3 (connections) – Liquid*	B01-08A-S	12,729	32	104	F 1.8m/s (4.0 mph) S-N	14	47	F 1.8m/s (4.0 mph) S-N
	B01-08A-M	318,220	239	783	D 2.9m/s (6.5 mph) S-N	112	367	D 7.2m/s (16.1 mph) S-D
	B01-08A-L	1,272,879	485	1,590	D 2.9m/s (6.5 mph) S-N	265	869	D 7.2m/s (16.1 mph) S-D
	B01-08A-R	2,150,503	622	2,040	D 2.9m/s (6.5 mph) S-N	351	1,152	D 7.2m/s (16.1 mph) S-D
Propane Unloading Storage Group3 (connections) – Gas*	B01-08B-S	1,571	6.6	22	F 1.8m/s (4.0 mph) S-N	3.7	12	F 1.8m/s (4.0 mph) S-N
	B01-08B-M	39,263	52	169	F 1.8m/s (4.0 mph) S-N	21	69	F 1.8m/s (4.0 mph) S-N
	B01-08B-L	156,641	133	436	D 7.2m/s (16.1 mph) S-D	52	170	F 1.8m/s (4.0 mph) S-N
	B01-08B-R	963,649	367	1,203	D 7.2m/s (16.1 mph) S-D	164	538	D 7.2m/s (16.1 mph) S-D
Propane Unloading Storage Group1 – Bullets	B01-06C-S	21,512	46	152	F 1.8m/s (4.0 mph) S-N	20	66	F 1.8m/s (4.0 mph) S-N
	B01-06C-M	79,555	109	358	F 1.8m/s (4.0 mph) S-N	46	152	F 1.8m/s (4.0 mph) S-N
	B01-06C-L	318,220	239	783	D 2.9m/s (6.5 mph) S-N	112	367	D 7.2m/s (16.1 mph) S-D
	B01-06C-R	2,153,813	622	2,040	D 2.9m/s (6.5 mph) S-N	352	1,154	D 7.2m/s (16.1 mph) S-D
Propane Unloading Storage Group2 – Bullets	B01-07C-S	21,512	46	152	F 1.8m/s (4.0 mph) S-N	20	66	F 1.8m/s (4.0 mph) S-N
	B01-07C-M	79,555	109	358	F 1.8m/s (4.0 mph) S-N	46	152	F 1.8m/s (4.0 mph) S-N
	B01-07C-L	318,220	239	783	D 2.9m/s (6.5 mph) S-N	112	367	D 7.2m/s (16.1 mph) S-D

Event Description	Event Name	Release Rate	Distance to ½LFL			Distance to LFL		
			Max Distance		Weather Condition	Max Distance		Weather Condition
		(lb/hr)	(m)	(ft)		(m)	(ft)	
	B01-07C-R	2,153,813	622	2,040	D 2.9m/s (6.5 mph) S-N	352	1,154	D 7.2m/s (16.1 mph) S-D
Propane Unloading Storage Group3 – Bullets	B01-08C-S	21,512	46	152	F 1.8m/s (4.0 mph) S-N	20	66	F 1.8m/s (4.0 mph) S-N
	B01-08C-M	79,555	109	358	F 1.8m/s (4.0 mph) S-N	46	152	F 1.8m/s (4.0 mph) S-N
	B01-08C-L	318,220	239	783	D 2.9m/s (6.5 mph) S-N	112	367	D 7.2m/s (16.1 mph) S-D
	B01-08C-R	2,153,595	622	2,039	D 2.9m/s (6.5 mph) S-N	352	1,154	D 7.2m/s (16.1 mph) S-D
Propane Rundown Pumps	F02-06A-S	2,119	7.6	25	D 7.2m/s (16.1 mph) S-D	4.3	14	D 7.2m/s (16.1 mph) S-D
	F02-06A-M	52,987	85	280	F 1.8m/s (4.0 mph) S-N	31	103	D 7.2m/s (16.1 mph) S-D
	F02-06A-L	211,948	139	456	F 1.8m/s (4.0 mph) S-N	97	317	F 1.8m/s (4.0 mph) S-N
	F02-06A-R	434,990	174	571	F 1.8m/s (4.0 mph) S-N	123	404	F 1.8m/s (4.0 mph) S-N
Propane Rundown Pipe to Storage Tank	F02-06B-S	1,463	5.2	17	D 7.2m/s (16.1 mph) S-N	3.4	11	D 7.2m/s (16.1 mph) S-N
	F02-06B-M	36,580	81	264	F 1.8m/s (4.0 mph) S-N	23	75	D 7.2m/s (16.1 mph) S-D
	F02-06B-L	146,321	145	475	F 1.8m/s (4.0 mph) S-N	98	321	F 1.8m/s (4.0 mph) S-N
	F02-06B-R-LP	1,397,740	409	1,342	F 1.8m/s (4.0 mph) S-N	312	1,023	F 1.8m/s (4.0 mph) S-N
Storage Tank 1 - Connections – Liquid*	S04-01B-L	225,524	87	285	F 1.8m/s (4.0 mph) S-N	40	133	F 1.8m/s (4.0 mph) W-N
	S04-01B-R	434,858	168	550	B 1.8m/s (4.0 mph) S-D	44	145	D 2.9m/s (6.5 mph) W-N
Storage Tank 2 - Connections – Liquid*	S04-02B-M	56,381	65	212	F 1.8m/s (4.0 mph) S-N			
	S04-02B-L	225,524	118	388	F 1.8m/s (4.0 mph) S-N	38	123	D 2.9m/s (6.5 mph) W-N
	S04-02B-R	434,858	280	918	F 1.8m/s (4.0 mph) S-N	79	261	F 1.8m/s (4.0 mph) S-N
Earthquake	EQ-L	202,979	191	626	F 1.8m/s (4.0 mph) S-N	134	440	F 1.8m/s (4.0 mph) S-N
	EQ-R	2,029,716	517	1,695	F 1.8m/s (4.0 mph) S-N	396	1,300	F 1.8m/s (4.0 mph) S-N
Storage Tank 1	S04-01C-R1	2,029,716	517	1,695	F 1.8m/s (4.0 mph) S-N	396	1,300	F 1.8m/s (4.0 mph) S-N
	S04-01C-R2	22,552,398	975	3,198	F 1.8m/s (4.0 mph) S-N	746	2,448	F 1.8m/s (4.0 mph) S-N
	S04-01C-R3	**	2,387	7,831	F 1.8m/s (4.0 mph) S-N	1,910	6,267	F 1.8m/s (4.0 mph) S-N
Storage Tank 2	S04-02C-R1	2,029,716	517	1,695	F 1.8m/s (4.0 mph) S-N	396	1,300	F 1.8m/s (4.0 mph) S-N
	S04-02C-R2	22,552,398	975	3,198	F 1.8m/s (4.0 mph) S-N	746	2,448	F 1.8m/s (4.0 mph) S-N
	S04-02C-R3	**	1,893	6,212	F 1.8m/s (4.0 mph) S-N	1,506	4,940	F 1.8m/s (4.0 mph) S-N

Event Description	Event Name	Release Rate	Distance to ½LFL			Distance to LFL		
			Max Distance		Weather Condition	Max Distance		Weather Condition
		(lb/hr)	(m)	(ft)		(m)	(ft)	
Vapor from Tank to BOG – Pipe	S04-03Z-S	67	2.3	8	F 1.8m/s (4.0 mph) S-N	1.5	5	F 1.8m/s (4.0 mph) S-N
	S04-03Z-M	1,679	12	38	F 1.8m/s (4.0 mph) S-N	6.2	20	F 1.8m/s (4.0 mph) S-N
	S04-03Z-L	6,716	38	124	F 1.8m/s (4.0 mph) S-N	15	49	F 1.8m/s (4.0 mph) S-N
	S04-03Z-R-LP	53,053	117	382	F 1.8m/s (4.0 mph) S-N	82	270	F 1.8m/s (4.0 mph) S-N
Propane Feed Pumps	F02-01A-S	12,220	31	102	F 1.8m/s (4.0 mph) S-N	14	46	F 1.8m/s (4.0 mph) S-N
	F02-01A-M	305,492	238	779	D 2.9m/s (6.5 mph) S-N	111	363	D 7.2m/s (16.1 mph) S-D
	F02-01A-L	370,183	263	863	D 2.9m/s (6.5 mph) S-N	127	416	D 7.2m/s (16.1 mph) S-D
	F02-01A-R	369,780	263	863	D 2.9m/s (6.5 mph) S-N	127	416	D 7.2m/s (16.1 mph) S-D
Propane Subcooler	F02-01B-S	1,029	5.6	18	F 1.8m/s (4.0 mph) S-N	3.1	10	F 1.8m/s (4.0 mph) S-N
	F02-01B-M	25,725	41	134	F 1.8m/s (4.0 mph) S-N	17	55	F 1.8m/s (4.0 mph) S-N
	F02-01B-L	102,899	105	343	D 7.2m/s (16.1 mph) S-D	41	135	F 1.8m/s (4.0 mph) S-N
	F02-01B-R	386,032	233	766	D 7.2m/s (16.1 mph) S-D	105	345	D 7.2m/s (16.1 mph) S-D
HP Suction Drum – Liquid	F02-01C-S	9,316	31	101	F 1.8m/s (4.0 mph) S-N	14	47	F 1.8m/s (4.0 mph) S-N
	F02-01C-M	232,894	282	924	F 1.8m/s (4.0 mph) S-N	116	380	F 1.8m/s (4.0 mph) S-N
	F02-01C-L	279,041	309	1,015	F 1.8m/s (4.0 mph) S-N	128	420	F 1.8m/s (4.0 mph) S-N
	F02-01C-R	520,523	423	1,389	F 1.8m/s (4.0 mph) S-N	176	579	F 1.8m/s (4.0 mph) S-N
HP Suction Drum – Gas	F02-01D-S	1,003	5.4	18	F 1.8m/s (4.0 mph) S-N	3.0	10	F 1.8m/s (4.0 mph) S-N
	F02-01D-M	25,083	40	130	F 1.8m/s (4.0 mph) S-N	16	53	F 1.8m/s (4.0 mph) S-N
	F02-01D-L	100,330	101	332	D 7.2m/s (16.1 mph) S-D	40	131	F 1.8m/s (4.0 mph) S-N
	F02-01D-R	477,567	257	844	D 7.2m/s (16.1 mph) S-D	113	372	D 7.2m/s (16.1 mph) S-D
HP Propane Compression	F02-01E-S	3,352	9.1	30	F 1.8m/s (4.0 mph) S-N	5.0	16	F 1.8m/s (4.0 mph) S-N
	F02-01E-M	83,797	78	256	D 7.2m/s (16.1 mph) S-D	32	103	F 1.8m/s (4.0 mph) S-N
	F02-01E-L	335,188	200	655	D 7.2m/s (16.1 mph) S-D	76	249	F 1.8m/s (4.0 mph) S-N
	F02-01E-R	431,950	232	761	D 7.2m/s (16.1 mph) S-D	89	293	D 7.2m/s (16.1 mph) S-D
BOG Air Cooler	F02-01F-S	939	5.1	17	F 1.8m/s (4.0 mph) S-N	2.8	9	F 1.8m/s (4.0 mph) S-N
	F02-01F-M	23,480	36	118	F 1.8m/s (4.0 mph) S-N	15	48	F 1.8m/s (4.0 mph) S-N

Event Description	Event Name	Release Rate	Distance to ½LFL			Distance to LFL		
			Max Distance		Weather Condition	Max Distance		Weather Condition
		(lb/hr)	(m)	(ft)		(m)	(ft)	
	F02-01F-L	65,169	70	230	D 7.2m/s (16.1 mph) S-D	29	94	F 1.8m/s (4.0 mph) S-N
	F02-01F-R	65,169	70	230	D 7.2m/s (16.1 mph) S-D	29	94	F 1.8m/s (4.0 mph) S-N
BOG Compressor	F02-02Z-S	1,099	5.5	18	F 1.8m/s (4.0 mph) S-N	3.0	10	F 1.8m/s (4.0 mph) S-N
	F02-02Z-M	27,479	39	128	F 1.8m/s (4.0 mph) S-N	16	53	F 1.8m/s (4.0 mph) S-N
	F02-02Z-L	65,136	69	225	F 1.8m/s (4.0 mph) S-N	28	92	F 1.8m/s (4.0 mph) S-N
	F02-02Z-R	65,136	69	225	F 1.8m/s (4.0 mph) S-N	28	92	F 1.8m/s (4.0 mph) S-N
MP Suction Drum – Liquid	F02-03A-S	5,358	22	73	F 1.8m/s (4.0 mph) W-N	10	34	F 1.8m/s (4.0 mph) W-N
	F02-03A-M	133,954	207	678	F 1.8m/s (4.0 mph) S-N	146	477	F 1.8m/s (4.0 mph) S-N
	F02-03A-L	535,817	412	1,352	F 1.8m/s (4.0 mph) S-N	291	956	F 1.8m/s (4.0 mph) S-N
	F02-03A-R	773,378	489	1,603	F 1.8m/s (4.0 mph) S-N	335	1,100	F 1.8m/s (4.0 mph) S-N
MP Suction Drum – Gas	F02-03B-S	410	3.9	13	F 1.8m/s (4.0 mph) S-N	2.2	7	F 1.8m/s (4.0 mph) S-N
	F02-03B-M	10,260	25	83	F 1.8m/s (4.0 mph) S-N	11	35	F 1.8m/s (4.0 mph) S-N
	F02-03B-L	41,042	63	206	F 1.8m/s (4.0 mph) S-N	26	86	F 1.8m/s (4.0 mph) S-N
	F02-03B-R	216,219	183	601	D 2.9m/s (6.5 mph) S-N	82	267	D 7.2m/s (16.1 mph) S-D
MP Propane Compression	F02-03C-S	959	5.2	17	F 1.8m/s (4.0 mph) S-N	2.9	10	F 1.8m/s (4.0 mph) S-N
	F02-03C-M	23,964	37	122	F 1.8m/s (4.0 mph) S-N	15	50	F 1.8m/s (4.0 mph) S-N
	F02-03C-L	95,857	95	313	D 7.2m/s (16.1 mph) S-D	37	123	F 1.8m/s (4.0 mph) S-N
	F02-03C-R	138,678	123	404	D 7.2m/s (16.1 mph) S-D	47	156	F 1.8m/s (4.0 mph) S-N
LP Suction Drum – Liquid	F02-04A-S	2,119	8.1	27	D 7.2m/s (16.1 mph) S-N	4.4	15	D 7.2m/s (16.1 mph) S-N
	F02-04A-M	52,987	95	312	F 1.8m/s (4.0 mph) S-N	62	204	F 1.8m/s (4.0 mph) S-N
	F02-04A-L	211,948	156	513	F 1.8m/s (4.0 mph) S-N	109	358	F 1.8m/s (4.0 mph) S-N
	F02-04A-R	240,216	163	534	F 1.8m/s (4.0 mph) S-N	114	375	F 1.8m/s (4.0 mph) S-N
LP Suction Drum – Gas	F02-04B-S	90	2.5	8	F 1.8m/s (4.0 mph) S-N	1.6	5	F 1.8m/s (4.0 mph) S-N
	F02-04B-M	2,258	14	45	F 1.8m/s (4.0 mph) S-N	6.7	22	F 1.8m/s (4.0 mph) S-N
	F02-04B-L	9,034	42	138	F 1.8m/s (4.0 mph) S-N	17	55	F 1.8m/s (4.0 mph) S-N
	F02-04B-R	56,461	145	475	F 1.8m/s (4.0 mph) S-N	62	205	F 1.8m/s (4.0 mph) S-N

Event Description	Event Name	Release Rate	Distance to ½LFL			Distance to LFL		
			Max Distance		Weather Condition	Max Distance		Weather Condition
		(lb/hr)	(m)	(ft)		(m)	(ft)	
LP Propane Compression	F02-04C-S	394	3.7	12	F 1.8m/s (4.0 mph) S-N	2.1	7	F 1.8m/s (4.0 mph) S-N
	F02-04C-M	9,853	24	79	F 1.8m/s (4.0 mph) S-N	10	33	F 1.8m/s (4.0 mph) S-N
	F02-04C-L	39,413	60	198	F 1.8m/s (4.0 mph) S-N	25	81	F 1.8m/s (4.0 mph) S-N
	F02-04C-R	48,482	68	225	F 1.8m/s (4.0 mph) S-N	28	93	F 1.8m/s (4.0 mph) S-N
Propane Air Cooler – Liquid	F02-05A-S	15,399	33	108	F 1.8m/s (4.0 mph) S-N	14	46	F 1.8m/s (4.0 mph) S-N
	F02-05A-M	384,975	228	748	D 2.9m/s (6.5 mph) S-N	108	356	D 7.2m/s (16.1 mph) S-D
	F02-05A-L	691,261	309	1,012	D 2.9m/s (6.5 mph) S-N	160	524	D 7.2m/s (16.1 mph) S-D
	F02-05A-R	691,261	309	1,012	D 2.9m/s (6.5 mph) S-N	160	524	D 7.2m/s (16.1 mph) S-D
Propane Air Cooler – Gas	F02-05B-S	3,352	9.1	30	F 1.8m/s (4.0 mph) S-N	5.0	16	F 1.8m/s (4.0 mph) S-N
	F02-05B-M	83,797	78	256	D 7.2m/s (16.1 mph) S-D	32	103	F 1.8m/s (4.0 mph) S-N
	F02-05B-L	335,188	200	655	D 7.2m/s (16.1 mph) S-D	76	249	F 1.8m/s (4.0 mph) S-N
	F02-05B-R	651,114	299	981	D 7.2m/s (16.1 mph) S-D	127	418	D 7.2m/s (16.1 mph) S-D
Propane Accumulator & Condenser - Liquid	F02-05C-S	15,399	33	108	F 1.8m/s (4.0 mph) S-N	14	46	F 1.8m/s (4.0 mph) S-N
	F02-05C-M	384,975	228	748	D 2.9m/s (6.5 mph) S-N	108	356	D 7.2m/s (16.1 mph) S-D
	F02-05C-L	691,261	309	1,012	D 2.9m/s (6.5 mph) S-N	160	524	D 7.2m/s (16.1 mph) S-D
	F02-05C-R	691,261	309	1,012	D 2.9m/s (6.5 mph) S-N	160	524	D 7.2m/s (16.1 mph) S-D
Propane Accumulator & Condenser - Gas	F02-05D-S	3,352	9.1	30	F 1.8m/s (4.0 mph) S-N	5.0	16	F 1.8m/s (4.0 mph) S-N
	F02-05D-M	83,797	78	256	D 7.2m/s (16.1 mph) S-D	32	103	F 1.8m/s (4.0 mph) S-N
	F02-05D-L	335,188	200	655	D 7.2m/s (16.1 mph) S-D	76	249	F 1.8m/s (4.0 mph) S-N
	F02-05D-R	1,025,548	376	1,235	D 7.2m/s (16.1 mph) S-D	161	528	D 7.2m/s (16.1 mph) S-D
Marine Propane Loading Line - Holding Mode***	M03-01H-S	2,256	9.7	32	D 7.2m/s (16.1 mph) S-D	5.1	17	D 7.2m/s (16.1 mph) S-D
	M03-01H-M	56,395	104	341	F 1.8m/s (4.0 mph) S-N	69	226	F 1.8m/s (4.0 mph) S-N
	M03-01H-L	225,579	198	649	F 1.8m/s (4.0 mph) S-N	140	458	F 1.8m/s (4.0 mph) S-N
	M03-01H-R	570,860	278	912	F 1.8m/s (4.0 mph) S-N	204	670	F 1.8m/s (4.0 mph) S-N
Marine Propane Loading Line – Recirculation Mode	M03-01R-S	8,862	36	118	F 1.8m/s (4.0 mph) W-N	14	44	F 1.8m/s (4.0 mph) S-N
	M03-01R-M	124,893	180	590	C/D 2.2m/s (4.9 mph) S-D	134	439	F 1.8m/s (4.0 mph) S-N

Event Description	Event Name	Release Rate	Distance to ½LFL			Distance to LFL		
			Max Distance		Weather Condition	Max Distance		Weather Condition
		(lb/hr)	(m)	(ft)		(m)	(ft)	
	M03-01R-L	124,893	180	590	C/D 2.2m/s (4.9 mph) S-D	134	439	F 1.8m/s (4.0 mph) S-N
	M03-01R-R	124,893	180	590	C/D 2.2m/s (4.9 mph) S-D	134	439	F 1.8m/s (4.0 mph) S-N
Propane Recirculation	M03-03Z-S	8,862	36	118	F 1.8m/s (4.0 mph) W-N	14	44	F 1.8m/s (4.0 mph) S-N
	M03-03Z-M	124,893	179	588	C/D 2.2m/s (4.9 mph) S-D	131	431	F 1.8m/s (4.0 mph) S-N
	M03-03Z-L	124,893	175	575	C/D 2.2m/s (4.9 mph) S-D	130	427	F 1.8m/s (4.0 mph) S-N
	M03-03Z-R	124,893	175	574	C/D 2.2m/s (4.9 mph) S-D	130	426	F 1.8m/s (4.0 mph) S-N
Marine Propane Loading Line - Loading Mode	M03-01L-S	10,669	44	145	F 1.8m/s (4.0 mph) W-N	17	57	F 1.8m/s (4.0 mph) S-N
	M03-01L-M	266,719	274	900	F 1.8m/s (4.0 mph) S-N	212	694	F 1.8m/s (4.0 mph) S-N
	M03-01L-L	1,066,875	541	1,775	F 1.8m/s (4.0 mph) S-N	416	1,365	F 1.8m/s (4.0 mph) S-N
	M03-01L-R-LP	5,319,009	617	2,025	F 1.8m/s (4.0 mph) S-N	473	1,550	F 1.8m/s (4.0 mph) S-N
Loading Vapor Return Line to Tank	M03-04Z-S	66	2.3	7	F 1.8m/s (4.0 mph) S-N	1.4	5	F 1.8m/s (4.0 mph) S-N
	M03-04Z-M	1,646	12	38	F 1.8m/s (4.0 mph) S-N	6.1	20	F 1.8m/s (4.0 mph) S-N
	M03-04Z-L	6,583	37	121	F 1.8m/s (4.0 mph) S-N	15	49	F 1.8m/s (4.0 mph) S-N
	M03-04Z-R-LP	25,769	74	243	F 1.8m/s (4.0 mph) S-N	26	84	D 7.2m/s (16.1 mph) W-D
Jetty Loading Pipe	M03-05Z-S	10,669	44	145	F 1.8m/s (4.0 mph) W-N	17	57	F 1.8m/s (4.0 mph) S-N
	M03-05Z-M	266,719	258	847	F 1.8m/s (4.0 mph) S-N	198	649	F 1.8m/s (4.0 mph) S-N
	M03-05Z-L	1,066,875	480	1,576	F 1.8m/s (4.0 mph) S-N	362	1,188	F 1.8m/s (4.0 mph) S-N
	M03-05Z-R-LP	3,233,550	564	1,852	F 1.8m/s (4.0 mph) S-N	430	1,412	F 1.8m/s (4.0 mph) S-N
Vapor Return from Jetty Pipe	M03-06Z-S	66	2.3	7	F 1.8m/s (4.0 mph) S-N	1.4	5	F 1.8m/s (4.0 mph) S-N
	M03-06Z-M	1,646	12	38	F 1.8m/s (4.0 mph) S-N	6.1	20	F 1.8m/s (4.0 mph) S-N
	M03-06Z-L	6,583	37	121	F 1.8m/s (4.0 mph) S-N	15	49	F 1.8m/s (4.0 mph) S-N
	M03-06Z-R-LP	14,286	51	168	F 1.8m/s (4.0 mph) S-N	15	50	D 7.2m/s (16.1 mph) W-D
Liquid Loading Arm	M03-07Z-S	10,669	44	144	F 1.8m/s (4.0 mph) W-N	17	57	F 1.8m/s (4.0 mph) S-N
	M03-07Z-M	266,719	251	825	F 1.8m/s (4.0 mph) S-N	190	624	F 1.8m/s (4.0 mph) S-N
	M03-07Z-R	3,666,395	848	2,781	F 1.8m/s (4.0 mph) S-N	607	1,992	F 1.8m/s (4.0 mph) S-N
Vapor Recovery Loading	M03-08Z-S	66	2.3	7	F 1.8m/s (4.0 mph) S-N	1.4	5	F 1.8m/s (4.0 mph) S-N

Event Description	Event Name	Release Rate	Distance to ½LFL			Distance to LFL		
			Max Distance		Weather Condition	Max Distance		Weather Condition
		(lb/hr)	(m)	(ft)		(m)	(ft)	
Arm	M03-08Z-M	1,646	12	38	F 1.8m/s (4.0 mph) S-N	6.1	20	F 1.8m/s (4.0 mph) S-N
	M03-08Z-R	9,897	51	168	F 1.8m/s (4.0 mph) S-N	20	65	F 1.8m/s (4.0 mph) S-N

Note:
*: These events are not releases from the tanks but releases from the connections associated with the tanks.
**: Tank Catastrophic Rupture with instantaneous release (within 1 second)
***: This event reflects the marine loading pipe during the holding mode. Once the ship finishes loading, the marine loading pipe will be full of propane. The pipe will be left full, but open to the storage tank. Thus propane will slowly vaporize and go back to the tank. The pipe is expected to be empty by the time the next ship comes in. Hence the pipe is conservatively assumed to be 50% full and has no dynamic inventory.

IV.5.4 BLEVE and Fireball Events

BLEVE (Boiling Liquid Expanding Vapor Explosion) refers to any sudden loss of containment of a fluid above its normal boiling point at the moment of vessel failure. A common cause of this type of event is fire engulfment of a vessel, which contains liquid under pressure, where the heating both raises the pressure in the vessel and lowers the yield strength of the equipment material. The BLEVE event can give rise to a blast wave, to fragment projection and if a flammable fluid is involved; to either a fireball, a flash fire or a vapor cloud explosion.

Note that it takes time for the vessel to fail and result in a BLEVE; thus onsite personnel should have time to escape and not be exposed. The BLEVE scenarios are included in the risk model in the current study.

For fire ball event, only release at propane unloading storage vessel may lead to a fireball hazard due to its short release duration. The following table shows the hazard distances to the specified overpressure and radiation levels.

Table IV-6: Distance to Overpressure and Thermal Radiation Levels from BLEVE and Fireball at 1 m (3.3 ft) above Grade

Propane Pressure Storage Vessels		Distance to Specified Hazard Levels (feet)		
Fire ball	Weather	5 kW/m^2	12.5 kW/m^2	35 kW/m^2
	Summer	3,264	1,978	855
	Winter	3,543	2,152	985
BLEVE Blast		1 PSI	3 PSI	5 PSI
		898	468	343

Fragment estimated hazard distances are presented in Section IV.4.4.

IV.5.5 Key Hazard Zones

The top 5 risk contributors to the overall societal risk are as follows:

- M03-07Z, Liquid Loading Arm
- B01-08C, Propane Pressure Storage Group3 - Bullets
- B01-06C, Propane Pressure Storage Group1 - Bullets
- B01-07C, Propane Pressure Storage Group2 - Bullets
- B01-06A, Propane Pressure Storage Group1 (connections) - Liquid

Figure IV-5, Figure IV-6 and Figure IV-7 present the consequence hazard zones for the top risk contributors.

Note that the figures present the 360 degree rotation of the potential hazard zone displayed, which include the following, as relevant to the scenario:

- Jet fire – Distance to thermal radiations (5, 12.5 and 35 kW/m^2)
- Pool fire – Distance to thermal radiations (5, 12.5 and 35 kW/m^2)
- Flash fire – ½LFL and LFL concentration dispersion distances

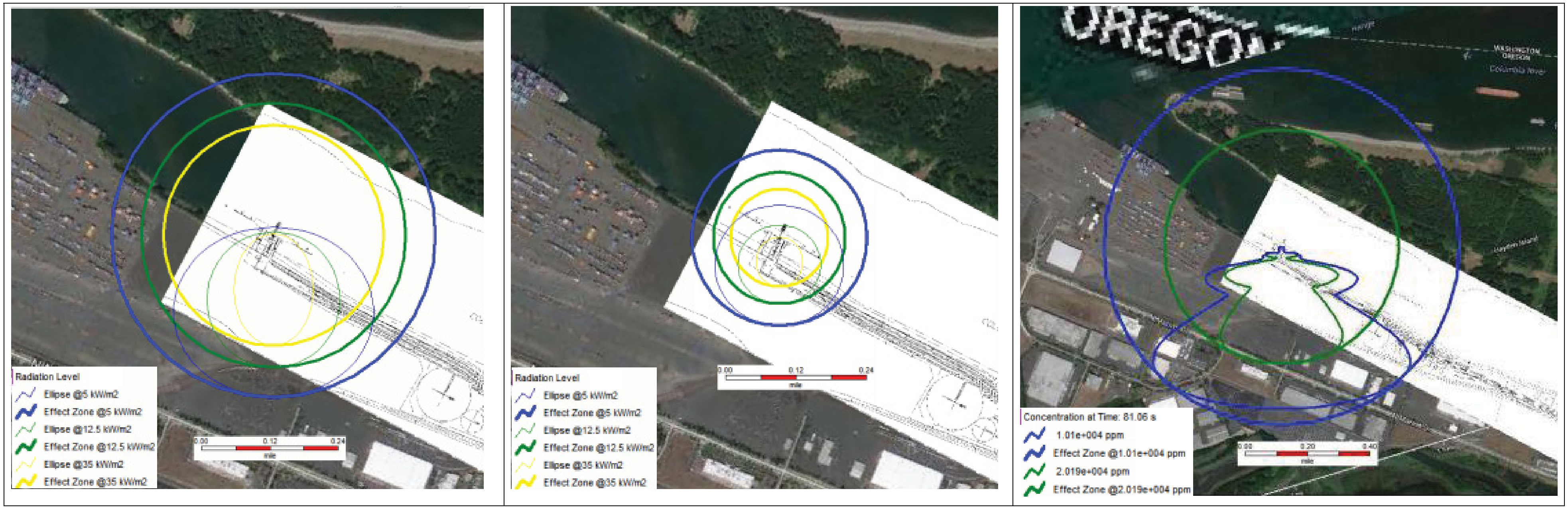

Figure IV-5: Hazard Zones for M03-07Z-R, Liquid Loading Arm Rupture (at 1 m (3.3 ft) Elevation above the ground)
Left: Jet Fires Effect Zones at B 1.8 m/s (4.0 mph) Summer-Day Weather Condition
Middle: Pool Fires Effect Zones at D 7.2 m/s (16.1 mph) Winter-Night Weather Condition
Right: Flammable Dispersion Effect Zones at F 1.8 m/s (4.0 mph) Summer-Night Weather Condition

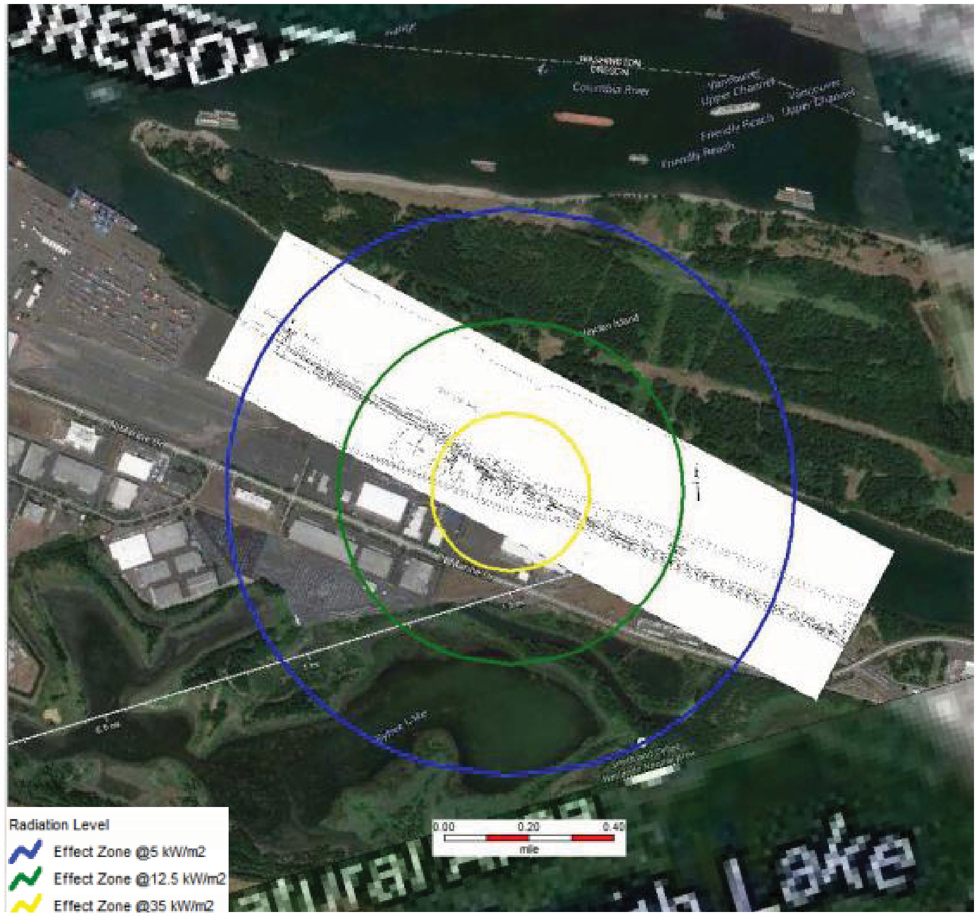

Figure IV-6: Fireball Radiation Effect Zones for Pressure Storage Tank Group 3 (at 1 m (3.3 ft) elevation above the ground), Winter Weather Condition

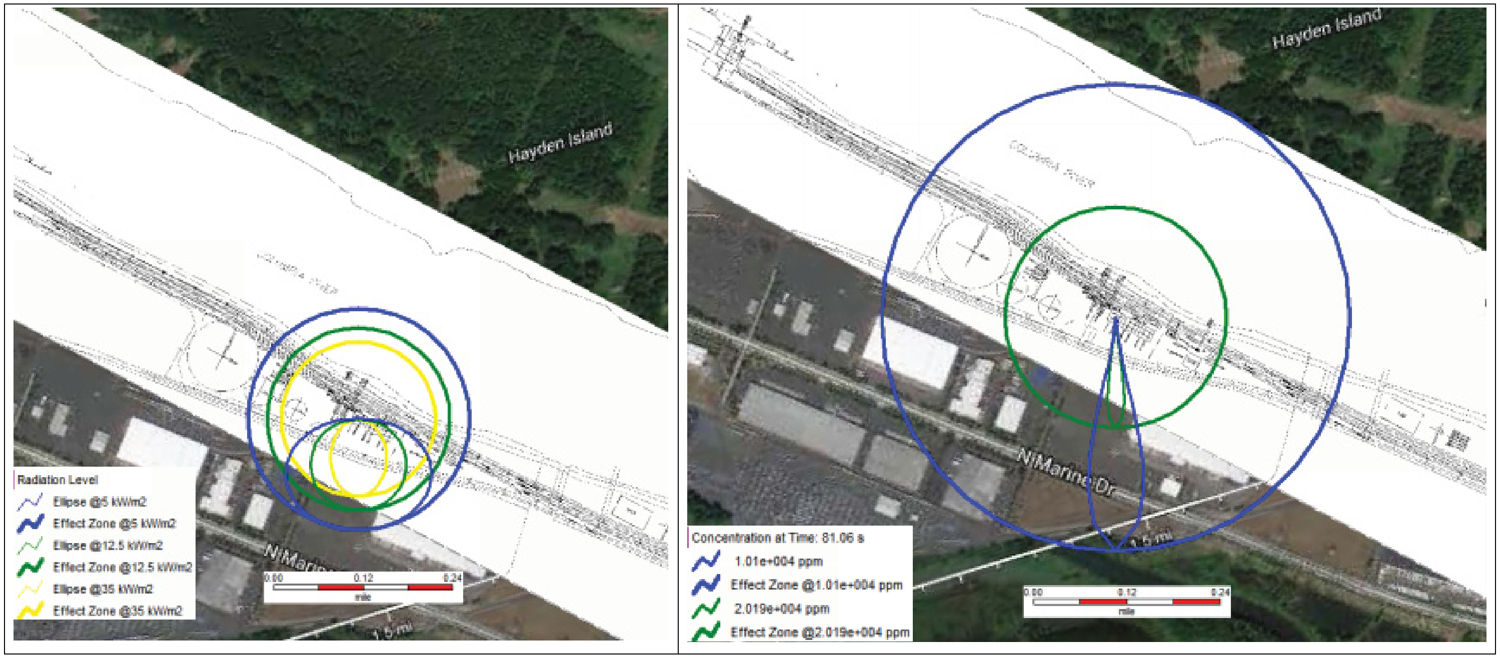

Figure IV-7: Hazard Zones for B01-06A-L, 100mm (4 inch) Hole Size Large Release of Propane Pressure Storage Group 1(Connections) – Liquid (at 1 m (3.3 ft) Elevation above the ground)
Left: Jet Fires Effect Zones at B 1.8 m/s (4.0 mph) Winter-Day Weather Condition
Right: Flammable Dispersion Effect Zones at D 2.9 m/s (6.5 mph) Summer-Night Weather Condition

IV.6 Worst Case Assessment

It is also requested by Pembina to complete a Worst Case Assessment for several scenarios of interest. Relevant guidance, standards, and regulation codes (e.g. NFPA 58, NFPA 59, NFPA 59A, API STD 2510, 40 CFR 68 and EPA RMP) were reviewed for defining and modeling the worst case scenarios at this propane terminal facility. Detailed scenario identification, assumptions, modeling procedures and hazard zone results are presented in the two attachments (Attachment IV-1 and IV-2).

Note that the worst-case release scenario modeling is ONLY a consequence analysis and has no frequency analysis to make it valid for a risk perspective. The two worst cases in Attachment IV-1 are IMPOSSIBLE to occur considering the chain of events that would need to occur instantly to mimic the scenario as modeled: tank instantly disappearing, all liquid propane vaporizes at once, the liquid pool spreading out evenly in a circle and only igniting when it gets to the end of the furthest LFL dispersion. Each of these event attributes are conservative and in reality would take time to develop, thus not instantaneously.

IV.7 References

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4. Mudan K. S. and P. A. Croce (1988), "Fire Hazard Calculations for Large Open Hydrocarbon Fires", SFPE handbook of Fire Protection Enginering, Boston, MA, Society of Fire Protection Engineers.

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ATTACHMENT IV-1

WORST CASE ASSESSMENT

PEMBINA FACILITY QRA

Pembina Portland Propane Terminal Worst Case Assessment

Pembina Marine Terminals, Inc.

Report No.: PP124992, Rev. 4
Document No.: 1MICKCR-1
Date: 2 April 2015

Project name: Pembina Facility QRA
Report title: Pembina Portland Propane Terminal Worst Case Assessment
Customer: Pembina Marine Terminals, Inc.
4000, 585 – 8th Avenue S.W.
Calgary, Alberta Canada
Contact person: Chris Hayes
Date of issue: 2 April 2015
Project No.: PP124992
Organization unit: Environmental and Navigational Risk
Report No.: PP124992, Rev. 4
Document No.: 1MICKCR-1
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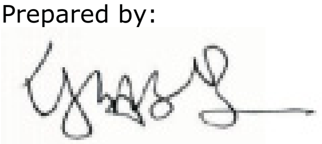
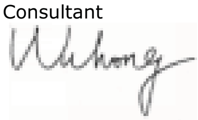
Det Norske Veritas (U.S.A.), Inc.
DNV GL Oil & Gas
Environmental and Navigational Risk
1400 Ravello Dr
77449 Katy
TX
United States
Tel: +1 281 396 1000

Objective:
DNV GL was requested by Pembina to complete a Worst Case Assessment for the Portland Propane Terminal. The worst case scenario as defined by EPA RMP was modeled.

Prepared by:



Minmin Le
Consultant



Hong Wu
Consultant

Verified by:

Cynthia Spitzenberger
Principle Consultant

Approved by:

Lindsay Deal
Deputy Head of Section, Safety Risk Analysis

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3	2015-04-01	Layout update	WHON	CSPI	CSPI
4	2015-04-02	Updated based on client comments	WHON	CSPI	CSPI

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1 INTRODUCTION

Pembina Marine Terminals Inc. and its affiliates (hereinafter referred to as "Pembina") propose to construct and operate a liquid propane export terminal in Portland, Oregon, the Pembina Portland Propane Terminal. The facility will be located at Terminal 6 in the Port of Portland.

The facility will receive approximately 3.2 million gallons of liquid propane from rail tracks every two days. There will be two rail tracks; each rail track will have 13 railcar unloading stations for a total of 26 railcar unloading stations. The liquid propane will be cooled at a rate of up to 1.7 million gallons per day and stored in two refrigerated double-walled storage tanks with the capacity of 550,000 bbls (23.1 million gallons) and 250,000 bbls (10.5 million gallons), respectively. A Very Large Gas Carrier (VLGC) up to approximately 23 million gallons capacity will load at the facility approximately two to three times per month for transit down the Columbia River to foreign markets.

Prior to the detailed facility QRA study, DNV GL was requested by Pembina to complete a Worst Case Assessment for the Portland Propane Terminal. Several relevant guidance, standards and regulation codes (e.g. NFPA 58, NFPA 59, NFPA 59A, API STD 2510, EPA RMP) were reviewed for defining and modeling the worst case scenarios for this propane storage facility. Detailed scenario identification, assumptions, modeling procedures and hazard zone results are presented in the following sections.

A simplified schematic of the process diagram and the tentative facility layout of the Pembina Portland Propane Terminal are shown in Figure 1-1 and Figure 1-2.

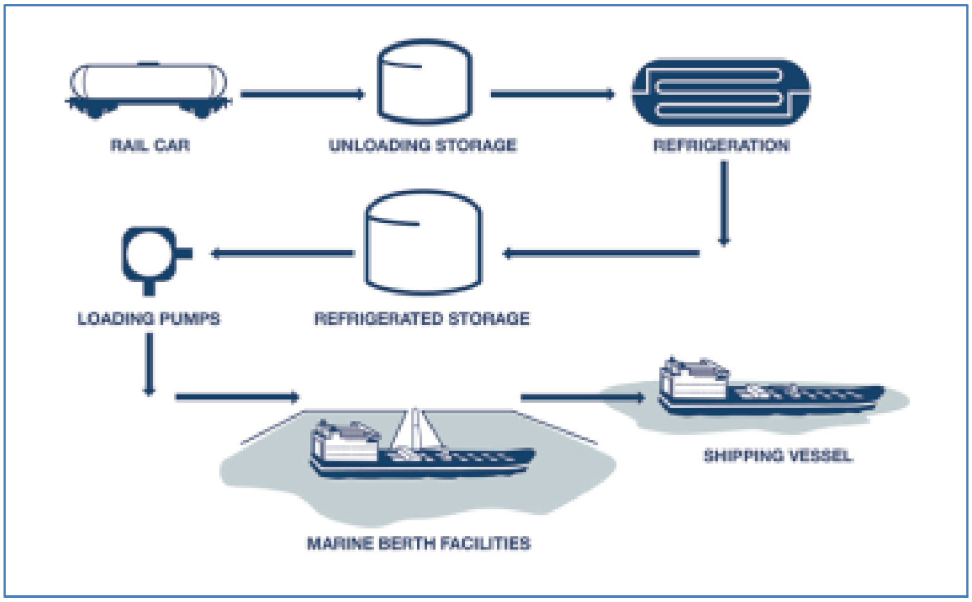

Figure 1-1 Facility Transportation, Refrigeration, Storage and Loading (1)

Figure 1-2 Pembina Portland Propane Terminal Tentative Facility Layout (2)

2 WORST-CASE SCENARIO DEFINITION REVIEW

Several relevant standards, guidelines, codes, rules and regulations have been reviewed for the worst case scenario definition to be considered at the Portland Propane Terminal:

- API 2510, *Design and Construction of Liquefied Petroleum Gas (LPG) Installation* (3)
- NFPA 58, *Liquefied Petroleum Gas Code* (4)
- NFPA 59, *Utility LP-Gas Plant Code* (5)
- NFPA 59A, *Production, Storage, and Handling of Liquefied Natural Gas (LNG)* (6)
- 40 CFR 68, *Code of Federal Regulations: Protection of Environment* (7)
- EPA RMP Guidance, *Risk Management Program Guidance for Propane Storage Facilities (40 CFR Part 68)* (8)
- EPA RMP Guidance, *Risk Management Program Guidance for Offsite Consequence Analysis* (9)

API 2510, *Design and Construction of Liquefied Petroleum Gas (LPG) Installation* (3), covers the design, construction and location of liquefied petroleum gas (LPG) installations at marine and pipeline terminals, natural gas processing plants, refineries, petrochemical plants, or tank farms. Regarding the sitting requirement, focus has been given to a more likely/relevant LPG incident, such as leakage from piping or other components attached to or near the vessel followed by ignition, a flash fire or vapor cloud explosion, and a continuing poor fire and pressure (torch) fire. A prescriptive approach is adopted for minimizing the risk exposed to the adjacent properties from the LPG tank. API 2510, Chapter 5 (Section 5.1.2) provides the minimum distance requirement between the shell of a pressurized LPG tank and the line of adjoining property. For a LPG tank with water capacity of 120,000 gallons or greater, the minimum distances to the line of adjoining property has to be at least 200 ft. Where residences, public buildings, places of assembly, or industrial sites are located on adjacent property, greater distances or other supplemental protection is required.

NFPA 58, *Liquefied Petroleum Gas Code* (4), applies to the storage, handling, transportation, and use of LP-Gas. Neither a more realistic scenario nor a worst case scenario regarding the liquid petroleum gas (LPG) storage container is specified in this code. The spacing requirement to the third party property is also prescriptive and based on the tank capacity. The minimum distance from aboveground, refrigerated LP-Gas containers that operate below 15 psig with the capacity over 700,000 gallons, to occupied buildings, storage containers for flammable or combustible liquids, and lines of adjoining property is 100 ft (Table 12.7.2). For the aboveground pressurized containers (propane bullets) with the capacity between 120,000 gallons and 200,000 gallons, the minimum distance is 200 ft.

NFPA 59, *Utility LP-Gas Plant Code* (5), provides the safety requirement for the design, construction, location, installation, operation and maintenance of refrigerated and non-refrigerated utility gas plants. Specific topics including refrigerated and non-refrigerated containers are covered. The minimum spacing requirement for the refrigerated LP-Gas container and the pressurized container is identical to those defined in NFPA 58 (Table 6.7.2 and Table 5.4.1.2).

NFPA 59A, *Production, Storage, and Handling of Liquefied Natural Gas (LNG)* (6), is applicable to LNG facilities. It is reviewed and included here since it also addresses the impounding area siting requirement for

LPG storage containers. A design spill (release from a 2 inch hole lasting 10 minutes, section 5.3.3.7) from a single-containment LPG storage container needs to be modelled for predicting the distance to the 1/2LFL concentration level for siting purposes. If the storage container is double or full containment, no design spill is defined. The spacing between the LPG storage impoundment to the nearest property line should be large enough to accommodate the 1/2LFL flammable cloud in the event of a design spill (Section 5.3.3.6). NFPA 59A also defines that the maximum radiant heat flux (at ground level) from an impounding fire received by the nearest point located outside the owner's property line used for outdoor assembly by groups of 50 or more persons should not exceed 5000 W/m^2 (Table 5.3.3.2).

The EPA RMP Guidance for Propane Storage Facilities (8) defines that if more than 10,000 pounds of propane stored in a single vessel or in a group of vessels that are connected or stored close together, this may need to comply with the rule codified as part 68 of Title 40 of the Code of Federal Regulations (40 CFR 68) (7). According to 40 CFR 68, the EPA RMP Program Guidance for Offsite Consequence Analysis (9) is referred to for the definition of the Worst-Case Release Scenario and the consequence analysis approach. Different from the above summarized standards, this EPA RMP provides a detailed consequence analysis approach including the Worst-Case Release Scenario determination and also the offsite consequence analysis parameters (e.g. endpoints for flammable and toxic hazards, wind speed/atmospheric stability class, ambient temperature, humidity, surface roughness and etc.).

In order to perform the Worst-Case Release Scenario consequence analysis for the Pembina Portland Propane Terminal Facility, DNV GL adopted the approach defined by the EPA RMP Guidance, which is also in line with the 40 CFR 68 code. Section 3 presents the two Worst-Case Release Scenarios identified at the Portland Propane Terminal Facility and describes the analysis approach with main assumptions. Note that two scenarios were evaluated to ensure that the worst possible hazard zone was evaluated.

3 WORST-CASE RELEASE SCENARIO CONSEQUENCE ANALYSIS APPROACH

3.1 Worst-Case Release Scenario Determination

Releases from the two largest containment sources – the largest propane storage tank and a rail car when onsite at the Pembina Portland Propane Terminal – were requested by Pembina for the Worst-Case Release Scenario modeling. The largest propane storage tank has a capacity of 550,000 bbls and thus is selected for the Worst-Case Release Scenario modeling. In addition to the largest storage tank, a rail car rupture and the possible subsequent escalation leading to a Boiling Liquid Expanding Vapor Explosion (BLEVE) outcome are modeled.

A release of liquid propane will result in flashing and vaporization of the LPG upon release, which will form a flammable vapor cloud. Any remaining liquid will rainout and form a pool that will continue to vaporize as the LPG absorbs heat from the surroundings. The flammable cloud will disperse with the wind. If it encounters an ignition source, the cloud could ignite resulting in a flash fire or an explosion. An explosion could occur if the cloud overlaps an area of congestion or confinement. The liquid pool of LPG may be ignited by the burn back of the flash fire or by other ignition sources it may encounter and thus result in a burning pool fire. For the Worst-Case Release Scenario modeling required by the EPA RMP, not all of these potential hazards need to be modeled; only the worst possible theoretical scenario is required.

Propane Tank Rupture

The two propane refrigerated storage tanks are located to the south west (SW) of the rail car unloading area as indicated in the plot plan (Figure 3-1). Both tanks are double walled with steel walls. They are naturally bounded by embankment of the rail lines to the NE and SW, but are not surrounded by any type of dike or bund. According to the EPA RMP (9), the Worst-Case Release Scenario from a tank is determined as the instantaneous rupture of the entire tank inventory. It needs to be noted no credit is given to the double-walled structure since according to the EPA RMP's definition the worst-case release is simply assumed to occur without considering the possible causes or the probability that such a release might occur.

For all regulated flammable substances, the Worst-Case Release Scenario modeling must assume that the entire inventory is released instantly to form a vapor cloud with the total quantity of the substance released contributing to a detonation. The rule requires the analysis to estimate the distance to a 1 psi overpressure (at 1 psi overpressure windows will break). This scenario is required by the regulation and is adopted for the analysis.

In addition to the overpressure consequence hazard zone, distances to the 37.5 and 5 kW/m^2 radiant heat fluxes and the Lower Flammable Limit (LFL) concentration are modelled, although not required for the EPA RMP Worst-Case Release Scenario. Additionally, the distance to 1/2 LFL is also modelled and reported for further reference.

Rail Car Rupture and BLEVE

Similar to the storage tank rupture release scenario, the rail car release Worst-Case Release Scenario is defined as the instantaneous rupture of one rail car. No dikes or bunds are built at the rail car unloading area for collecting spills. A vapor cloud explosion involving the entire propane inventory within one rail car is modelled as a detonation. As required by regulation, distances to a 1 psi overpressure are reported; additionally the distances to radiant heat flux of 37.5 and 5 kW/m^2 and to 1/2 LFL concentration are estimated to be conservative.

In addition to the rail car rupture scenario, a Boiling Liquid Expanding Vapor Explosion (BLEVE) event is also modelled. BLEVE is defined as a sudden loss of containment of a pressure-liquefied gas existing above its normal atmospheric boiling point at the moment of its failure, which results in rapidly expanding vapor and flashing liquid (10). The consequences of the BLEVE would include a blast wave due to expansion of the vapor and flashing liquid, and a fireball due to immediate ignition of the propane by the nearby fire, and fragment throw or rocketing of vessel pieces. In this study, the fragment throw is not assessed. Note that a BLEVE event is usually a secondary or escalation event, as for it to occur requires an external fire at the location of the storage vessel which heats the contents of the vessel and causes pressure build-up inside the vessel to the point of rupture.

3.2 Worst-Case Release Scenario Validation

Note that the worst-case release scenario modeling is ONLY a consequence analysis and has no frequency analysis to make it valid for a risk perspective. The two worst cases are IMPOSSIBLE to occur considering the chain of events that would need to occur instantly to mimic the scenario as modeled: tank instantly disappearing, all liquid propane vaporizing at once, pool spreading out evenly in a circle and only igniting when it gets to the end of the furthest LFL dispersion. Each of these event attributes are conservative and in reality would take time to develop, thus not instantaneously.

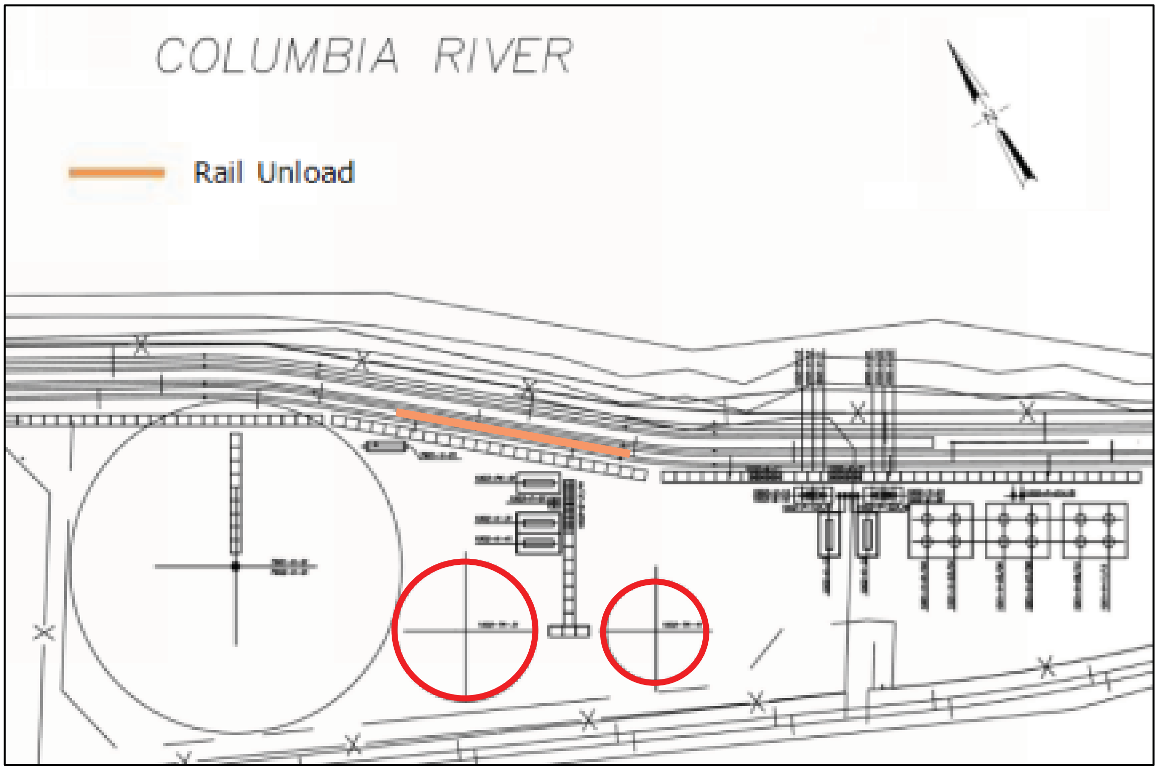

Figure 3-1 Propane Terminal Plot Plan – Propane Tanks and Railcar Unload Area (11)

3.3 Consequence Analysis Parameters

Table 3-1 defines the worst-case consequence analysis parameters that should be used when conducting the consequence modeling as defined in 40 CFR Part 68 (7) and also in the EPA RMP Guideline (9).

Table 3-1 Flammable Substance Worst-Case Release Scenario Consequence Analysis Parameters (7), (9)

Parameters	Value
Weather Data	
Wind speed/atmospheric stability class	1.5 m/s F
Ambient temperature	25 °C
Humidity	50%
Topography	
Surface Roughness	Urban or rural as appropriate
Consequence Endpoints	
Overpressure	1 psi
Radiant heat flux	5 kW/m^2
Flammable concentration	LFL, 1/2LFL*
Scenario Definition for Pembina Facility	
Worst-Case Scenario	Vessel rupture
Release substance	Liquid propane
Release inventory (Tank Rupture)	550,000 bbls

Parameters	Value
Release inventory (Rail car Rupture)	33,460 gallons
Temperature of released substance	Highest daily maximum temperature
Secondary containment (mitigation)	No secondary containment (bunding around tanks) has been considered
Propane Flammability Limits (percent by volume)	
UFL	9.5
LFL	2.0
1/2LFL	1.0

* Vapor cloud dispersion is modelled out to 1/2LFL to be conservative but this is not required by the 40 CFR Part 68 code

In the following Section 4 case specific input with the consequence results are presented in detail.

4 CONSEQUENCE RESULTS

The magnitude of the potential consequence hazard zones from the two identified worst cases was estimated using DNV GL's proprietary software package Phast 6.7.

The EPA RMP Guideline requires the use of conservative weather conditions for dispersion, F atmospheric stability and 1.5 m/s wind speed, for the worst-case scenario. Since the pool fire thermal radiation hazard is also reported for the Worst-Case Release Scenario, the hazard zone is also estimated for a conservative weather of D atmospheric stability and 10 m/s wind speed (higher wind speed will push the flame downwind further and thus results in a greater thermal radiation hazard zone). Rural surface roughness is selected for the study. The downwind distances to hazard zones related to LFL, ½ LFL, 5 kW/m^2, 37.5 kW/m^2 and 1 psi are reported at a height of 1 m (3.3 ft).

RMP*Comp (12) is a free online program to complete the Off-site Consequence Analyses (both Worst-Case Release Scenarios and Alternative Scenarios) required under the Risk Management Program rule. The worst-case scenario results (distance to 1 psi overpressure) from the RMP*Comp Online tool are also presented for comparison to the Phast results.

4.1 Case 1 – Storage Tank Release Case

As stated in the previous text, the instantaneous rupture from the 550,000 bbl, double-walled propane storage tank is selected as the Worst-Case Release Scenario to comply with EPA RMP. Table 4-1 summarizes the downwind distances to each hazard zone endpoint.

Table 4-1 Propane Storage Tank Consequence Results

Capacity (bbl)	Operating Condition		Distance Unit	Thermal Radiation Downwind Distance				Flammable Vapor Dispersion Downwind Distance		Explosion Hazard Zone Distance	RMP*Comp Result
				5 kW/m²		37.5 kW/m²		1/2LFL	LFL	1 psi	1 psi
	Temp. (F)	Pressure (psig)		F1.5	D10	F1.5	D10	F1.5	F1.5	F1.5	F1.5
550,000	-44	4.3	m	3,580	3,680	1,490	1,830	10,380	8,540	6,340	6,300
			mi	2.2	2.3	0.9	1.1	6.4	5.3	3.9	3.9

The 1 psi overpressure hazard effect zone according to EPA RMP Worst-Case Release Scenario is presented in Figure 4-1. It shows that the theoretical catastrophic rupture 1 psi hazard zone reaches approximately 6.3 km (3.9 mi) away from the facility. Note the Worst-Case Release Scenario as defined by EPA RMP by definition does not consider the probability of the event to occur.

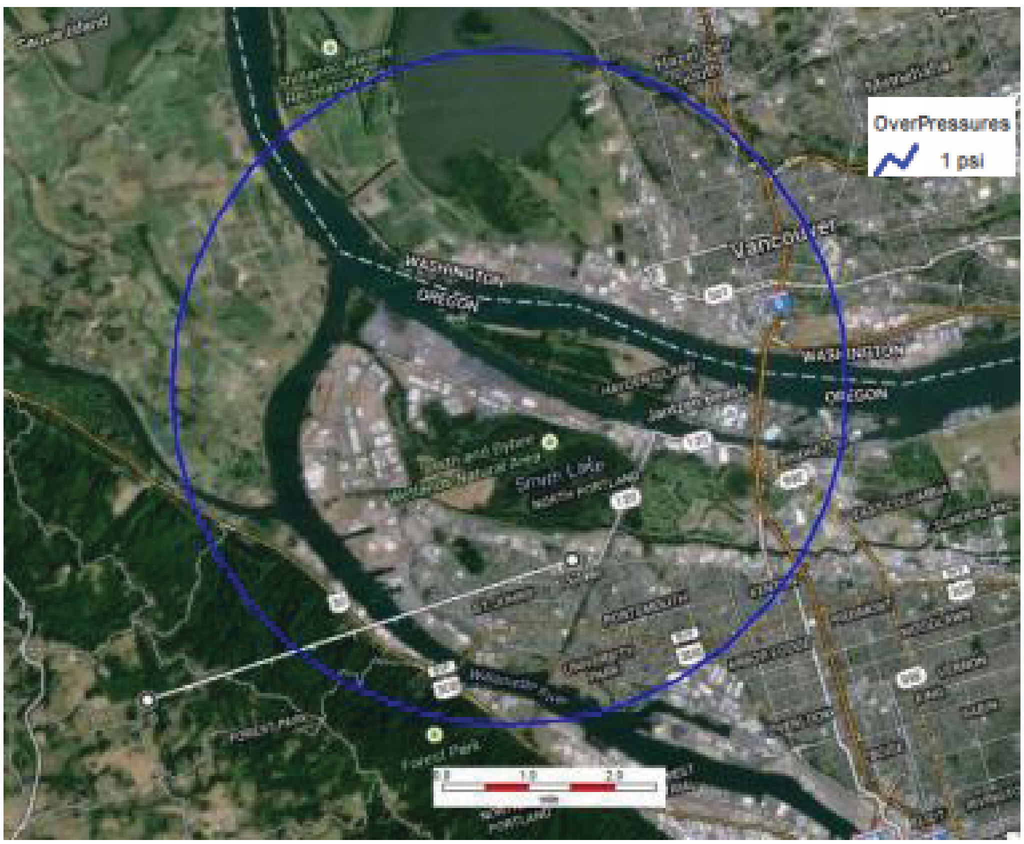

Figure 4-1 EPA RMP Worst-Case Release Scenario, LPG Storage Tank, 1 psi Overpressure Effect Zone

The ½ LFL and LFL downwind hazard effect zones according to EPA RMP Worst-Case Release Scenario are presented in Figure 4-2. Note that the flammable dispersion hazard distance is not required to comply with the EPA RMP Worst-Case Release Scenario. It shows that the instantaneous rupture of the tank results in the ½ LFL hazard zone reaching more than 10 km (6.4 mi) away from the facility (blue contour) and LFL hazard zone is 8.5 km (5.3 mi) from the facility (green contour). Note that in Figure 4-2 the flammable cloud will disperse in the downwind direction at the time of the release; the figure shows the 360 degree rotation of the cloud dispersion to illustrate the potential hazard zone for each wind direction.

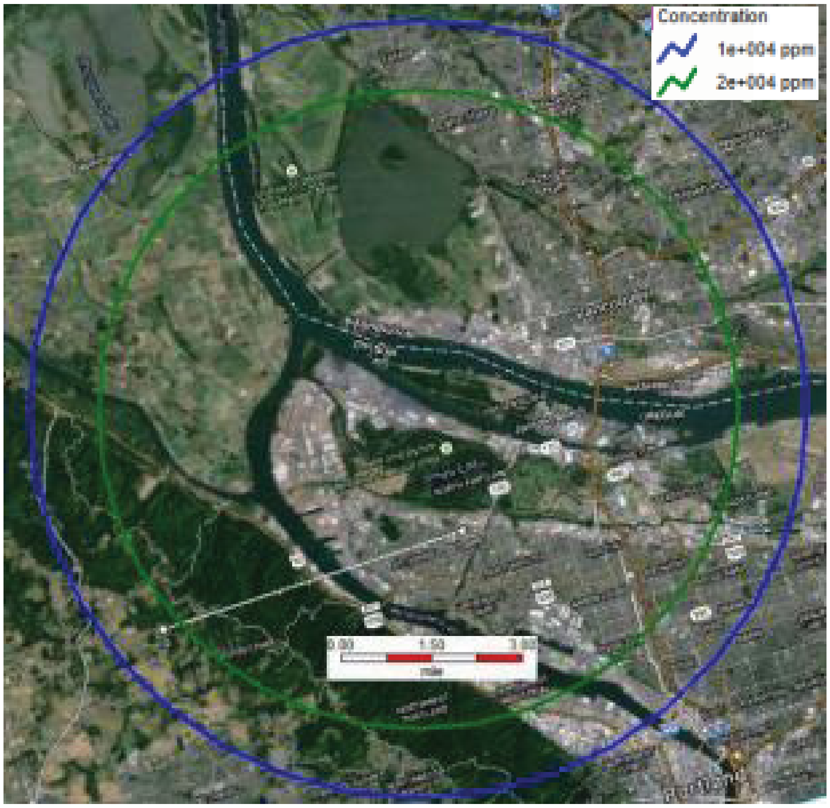

Figure 4-2 Worst-Case Release Scenario, LPG Storage Tank, Flammable Dispersion Effect Zones (360deg rotation of potential cloud plume)

4.2 Case 2 – Rail Car Release Case

As stated in the previous text, the instantaneous rupture from a 33,460 gallon railcar is selected as the Worst-Case Release Scenario to comply with EPA RMP. The BLEVE event is also modelled. Table 4-2 summarizes the downwind distances to each hazard zone endpoint.

Table 4-2 Railcar Consequence Results

Railcar Capacity 33,460 gallons	Operating Condition		Distance Unit	Thermal Radiation Downwind Distance		Flammable Vapor Dispersion Downwind Distance		Explosion Hazard Zone Distance	RMP*Comp Result
	Temp. (F)	Pressure (psig)		5 kW/m^2	37.5 kW/m^2	1/2LFL	LFL	1 psi	1 psi
				F1.5	F1.5	F1.5	F1.5	F1.5	F1.5
Worst-case Rupture	85	140	m	-	-	245	95	674	700
			mi	-	-	0.15	0.06	0.42	0.43
BLEVE	85	340	m	715	192	-	-	174	-
			mi	0.44	0.12	-	-	0.11	-

Rail Car Rupture

The 1 psi overpressure hazard effect zone according to the EPA RMP Worst-Case Release Scenario is presented in Figure 4-3. It shows that the theoretical catastrophic rupture 1 psi hazard zone reaches approximately 700 m (0.4 mi) away from the rail car release location. Note the Worst-Case Release Scenario as defined by EPA RMP by definition does not consider the probability of the event to occur.

Figure 4-3 EPA RMP Worst-Case Release Scenario, Railcar, 1 psi Overpressure Effect Zone

The ½ LFL and LFL downwind hazard effect zones according to EPA RMP Worst-Case Release Scenario are presented in Figure 4-4. Note that the flammable dispersion hazard distance is not required to comply with the EPA RMP Worst-Case Release Scenario. It shows that the instantaneous rupture of the rail car results in the ½ LFL hazard zone reaching 245 m (0.15 mi) away from the release location (blue contour) and LFL hazard zone is 95 m (0.06 mi) from the location (green contour). Note that in the Figure 4-4 flammable cloud will disperse in the downwind direction at the time of the release; the figure shows the 360 degree rotation of the cloud dispersion to illustrate the potential hazard zone for each wind direction.

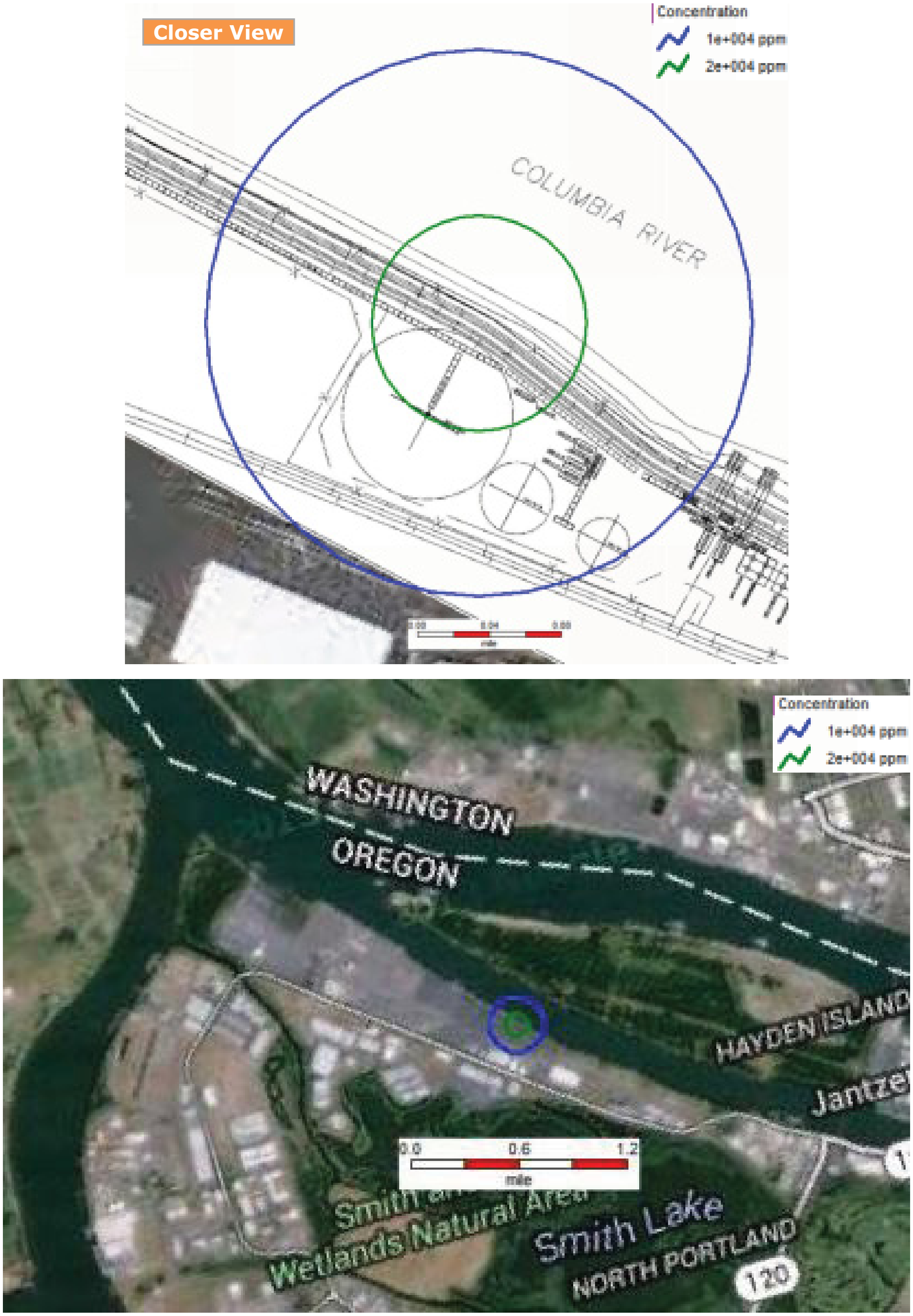

Figure 4-4 Worst-Case Release Scenario, Railcar, Flammable Dispersion Effect Zones (360 deg rotation of potential cloud plume)

Rail Car BLEVE

For the potential rail car BLEVE hazard, the worst hazard is from the thermal radiation from the fireball event. The 5 kW/m^2 fireball heat flux zone is presented in Figure 4-5. The 5 kW/m^2 hazard zone reaches 715 m (0.44 mi) away from the rail car release location.

Figure 4-5 BLEVE, Railcar, 5 kW/m^2 Thermal Radiation Effect Zone

5 REFERENCES

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About DNV GL

ATTACHMENT IV-2

ADDITIONAL HAZARD ZONE MODELS

DNV·GL

PEMBINA FACILITY QRA

Pembina Portland Propane Terminal Additional Hazard Zone Models

Pembina Marine Terminals, Inc.

Report No.: PP124992, Rev. 4
Document No.: 1MICKCR-1
Date: 2 April 2015

Project name: Pembina Facility QRA
Report title: Pembina Portland Propane Terminal Additional Hazard Zone Models
Customer: Pembina Marine Terminals, Inc.
4000, 585 – 8th Avenue S.W.
Calgary, Alberta Canada
Contact person: Chris Hayes
Date of issue: 2 April 2015
Project No.: PP124992
Organization unit: Environmental and Navigational Risk
Report No.: PP124992, Rev. 4
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Det Norske Veritas (U.S.A.), Inc.
DNV GL Oil & Gas
Environmental and Navigational Risk
1400 Ravello Dr
77449 Katy
TX
United States
Tel: +1 281 396 1000

Objective:
DNV GL was requested by Pembina to complete two release hazard zone consequence assessments for the Portland Propane Terminal.

Prepared by:	Verified by:	Approved by:
Hong Wu Consultant	Cynthia Spitzenberger Principal Consultant	Cynthia Spitzenberger Principal Consultant

DNV GL Distribution:
☐ Unrestricted distribution (internal and external)
☒ Unrestricted distribution within DNV GL
☐ Limited distribution within DNV GL after 3 years
☐ No distribution (confidential)
☐ Secret

Keywords:
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0	2015-02-09	First issue	WHON	CSPI	CSPI
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2	2015-03-16	Third issue	WHON	CSPI	CSPI
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4	2015-04-02	Client comments	WHON	CSPI	CSPI

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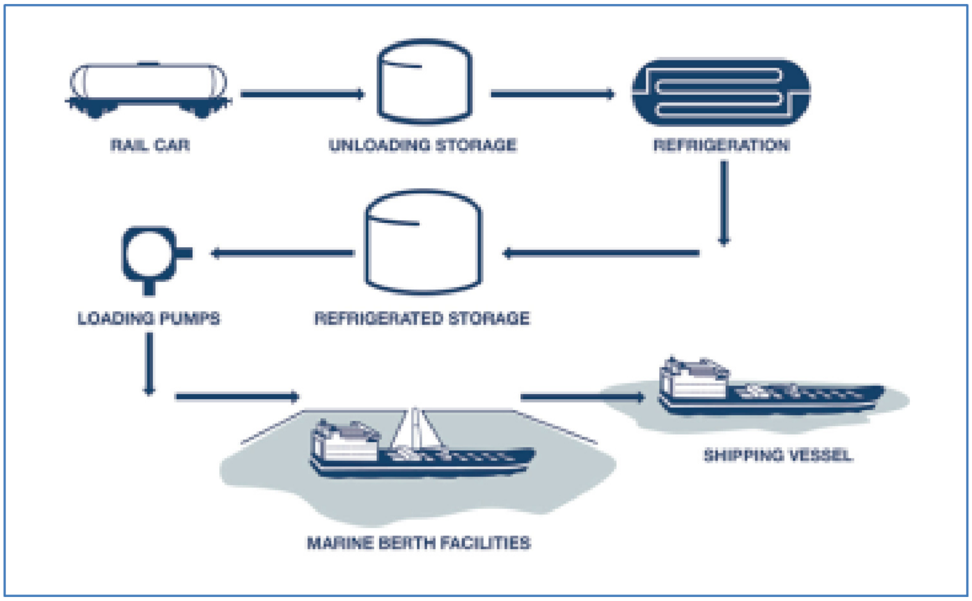

Figure 1-1 Facility Transportation, Refrigeration, Storage and Loading (1)

Figure 1-2 Pembina Portland Propane Terminal Tentative Facility Layout (2)

2 HAZARD ZONE RELEASE SCENARIO CONSEQUENCE ANALYSIS APPROACH

2.1 Release Scenario Determination

Two releases were requested by Pembina for the hazard zone modeling:

(1) 24 inch line rupture from the loading pipe to the dock

(2) instantaneous rupture from a pressure storage vessel

A release of liquid propane will result in flashing and vaporization of the LPG upon release, which will form a flammable vapor cloud. Any remaining liquid will rainout and form a pool that will continue to vaporize as the LPG absorbs heat from the surroundings. The flammable cloud will disperse with the wind. If it encounters an ignition source, the cloud could ignite resulting in a flash fire or an explosion. An explosion could occur if the cloud overlaps an area of congestion or confinement. The liquid pool of LPG may be ignited by the burn back of the flash fire or by other ignition sources it may encounter and thus result in a burning pool fire.

24" Line Rupture for Loading Pipe

A failure of the 24" propane load pipe to the dock was modelled. A 3000' length was estimated to account for the drop from the tank, the run to the berth area, and the run out onto the dock as shown in red routes (Figure 2-2). The facility is planning to install ESD valves at the top of the tank and on land at the dock area, so the length provided is relatively conservative. Distances to the 37.5 and 5 kW/m^2 jet fire and pool fire radiant heat fluxes and the LFL and ½ LFL concentrations for the line rupture are modelled.

Pressure Propane Storage Vessel Rupture

An instantaneous rupture is modeled for one pressure storage vessel. Twelve propane pressure vessels are located north east (NE) of the two large refrigerated storage tanks indicated as a square area in the plot plan (Figure 2-1). No dikes or bunds are built at the area for collecting spills. Similar to the Refrigerated Propane Storage 48'' leak study, distances to the 37.5 and 5 kW/m^2 jet fire and pool fire radiant heat fluxes and the LFL and ½ LFL concentrations are modelled. The distance to 1 psi overpressure is also reported for the instantaneous rupture as it is a required end-point for the Worst Case Scenario according to the EPA RMP Guideline.

In addition to the instantaneous rupture scenario, a Boiling Liquid Expanding Vapor Explosion (BLEVE) event is also modelled. BLEVE is defined as a sudden loss of containment of a pressure-liquefied gas existing above its normal atmospheric boiling point at the moment of its failure, which results in rapidly expanding vapor and flashing liquid (3). The consequences of the BLEVE would include a blast wave due to expansion of the vapor and flashing liquid, and a fireball due to immediate ignition of the propane by the nearby fire, and fragment throw or rocketing of vessel pieces. In this study, the fragment throw is not assessed. Note that a BLEVE event is usually a secondary or escalation event; for it to occur requires an external fire at the location of the storage vessel which heats the contents of the vessel and causes pressure build-up inside the vessel to the point of rupture.

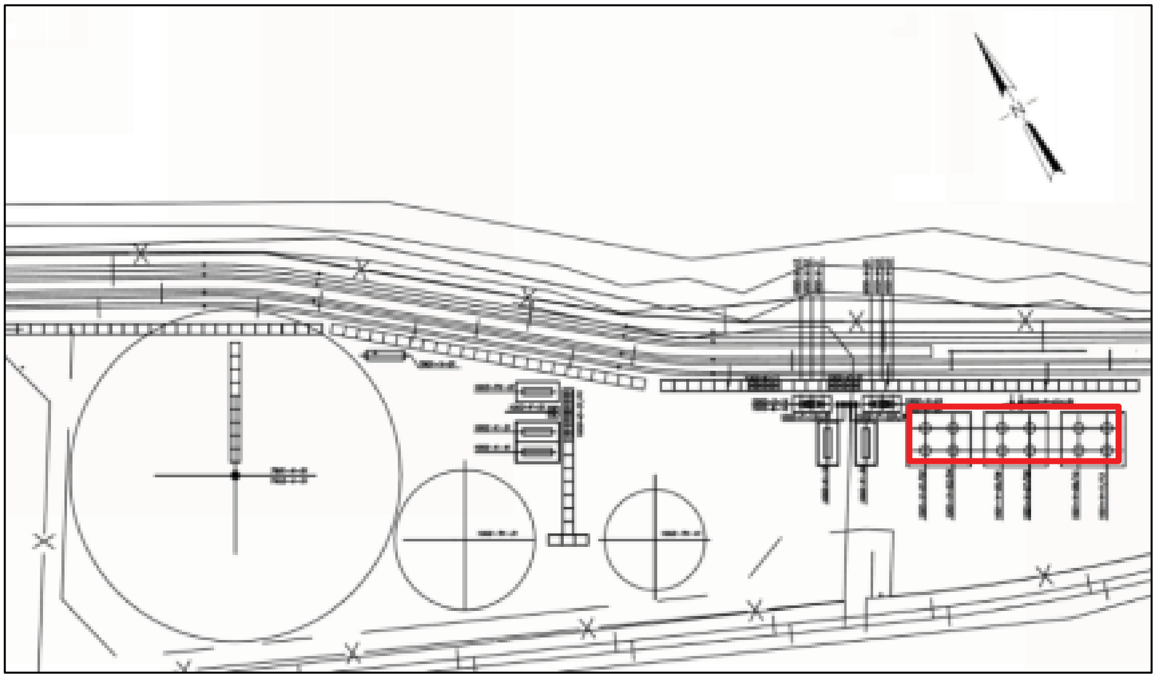

Figure 2-1 Propane Terminal Plot Plan –Pressurized Propane Vessel (4)

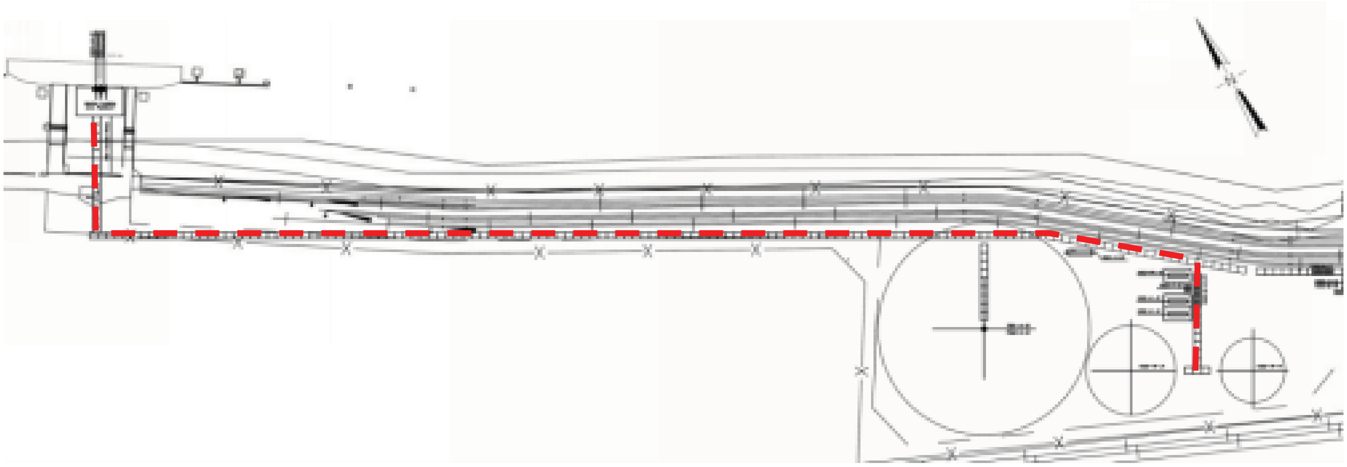

Figure 2-2 Propane Terminal Plot Plan – LPG Loading Pipeline (4)

2.2 Consequence Analysis Parameters

Table 2-1 defines the consequence analysis parameters that are used when conducting the consequence modeling. To be consistent with the previously issued Worst Case study, parameters are defined in accordance with 40 CFR Part 68 (5) and the EPA RMP Guideline (6).

Table 2-1 Flammable Substance Scenario Consequence Analysis Parameters (5), (6)

Parameters	Value
Weather Data	
Wind speed/atmospheric stability class	1.5 m/s F
Ambient temperature	25 ^{o}C
Humidity	50%
Topography	
Surface Roughness	Rural
Consequence Endpoints	
Overpressure	1 psi if applicable
Radiant heat flux	5 kW/m^2 and 37.5 kW/m^2
Flammable concentration	LFL, 1/2LFL*
Scenario Definition for Pembina Facility	
Release substance	Liquid propane
Propane Flammability Limits (percent by volume)	
UFL	9.5
LFL	2.0
1/2LFL	1.0

* Vapor cloud dispersion is modelled out to 1/2LFL to be conservative

In the following Section 3, case specific input with the consequence results are presented in detail.

3 CONSEQUENCE RESULTS

The magnitude of the potential consequence hazard zones from the two models was estimated using DNV GL's proprietary software package Phast 6.7.

In addition to the F atmospheric stability and 1.5 m/s wind speed, the thermal radiation hazard zone is also estimated for a conservative weather of D atmospheric stability and 10 m/s wind speed (higher wind speed will push the flame downwind further and thus results in a greater thermal radiation hazard zone). Rural surface roughness is selected for the study. The downwind distances to hazard zones related to LFL, ½ LFL, 5 kW/m^2, 37.5 kW/m^2 and 1 psi (if applicable) are reported at a height of 1m.

RMP*Comp (7) is a free online program to complete the Off-site Consequence Analyses (both Worst-Case Release Scenarios and Alternative Scenarios) required under the Risk Management Program rule. The worst-case scenario results (distance to 1 psi overpressure) from the RMP*Comp Online tool are also presented for comparison to the Phast results.

3.1 Loading Pipe Line Rupture Case

As stated in the previous text, the 24" line rupture case from a 3000 ft long loading pipe is modeled and Table 3-1 summarizes the potential downwind distances to each hazard zone endpoint.

Table 3-1 24” Loading Pipe Line Rupture Consequence Results

Capacity (m^3)	Operating Condition		Distance Unit	Pool Fire Thermal Radiation Downwind Distance				Jet Fire Thermal Radiation Downwind Distance				Flammable Vapor Dispersion Downwind Distance	
				5 kW/m^2		37.5 kW/m^2		5 kW/m^2		37.5 kW/m^2		1/2LFL	LFL
	Temp (F)	Pressure (psig)		F1.5	D10	F1.5	D10	F1.5	D10	F1.5	D10	F1.5	F1.5
267	-42.9	96.2	m	407	434	145	213	432	346	292	223	1470	1115
			mi	0.25	0.27	0.09	0.13	0.27	0.21	0.18	0.14	0.91	0.69

The ½ LFL and LFL downwind hazard effect zones are presented in Figure 3-1. It shows that the 24” line rupture of the loading pipe results in the ½ LFL hazard zone reaching 1470 m (0.91 mi) away from the facility (blue contour) and LFL hazard zone is 1115 m (0.69 mi) from the facility (green contour). Note that in Figure 3-1 the flammable cloud will disperse in the downwind direction at the time of the release, however, the figure shows the 360 degree rotation of the cloud dispersion to illustrate the potential hazard zone for each wind direction.

Figure 3-1 24” Line Rupture Scenario, Loading Pipe, Flammable Dispersion Effect Zones (360 deg rotation of potential cloud plume)

3.2 Pressure Storage Vessel Release Case

As stated in the previous text, the instantaneous rupture and the BLEVE event from a 461 m^3 propane pressure storage vessel are modelled and Table 3-2 summarizes the potential downwind distances to each hazard zone endpoint.

Table 3-2 Propane Pressure Storage Vessel Consequence Results

Pressure Storage Vessel 461 m^3	Operating Condition		Distance Unit	Fireball Thermal Radiation Downwind Distance		Flammable Vapor Dispersion Downwind Distance		Explosion Hazard Zone Distance	RMP*Comp Result
	Temp (F)	Pressure (psig)		5 kW/m^2	37.5 kW/m^2	1/2LFL	LFL	1 psi	1 psi
				F1.5	F1.5	F1.5	F1.5	F1.5	F1.5
Instantaneous Rupture	85	160	m	-	-	406	172	1037	1000
			mi	-	-	0.25	0.11	0.64	0.62
BLEVE	85	160	m	989	236	-	-	270	-
			mi	0.61	0.15	-	-	0.17	-

Instantaneous Rupture

The 1 psi overpressure hazard effect zone is presented in Figure 3-2. It shows that the theoretical catastrophic rupture 1 psi hazard zone reaches approximately 1037 m (0.64 mi) away from the pressure vessel release location.

Figure 3-2 Instantaneous Release Scenario, Pressure Storage Vessel, 1 psi Overpressure Effect Zone

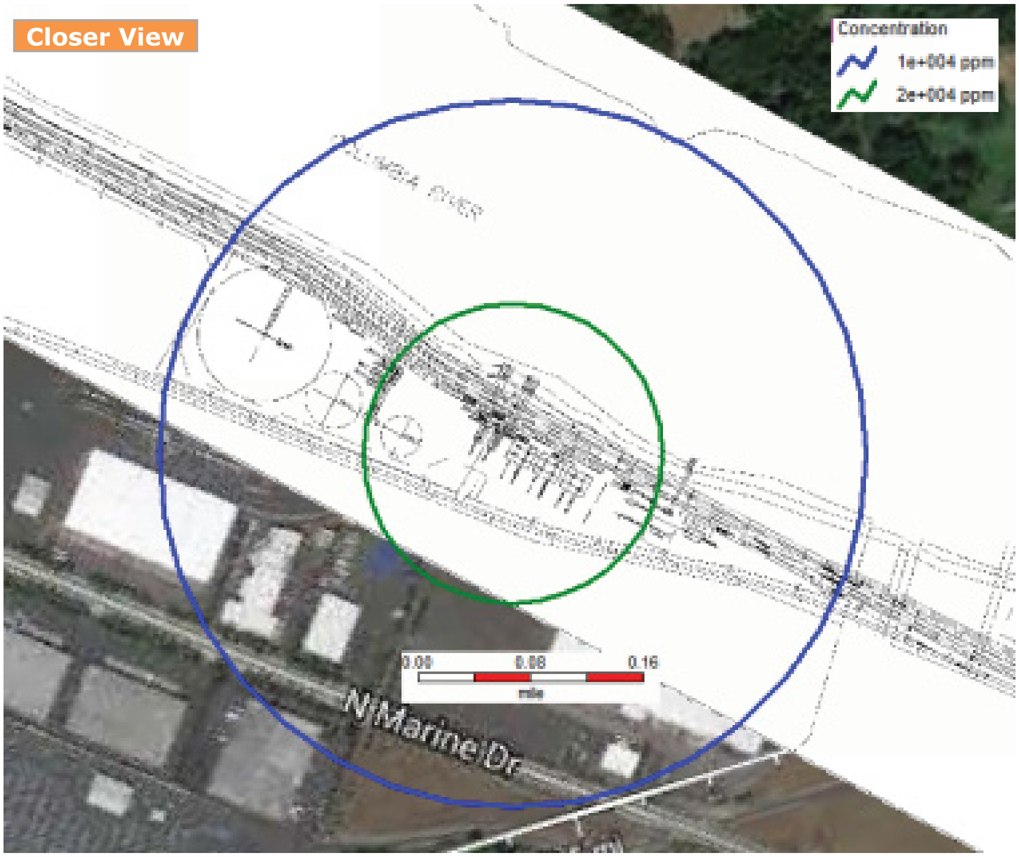

Figure 3-3 Instantaneous Release Scenario, Pressure Storage Vessel, Flammable Dispersion Effect Zones (360 deg rotation of potential cloud plume)

The ½ LFL and LFL downwind hazard effect zones are presented in Figure 3-3. It shows that the instantaneous rupture of the pressure vessel results in the ½ LFL hazard zone reaching 406 m (0.25 mi) away from the release location (blue contour) and LFL hazard zone is 172 m (0.11 mi) from the location (green contour). Note that in Figure 3-3 the flammable cloud will disperse in the downwind direction at the time of the release, however, the figure shows the 360 degree rotation of the cloud dispersion to illustrate the potential hazard zone for each wind direction.

BLEVE

For the potential BLEVE hazard, the worst hazard is from the thermal radiation from the fireball event. The 5 kW/m^2 fireball heat flux zone is presented in Figure 3-4. The 5 kW/m^2 hazard zone may extend 989 m (0.61 mi) away from the pressure vessel release location.

Figure 3-4 BLEVE, Pressure Storage Vessel, 5 kW/m^2 Thermal Radiation Effect Zone

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