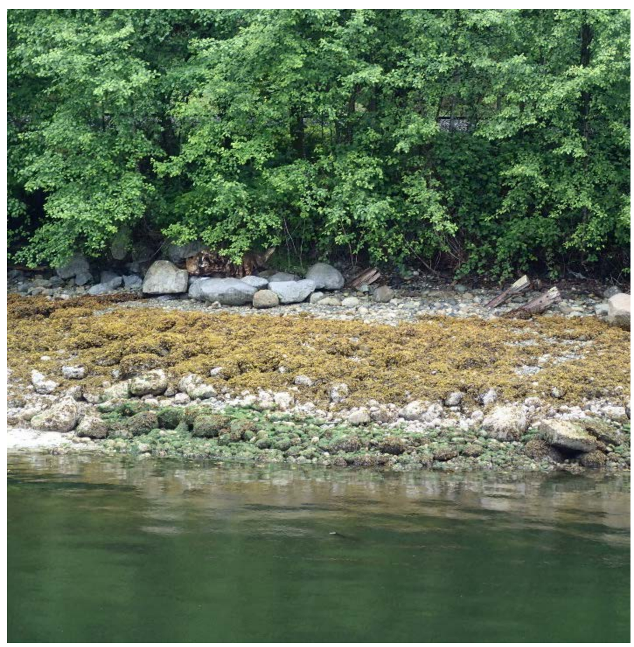
WESTRIDGE MARINE TERMINAL FIRE RISK ASSESSMENT TECHNICAL REPORT

WESTRIDGE MARINE TERMINAL UPGRADE AND EXPANSION PROJECT APPLICATION TO VANCOUVER FRASER PORT AUTHORITY



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WESTRIDGE MARINE TERMINAL

Fire Risk Assessment

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TABLE OF CONTENTS

Table of Contents i
Executive Summary 1
1.0 Introduction 2
1.1 Background 2
1.2 Scope and Objective 2
1.3 Approach to Risk Assessment 3
2.0 Facility Description 4
2.1 Proposed Facility Upgrades and Layout 4
2.2 Process Configuration and Operation 6
2.2.1 Control Building 7
2.2.2 Pipeline Routing 10
2.2.3 Road Access 14
2.3 System Operation 15
2.3.1 General Operation 15
2.3.2 Loading Procedure 16
2.3.3 Leak Prevention, Detection and Response 17
2.4 Wind Conditions 18
3.0 Regulatory Framework 19
3.1 Applicable Regulatory Requirements 19
3.2 High Level 2015 NFCC Requirements 20
3.2.1 Commodity Hazard Classification 20
3.2.2 Fire Prevention and Protection 21
3.2.3 Electrical Installations 21
3.2.4 Spill Control and Drainage Systems 21
3.2.5 Piping and Transfer Systems 22
3.2.6 Storage Systems 22
3.2.7 Control of Static Electric Charge 22
3.2.8 Leak Detection 22
3.2.9 Piers and Wharves 22
3.2.10 Process Plants 24
3.3 Summary 25
4.0 Hazard Identification and Quantification 26
4.1 Commodity Characteristics 26
4.2 Historical Incidents 26
4.3 Event Tree Considerations 28
4.3.1 Sources of Data 29
4.3.2 Loss of Containment 29
4.3.3 Ignition Events 31
4.3.4 Deflagration 32
4.3.5 Fire Growth 33
4.4 Sequences 33
4.4.1 Events Following Rupture of the Pipeline to Fire/Deflagration 34
4.4.2 Loading Arm Rupture and Fire/Deflagration 36
4.4.3 Vapour Recovery Unit Process Area Fire/Deflagration 37
4.5 Probability Criteria (MIACC) 37
5.0 Analysis Methodology 40

5.1 Phenomena of Interest 40
5.2 Quantification of Crude Oil Release 40
5.2.1 Spill Rate 40
5.2.2 Liquid Pool Area 41
5.2.3 Pool Evaporation 41
5.3 Quantification of Explosive Pressure - Unobstructed 41
5.4 Quantification of Radiative Heat Transfer 44
5.4.1 Radiative Heat Flux Equation 44
5.4.2 View Factor ($\boldsymbol{\phi total}$) 44
5.4.3 Large Pool Fire Concept 46
5.4.4 Flame Height 47
5.4.5 Emissive Power 48
5.5 Quantification of Products of Combustion 49
6.0 Evaluation Criteria 50
6.1 Location of Persons 50
6.2 Heat Effects (Pain and Burns) 50
6.2.1 No Pain Threshold 51
6.2.2 Pain Threshold 51
6.2.3 Second Degree Burn Threshold 52
6.2.4 Firefighting Criteria 52
6.3 Pressure Effects 53
6.4 Individual Annual Risk 54
7.0 Evaluation 55
7.1 Approach to Cumulative Individual Annual Risk 55
7.2 Pipeline Rupture/Spill 55
7.2.1 Spill Rate and Volume 55
7.2.2 Liquid Pool Area and Shape 56
7.3 Loading Arm Rupture/Spill 59
7.3.1 Spill Rate and Volume 59
7.3.2 Liquid Pool Area 60
7.4 Pool Evaporation 61
7.5 Ignition 62
7.5.1 Pipeline - Full Rupture and Spill, Loading Arm – Full Rupture 62
7.5.2 Loading Arm - Spill 62
7.6 Quantification of Impact of Radiated Heat from a Pool Fire 62
7.7 Quantification of Potential for Deflagration and Impact of Pressure Wave 66
7.7.1 Pipeline - Full Rupture 67
7.7.2 Loading Arm - Full Rupture 68
7.7.3 Loading Arm - Spill 68
7.7.4 Summary of Results for Deflagration 69
7.8 Annual Individual Risk at the WMT Facility Boundaries 69
8.0 Conclusions 73
9.0 Sources of Information 74

Appendix A – Electrical Zone Drawings
Appendix B – Configuration Factor Equations

EXECUTIVE SUMMARY

This report has been prepared in response to a requirement by the Vancouver Fraser Port Authority that a fire risk assessment be conducted for the proposed expansion to the Westridge Marine Terminal Facility (WMT Facility), and the proposed increase in transport of crude petroleum product by twinning of the existing pipeline at the WMT Facility.

The upgrades to the WMT Facility to support the additional transfer of crude oil include expanded/upgraded foreshore process and transfer area; and expanded/upgraded dock transfer area. The upgraded WMT Facility components are required to be designed in conformance with current applicable regulations and standards, including the National Fire Code of Canada (NFCC). The requirements in the NFCC are intended to limit the probability of:

- Release of flammable or combustible liquids;
- Spread of flammable or combustible liquids outside areas of containment;
- Ignition sources in proximity to areas that may contain flammable vapours;
- Explosive concentrations of flammable vapour; and
- Growth and spread of fire to buildings in the WMT Facility and areas adjacent to the WMT Facility.

A hazard analysis of the upgraded portions of the WMT Facility was conducted based on risk factors outlined above and conditions associated with historical incidents to establish undesirable events that could impact the safety of areas surrounding the Facility. The hazard analysis considered:

- Key characteristics of crude oil associated with the risk of fire;
- The potential loss of containment, ignition, fire, and deflagration events; and
- The impact of the undesirable events on the areas adjacent to the WMT Facility.

Two key loss of containment events were considered for the upgrades to the WMT Facility: a pipeline failure and a loading arm failure. These events included consideration of a rupture leakage scenarios. Event trees were developed to represent the sequence of events resulting in undesirable consequences, and frequencies/probabilities attributed to those events based on data from statistical analyses of historical incidents and published industry values.

The impact of the fire and deflagration events was quantified using representative models and attributed probabilities of impact on public safety. The cumulative probability of the risk of the sequence of events impacting the safety of the public was expressed as an individual annual risk of death at the site boundaries based on acceptability criteria associated with the design and operation of the WMT Facility.

The results of the analysis indicate that the total individual risk at the WMT Facility site boundaries is below acceptable limits, and near zero at the boundary of the nearest residential development for the scenarios considered. Therefore, the risk of fire associated with the proposed upgrades to the WMT Facility are within limits considered acceptable by industry guidelines.

1.0 INTRODUCTION

Jensen Hughes Consulting Canada Ltd. has prepared this report at the request of Trans Mountain (TM) relative to the preparation of a fire risk assessment for the Westridge Marine Terminal (the WMT) in Burnaby, British Columbia.

1.1 Background

TM proposes to expand the WMT to include a new dock complex with three berths, a berth for service vessels, three new 30-inch delivery pipelines, and an extension of the land along the shoreline to accommodate the following new facilities:

- Dock delivery lines and metering equipment
- Emissions management equipment and control system
- Fire-water and foam pumping system
- Storm water management system
- Electrical equipment and control system
- New control building
- Emergency response booms and areas for deployment of emergency response equipment

The proposed expansion is located in a jurisdiction under the authority of the Vancouver Fraser Port Authority (VFPA). The VFPA provided a "Project and Environmental Review Application Submission Requirements" document that requires a "Hazard Risk Assessment/Fire Risk Assessment & Dust Explosion Hazard Analysis" to be conducted. More specifically, the following is noted as being required:

- A Fire Risk Assessment for the terminal conducted by a Fire Protection Engineer, and a Dust Explosion Hazard Analysis specific to the commodities proposed to be handled will be required in support of the Building Permit application, and will be reviewed by a PMV chosen Code Consultant at the cost of the applicant.
- These two documents may also be reviewed separately by PMV, and referred to local municipalities as part of the Project Permit review, and must be provided in support of the Project Permit application, as well as in support of the Building Permit application.

1.2 Scope and Objective

The purpose of this report is to detail a fire risk assessment in response to the VFPA document outlined above. TM does not anticipate storing or processing any commodities that would be considered a dust explosion hazard; therefore, dust explosion hazard analysis has not been included in this analysis.

The objective of the fire risk assessment is to detail a hazard risk assessment/ fire risk assessment relative to the risk of injury or death adjacent to the WMT facility site as a result of exposure to the effects of credible fire or deflagration scenarios as a result of the potential for loss of containment of crude oil, identified in the hazard analysis. This risk assessment addresses the upgraded areas of the Facility including:

1. The twinned pipeline;
2. An expanded foreshore process and transfer area; and
3. Expanded dock transfer areas.

The risk assessment does not address the potential for failure of existing facility components, such as the three jet fuel storage tanks, that are not intended to be upgraded. These tanks are located at the south extent of the Facility.

1.3 Approach to Risk Assessment

Examination of the performance of the WMT Facility relative to these objectives requires consideration of the following assessment components:

1. Facility Description,
2. Regulatory Framework,
3. Hazard Identification and Quantification,
4. Analysis Methodology,
5. Evaluation Criteria, and
6. Evaluation.

These assessment components are expanded in the remainder of this report.

2.0 FACILITY DESCRIPTION

The existing Trans Mountain Pipeline (TMPL) system is an approximately 1,147-km pipeline system between Edmonton, Alberta and Burnaby, British Columbia and transports a range of crude petroleum and refined products to multiple locations in BC [1]. The system has an operating capacity of approximately 47,690 m^3/d (300,000 bbl/d). An expansion of the TMPL is proposed to increase the operating capacity of the system to 141,500 m^3/d (890,000 bbl/d), including twinning of the existing pipeline, new and modified facilities (i.e., pump stations and tanks), and an expansion of the WMT Facility [1]. The key focus of this risk assessment is the expanded components of the WMT Facility.

The following sections outline our understanding of the proposed upgrades to the WMT Facility and the nature of the operations and controls that lead to conducting the risk analysis.

2.1 Proposed Facility Upgrades and Layout

The WMT Facility is an existing transfer facility located on the south shore of the Burrard Inlet, east of the Second Narrows Bridge in Burnaby, British Columbia, and has been in operation since 1953 [1]. The existing dock was constructed in 1957 [1]. A picture showing the existing facility is included as **Figure 1** below.

Figure 1: The existing Westridge Terminal [3].

The proposed WMT Facility when upgraded will be composed of three main areas as a function of use. These three areas are:

1. The existing aviation fuel storage tanks and associated infrastructure (not intended to be upgraded or altered);
2. Expanded foreshore process and transfer area; and
3. Expanded dock transfer area.

Each of these areas are highlighted on an artist's rendering showing the proposed upgraded WMT Facility is included as **Figure 2** below. The existing storage area is outlined in blue; the expanded foreshore process and transfer area is outlined in green; and the expanded dock transfer area is outlined in orange.

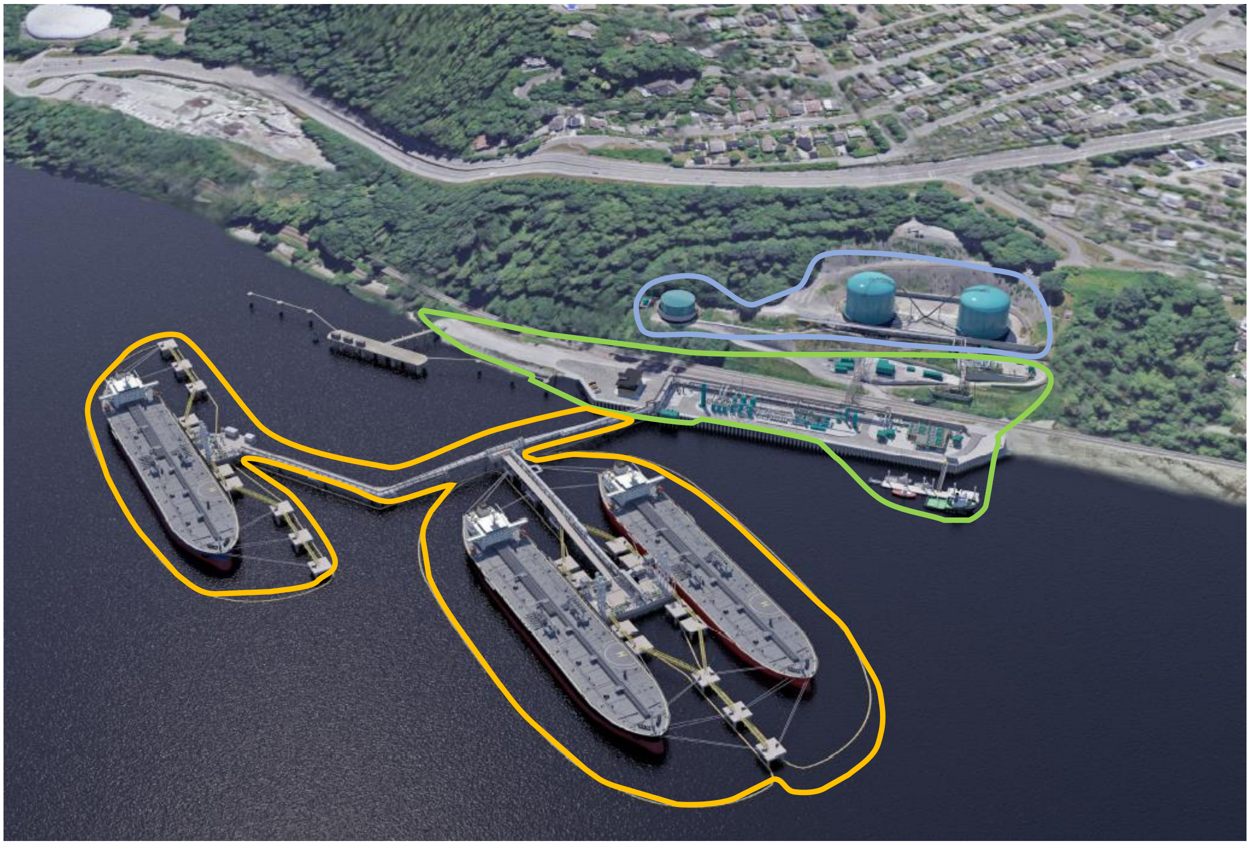


Figure 2: Proposed Westridge Facility (artist rendering) [3].

The proposed upgrades to the WMT Facility include:

- Foreshore Facilities (**Figure 3**) as follows:
    - dock delivery lines and metering equipment;
    - an extension of the land along the shoreline;
    - one receiving trap and one sending trap;
    - a valve manifold, complete with interconnecting piping;
    - custody transfer meters;
    - two vapour recovery units (VRUs);
    - one vapour combustion unit (VCU);
    - a nitrogen purge system;
    - a fire-protection system (fire water and foam), complete with a fire-water pump house;
    - a storm-water handling system, complete with an oil/water separator;
    - a standby generator at each ESB;
    - electrical equipment and control system, with space for potential future installation of shore power facilities; and
    - new control building.

- Dock Facilities (**Figure 4**) as follows:
  - a new dock complex with three berths, each capable of accommodating up to an Aframax class vessels size, and one berth capable of receiving jet fuel (temporary – intended to be eliminated in the near future);
  - a small utility dock with multiple berths for tugs, pilot boats, spill response vessels and equipment, and boom boats;
  - fender and mooring structures;
  - vessel access towers;
  - delivery piping systems, including loading arms;
  - one receiving trap;
  - vapour recovery systems; and
  - a fire protection system.

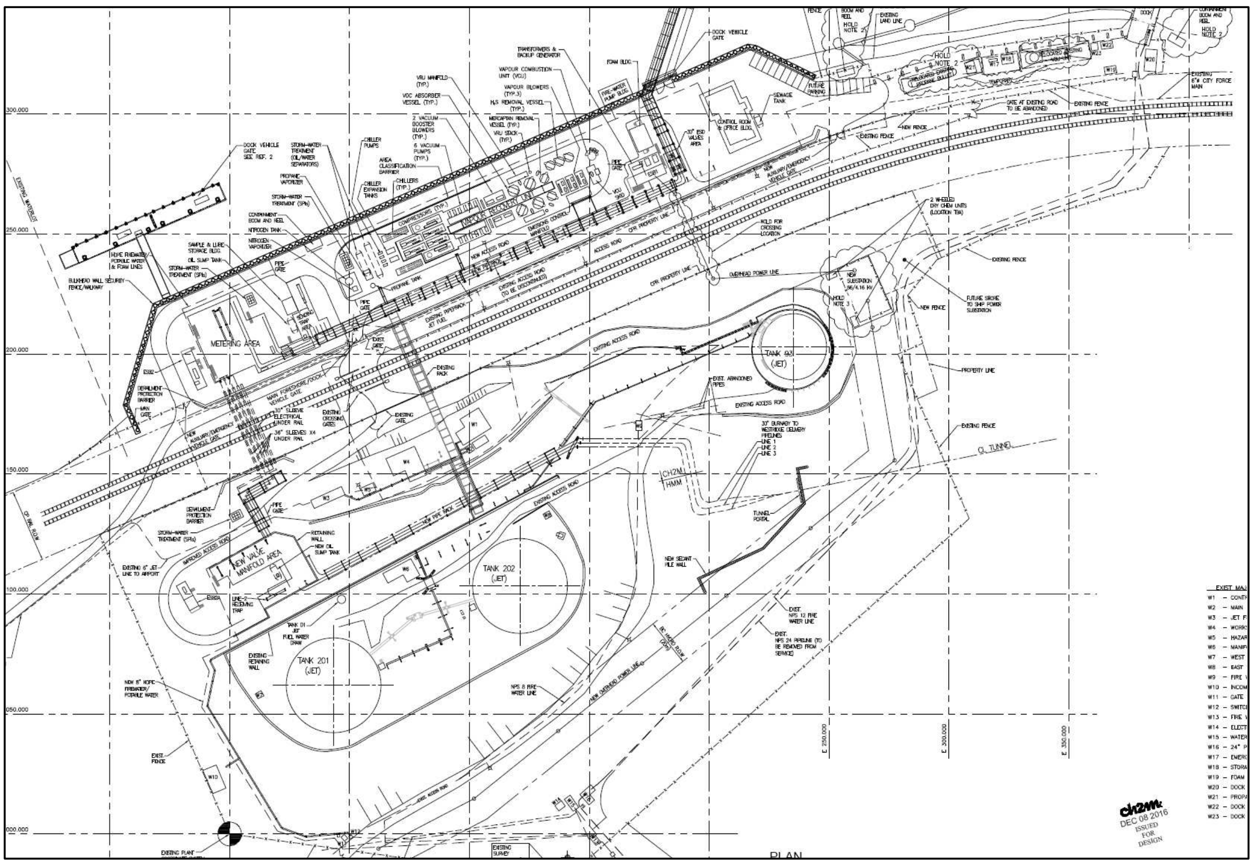


Figure 3: Foreshore facilities [5].

In addition, the WMT Facility is intended to have improved site access road, security fencing, updated parking and municipal water and a septic system.

2.2 Process Configuration and Operation

The existing WMT Facility has the capacity to load five tankers per month with heavy crude oil (diluted bitumen) [2]. Proposed upgrades to the Facility are intended to increase the transfer of heavy crude oil capacity from five vessels to 34 Aframax class vessels per month (3 simultaneously [2]), up to

100,200 m^3/d (630,000 bbl/d) [3]. Each Aframax class vessel is loaded up to 80 to 90% of its 650,000-barrel capacity [6]. The number of barges loaded and unloaded is not expected to change [2].

The existing WMT Facility has 3 fuel storage tanks with a combined capacity of 62,800 m^3 (395,000 bbl) to accommodate the unloading of jet fuel from tankers and barges to be delivered to the Vancouver International Airport by a separate pipeline [2]. The proposed upgrades to the WMT do not include new storage tanks [2]. Since no upgrades are proposed to the existing storage tanks, they are not included as part of this risk assessment.

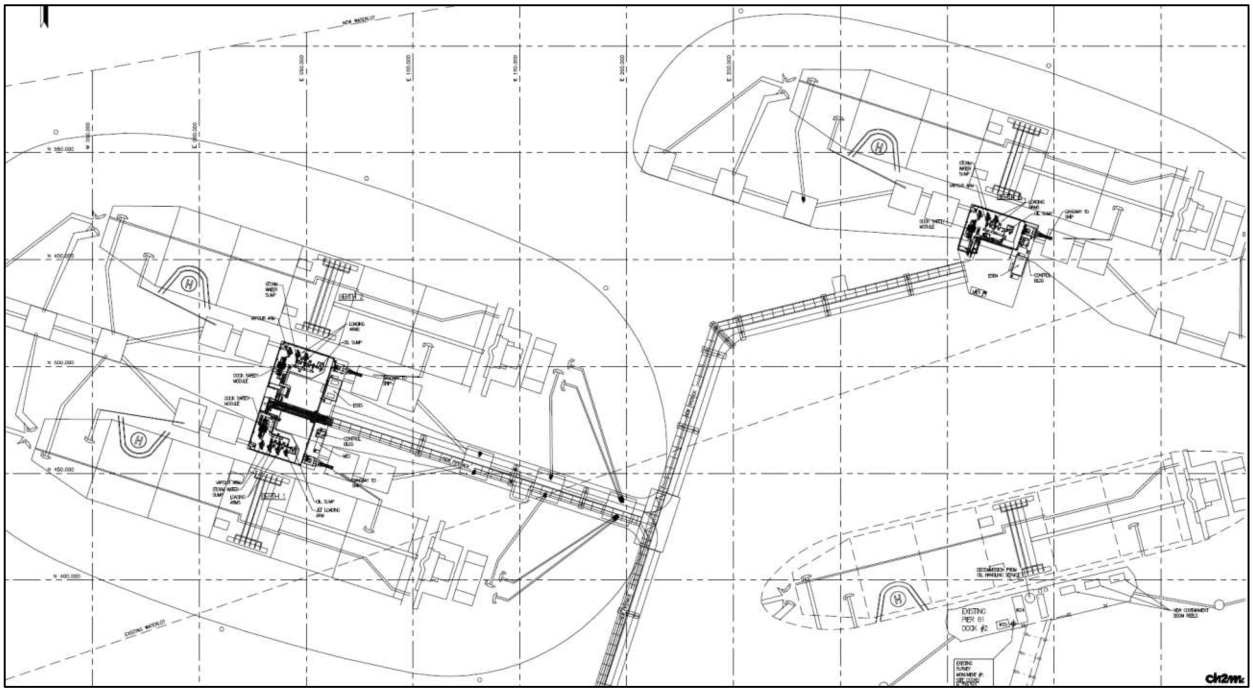


Figure 4: Dock facilities [5].

The design flow rate for each of the three new NPS 30 pipelines delivering heavy oil is 4,635 m^3/hour (700,000 bbl/d) [2]. The pipeline at the WMT Facility originates from storage tanks located 3.6 km away at the Burnaby Terminal [1].

Each of the three delivery pipelines will be equipped with an ultrasonic meter for leak detection and system flow measurement. Each meter will be rated for a flow rate of 4,635 m^3/hour (700,000 bbl/d) and will include instrumentation to continuously monitor the temperature, pressure, viscosity, and density of the crude oil [2].

Figure 5 provides a schematic overview showing the main components of the WMT Facility. The figures on the following pages illustrate the main components of the WMT Facility, which are also labelled on **Figure 5**.

2.2.1 Control Building

The WMT Facility will have an updated Control Centre Building [outlined red in **Figure 5** and illustrated in **Figure 6** to **Figure 8**] located at the approximate centre of the foreshore area adjacent to the dock access. The control building will have a direct view of the foreshore and dock facilities and control and monitor the start, ramp-up, ramp-down, and stop of vessel loading and unloading activities [2]. Constant redundant monitoring will be provided at the Primary Control Centre (PCC), located in Sherwood Park, AB [2].

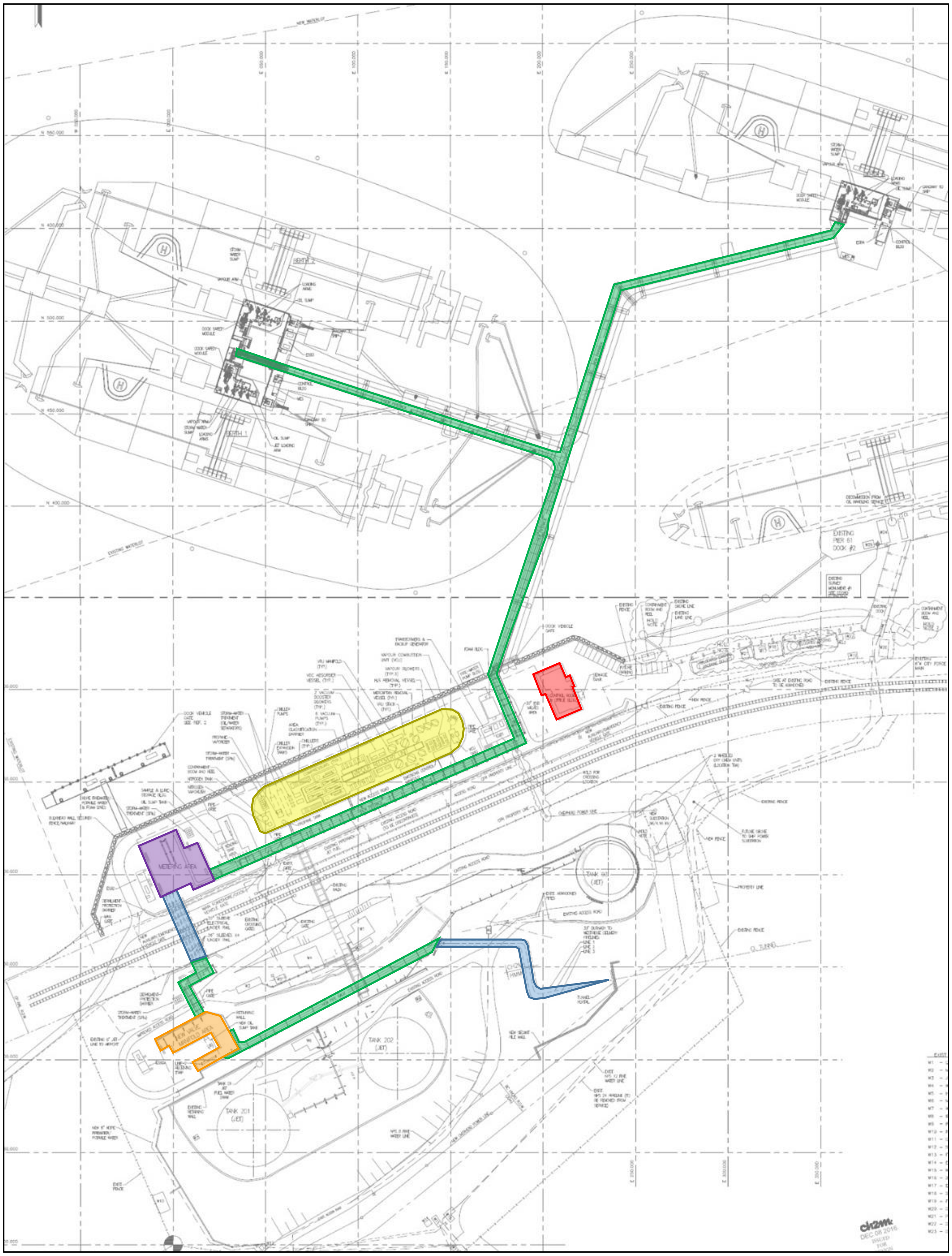


Figure 5: Schematic overview of the WMT Facility [4].

Figure 6: Illustration of the west face of the control room building [8].

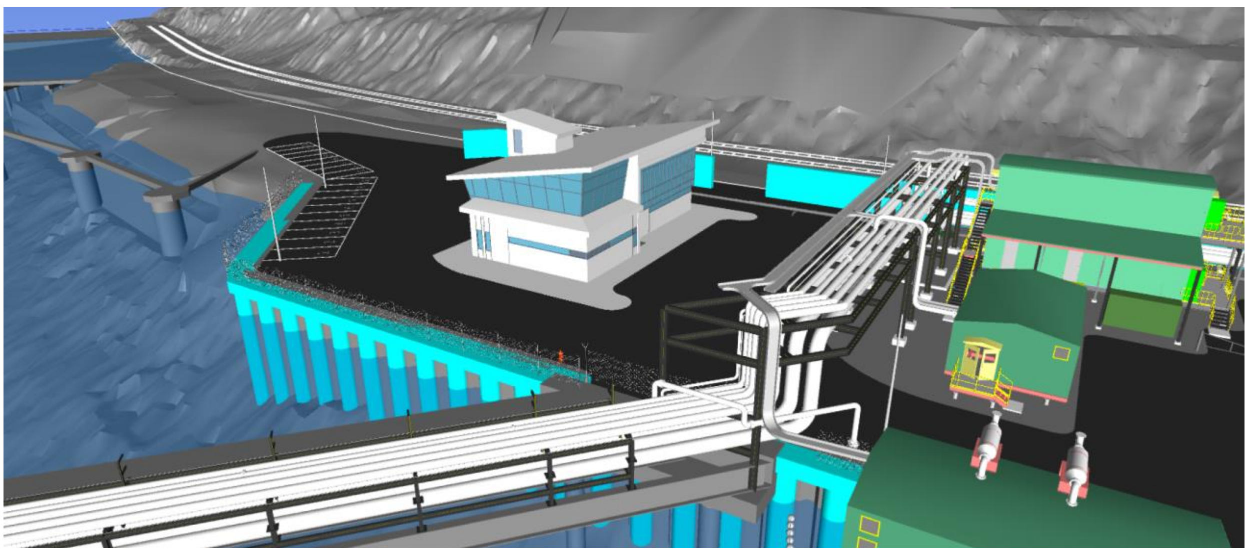


Figure 7: Illustration of the northwest corner of the control room building [8].

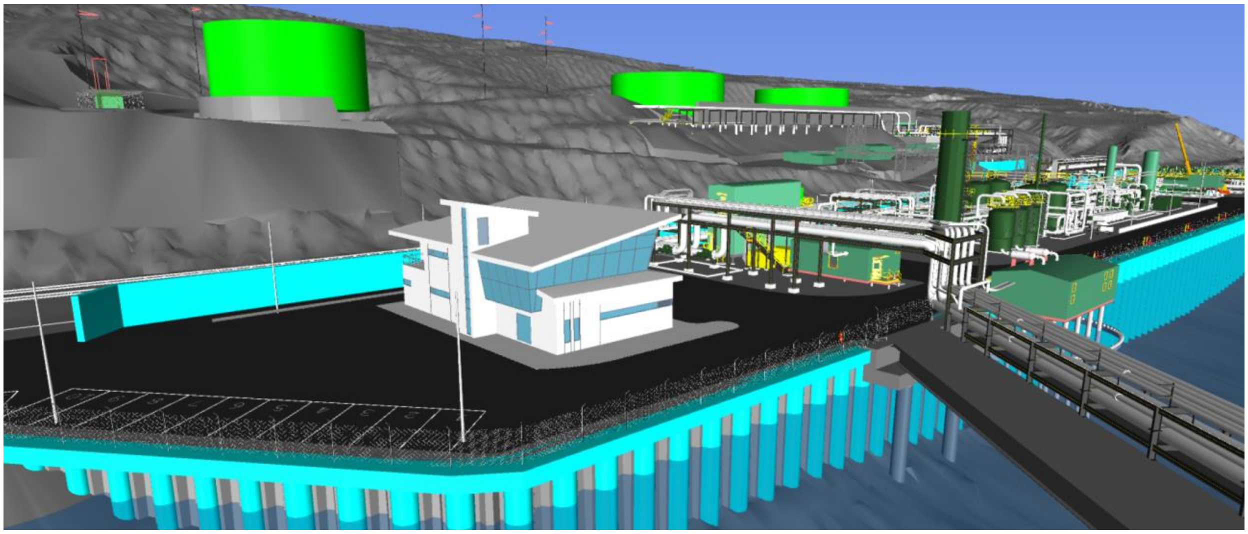


Figure 8: Illustration of the northeast corner of the control room building [8].

2.2.2 Pipeline Routing

The three delivery pipelines enter the east side of the WMT Facility site through a subsurface tunnel, and exits to above-grade as shown in **Figure 5** (subsurface location indicated in blue, above-grade indicated in green) and **Figure 9**. The pipeline routes southwest to the valve manifold area [**Figure 10**], which has interconnecting piping, leak detection, a receiving trap, and valve manifold to allow any of the three pipelines to deliver to any of the three berths and can be operated simultaneously [2]. The valve manifold area is highlighted in orange in **Figure 5**.

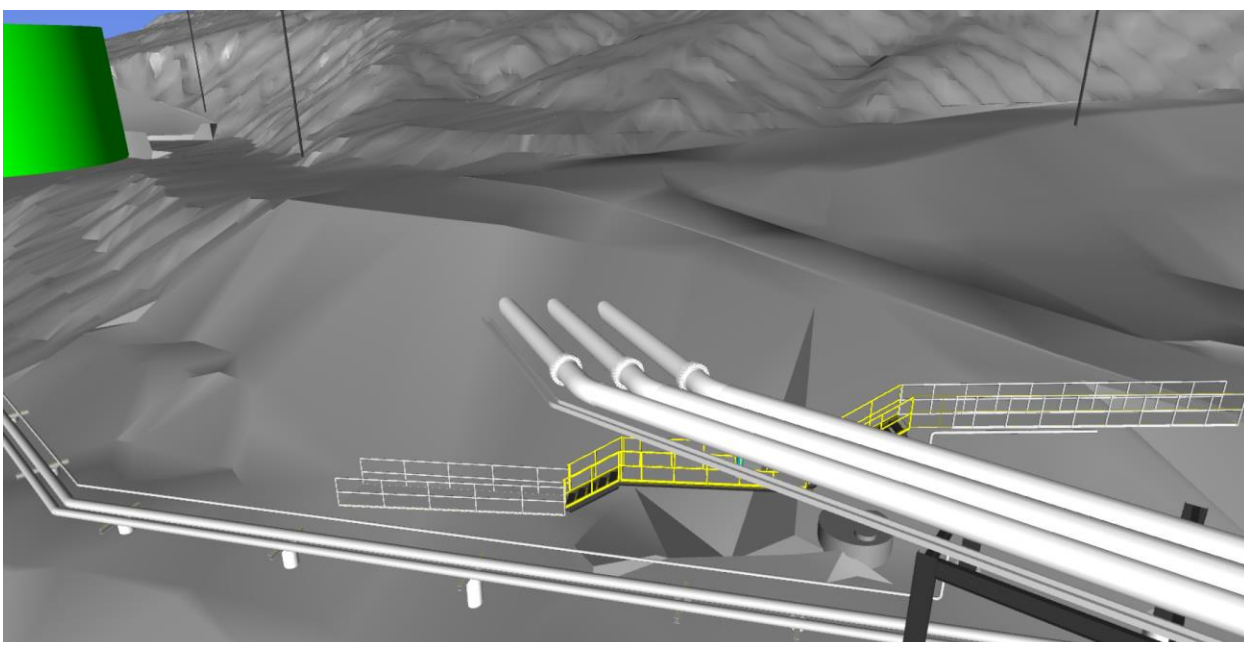


Figure 9: Illustration of pipeline entry on the WMT Facility site [8].

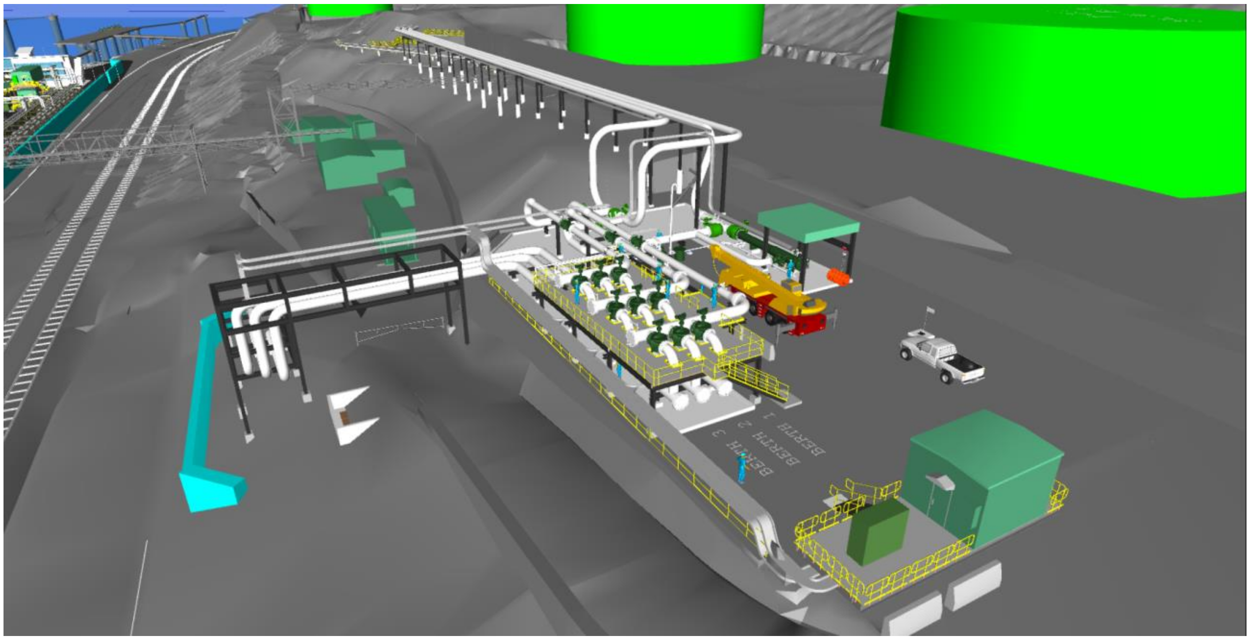


Figure 10: Illustration of the valve manifold equipment [8].

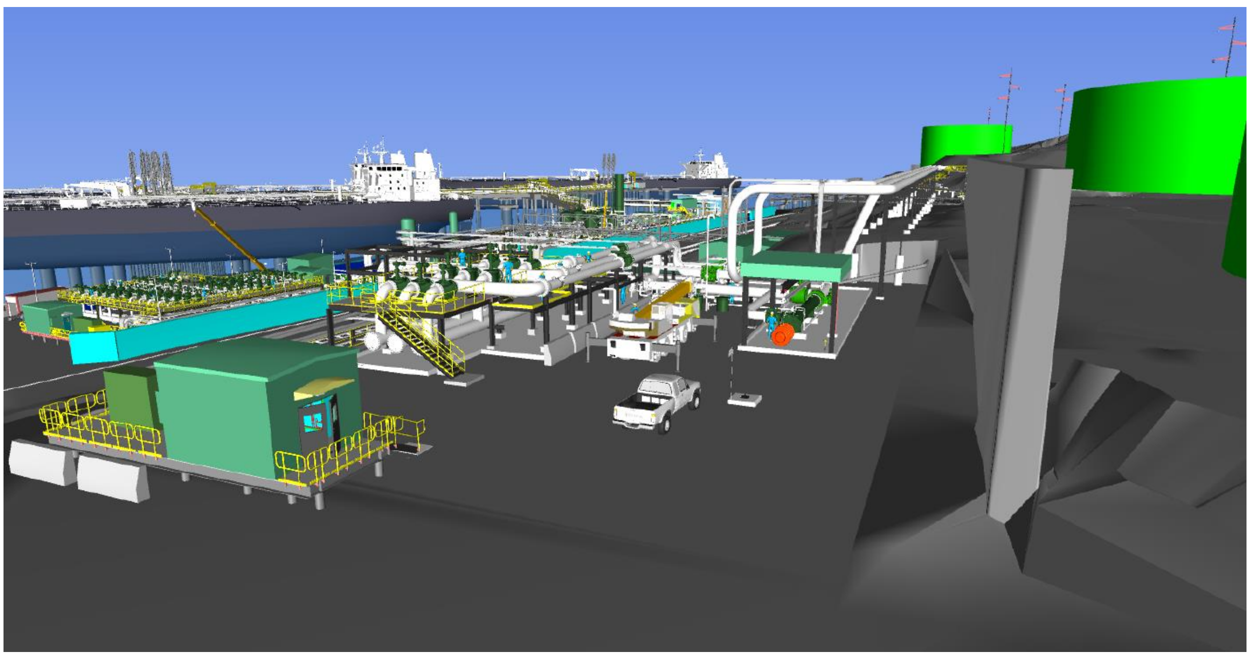


Figure 11: Illustration of a retaining wall south of the pipeline [8].

The pipeline routes north and underground of the train tracks from the valve manifold area to the metering area, as shown in **Figure 12**.

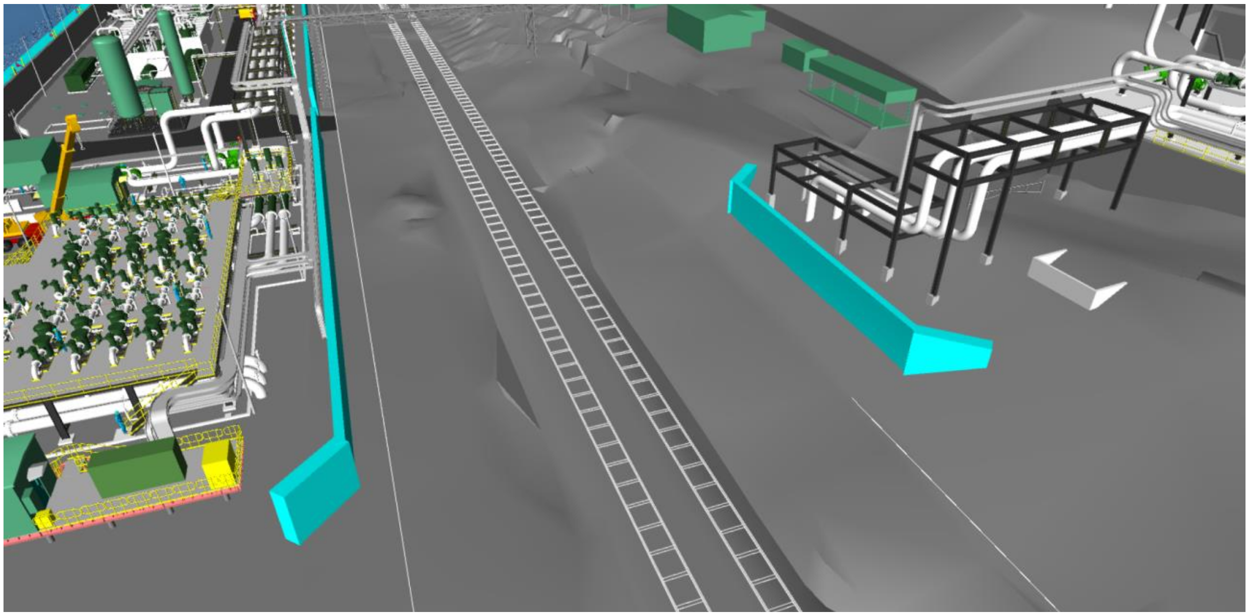


Figure 12: Illustration of the pipeline under-track routing [8].

The custody transfer meters are located in the west end of the foreshore area, highlighted in purple in **Figure 5**. The metering system will consist of five positive displacement meters for each berth delivery line, as shown in **Figure 13**. The metering system will be controlled by flow computers and a PLC [2].

Figure 13: Illustration of the metering area [8].

The berth delivery lines are routed from the east side of the metering area, along the south side of vapour recovery/combustion area, shown in **Figure 14**. The vapour recovery/combustion area is highlighted yellow in **Figure 5**.

Figure 14: Illustration of the vapour recovery area [8].

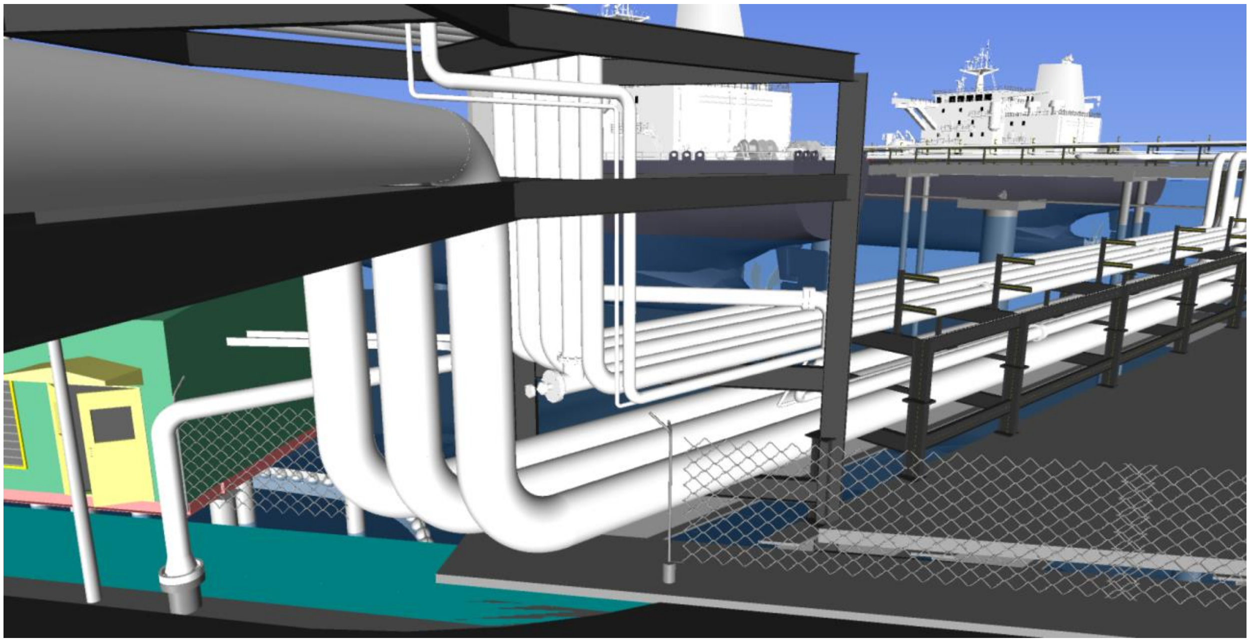


Figure 15: Illustration showing the pipeline dock access and vapour recovery piping [8].

The berth delivery lines route north at the east end of the vapour recovery/combustion area, onto the dock. The berth delivery lines route north and then 2 of the berth delivery lines route west toward Births No. 1 and 2, shown in **Figure 16**, and shown in green in **Figure 5**.

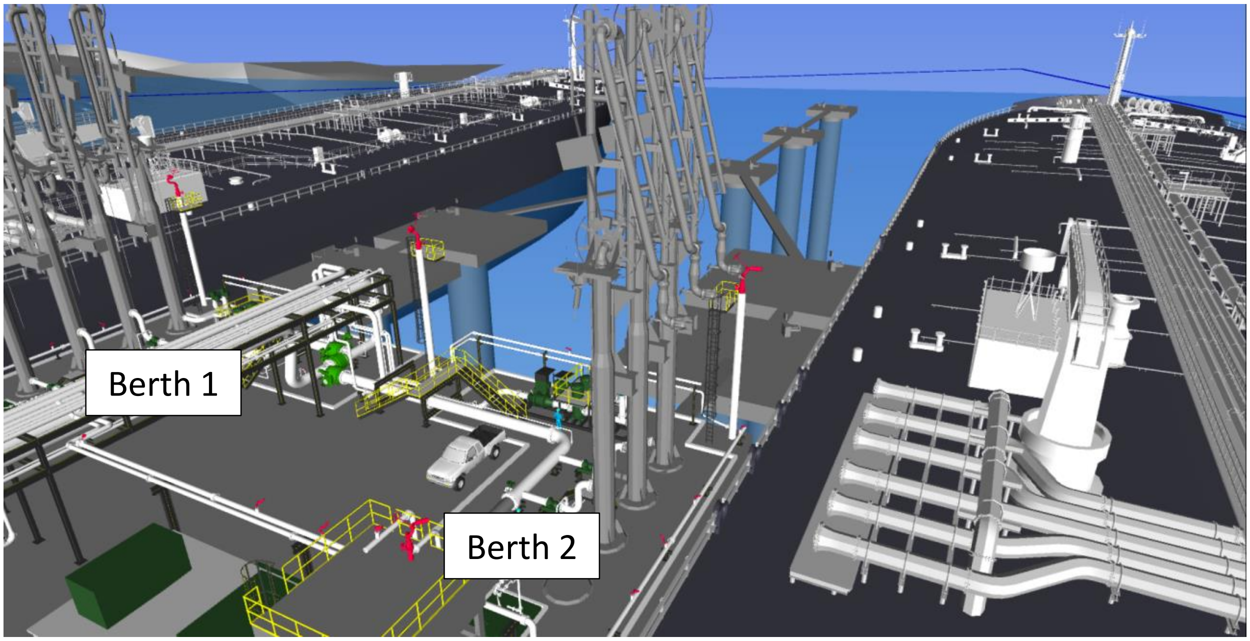


Figure 16: Illustration of west dock showing the Berth 2 delivery line piping and loading/vapour recovery arms [8].

The remaining berth delivery line is routed northeast toward Birth 3, shown in **Figure 17**.

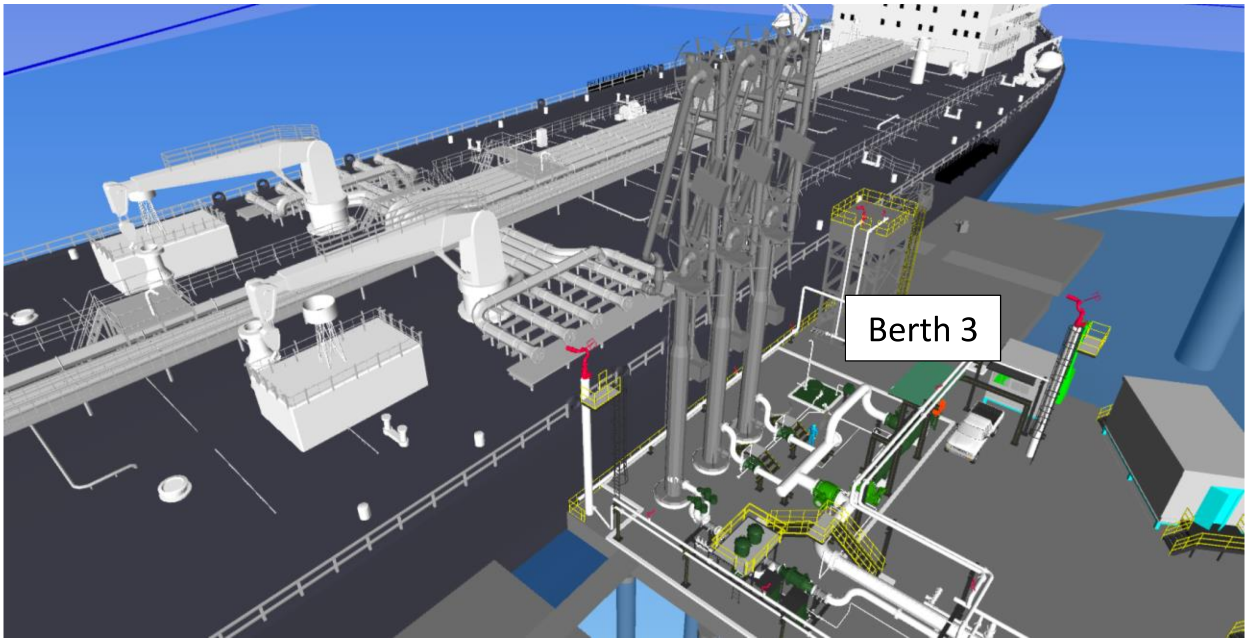


Figure 17: Illustration of the east dock showing the Berth 3 delivery line piping and loading/vapour recovery arms [8].

2.2.3 Road Access

Road access will be provided by way of Bayview Drive, which is accessed from Inlet Drive. The access road is provided with an occupied security gate. A picture illustrating the access road is provided in **Figure 18**. A secondary access road to the foreshore area is provided from Cliff Avenue.

Figure 18: Road access [2].

2.3 System Operation

The following sections summarize the intended operation of the WMT Facility including general operation, loading procedures and responses to incidents.

2.3.1 General Operation

The expanded TMPL system is intended to be monitored and operated by Control Centre Operators (CCOs) from Kinder Morgan Canada Inc. (KMC) Primary Control Centre (PCC) in Sherwood Park, AB. The WMT Facility is intended to be monitored and operated by operations personnel from the Westridge Marine Terminal Control Centre (WMTCC), with continuous redundant monitoring at the PCC [7].

The WMT Facility will have emergency shutdown (ESD) systems that will operate automatically in abnormal operating conditions and activated remotely from the PCC or locally by field operations where required [7]. The automated ESD systems may be initiated by combustible gas or fire detectors, sump tank high level switches, hydrocarbon detectors, pressure transmitters, or redundant fiber optic cable in the tunnel which will result in the immediate and automatic shutdown of all running pump units (located at Burnaby Terminal), the closing of the terminal ESD valves, the closing of the pump unit suction and discharge valves (if utility power is available), and the shutdown of waste oil sump lift/injection pumps [7]. In addition, the CCO can take immediate action as required by the Control Centre Procedures, including issuing step by step shut-down and isolation commands using the supervisory control and data acquisition (SCADA) system and dispatching field staff to investigate and initiate further emergency response measures, as appropriate [7].

CCOs will be trained in accordance with a Control Centre Training Program (CCTP), which will support the operation of the WMT Facility systems in a safe and efficient manner [7], and includes orientation, core training and procedures for specific general system operations, control and emergency response tasks [7]. The WMT will be staffed 24 hours per day, seven days per week [7].

The WMT Facility will have redundant and independent data communication circuits to reduce the likelihood of communication outages, as well as backup voice and data communication systems [7].

The WMT Facility will have a maintenance schedule with regular inspections and testing of containment systems, piping, pumps, motors, hydrocarbon detection, CP systems, emergency warning systems and suppression systems [7].

2.3.2 Loading Procedure

The following list summarizes the vessel operations for the WMT Facility [7]:

1. All vessels berthing at the WMT Facility are required to be have a sufficient number of crew to safely conduct all of the operations required to receive the transfer of crude oil from the loading arms.
2. The vessels are also required to be well equipped, maintained and operated to perform safe loading and unloading.
3. All vessels are assisted by tugs and a docking assistance system for each berth displaying the vessel's distance, speed and angle of approach.
4. Upon being secured by mooring lines, a containment boom will be deployed around the vessel and remain in place until loading is complete and the loading arm is disconnected.
5. A mandatory pre-loading conference will be held and attended by a WMT Facility operations representative, the loading master and the vessel's master or chief officer to review safety, operational, communications and security procedures.
6. The loading master and a third-party surveyor will check the cargo tanks to confirm that they are either empty or to confirm and record the quantity in each cargo tank.
7. Empty cargo tanks will be checked to confirm the gas within is inert (typically 5 % oxygen level, and not more than 8 %).
8. Confirmation of communications link between the WMT operations personnel and the vessel by the loading master.
9. The loading arms and vapour recovery system will be connected to the vessel by WMT Facility operations personnel in coordination with the cargo officer.
10. Transfer flow rates will initially be set at a low level to confirm the valve configurations and to ensure that oil is being directed to the correct cargo tank, and full transfer flow rate set through consultation between the loading master and the cargo officer, and directed through an appropriate number of flow meters to ensure measurement integrity.
11. The vessel will have the ability to initiate an ESD of the loading operation using a predetermined procedure, but will otherwise be prohibited from closing valves against the flow.
12. The loading master will remain aboard the vessel during loading and maintain a continuous liaison with WMT Facility (via radio) and the vessel.
13. The crude oil tanker loading operations are anticipated to take less than 24 hours depending on the vessel size, the cargo volume and the loading rate.

14. Each of the three vessel loading berths will be equipped with a control system that will allow WMT Facility operations personnel and CCOs to continuously monitor and adjust the loading flow rate from the WMT Facility control building and from the PCC. The CCOs will operate the Burnaby Terminal tank and manifold valves and the booster pumps which feed Westridge Marine Terminal via the delivery pipelines.
15. Flow control is established by the VFD's controlling the speed of the pumps and thereby the flow at Burnaby Terminal. The control valves in the metering manifold are intended to balance flow between meters during the meter proving process. The control valves downstream of the metering manifold are intended to maintain the liquid column in the pipelines between Burnaby and Westridge preventing slack flow so the leak detection system operates as designed.
16. As the loading approaches completion, the flow rate will be reduced in a controlled manner by WMT Facility operations personnel communicating with Burnaby Operator and/or the PCC who will control the delivery pump flow rate as directed by the loading master in consultation with the cargo officer.
17. The loading master and cargo officer will monitor the remote level instrumentation for the cargo tanks and can reconcile the total of these volumes with those measured by the WMT operations personnel.
18. Each vessel cargo tank is equipped with high and high-high level detection, which trigger audio and visual alarms in the vessel control room.
19. After loading operations end, the cargo tanks will be checked by a surveyor and compared with the WMT Facility records.
20. After loading operations are completed, the WMT Facility personnel will drain and disconnect the loading arms and vapour recovery system in accordance with WMT Facility operations procedures.
21. The vessels will then depart with assistance from pilots and tugs.

This procedure highlights the steps key to limiting the potential for unintended release of oil during transfer operations.

2.3.3 Leak Prevention, Detection and Response

The expanded pipeline will be equipped with a state-of-the-art, real-time, transient, computational pipeline leak detection system (CPM system), in conjunction with flow meters, pressure transmitters and other instrumentation for the measurement of fluid parameters [7]. The Supervisory Control and Data Acquisition (SCADA) system will acquire real time pressure, temperature, flow, and other fluid parameters from the pipelines, and pass the information on to the CPM system to validate the measurements against predefined limits. If the CPM system determines that flow or pressure parameters on one of the pipelines fall outside of the expected tolerances, the leak detection system will issue an alarm in the PCC and CCO, where the appropriate actions can be taken to determine if the alarm is false or there is a probable leak and initiate the ESD System and then immediately dispatch field operations personnel to verify if there is a leak or identify the cause of the alarm [7].

A storm water sump tank will be located below each loading platform containment area on each of the berths. The sump tanks are intended for storm water; however, their capacities will be equal to 30 seconds of the full flow from one loading arm in case of a leak. This is based on the emergency shutdown valve on the foreshore which complies with a US Coast Guard regulation requiring the last valve on the shore close fully in 30 seconds. US Coast Guard regulations are followed in absence of any applicable Canadian regulations in this specific case. Each sump tank will have a separate sump pump which will direct the contents of the tanks to the foreshore collection tank(s), and the sump tanks will be emptied prior to arrival of each new vessel [7].

Secondary containment will be provided for the process areas at the WMT Facility including the Vapour Recovery Unit (VRU) [7].

2.4 Wind Conditions

Figure 19 includes a wind rose of the frequency of wind direction by wind speed for the WMT Facility for the year 2011. The information from this wind rose is used to determine the probabilistic impact of wind on vapour movement and flame tilt, outlined later in this report.

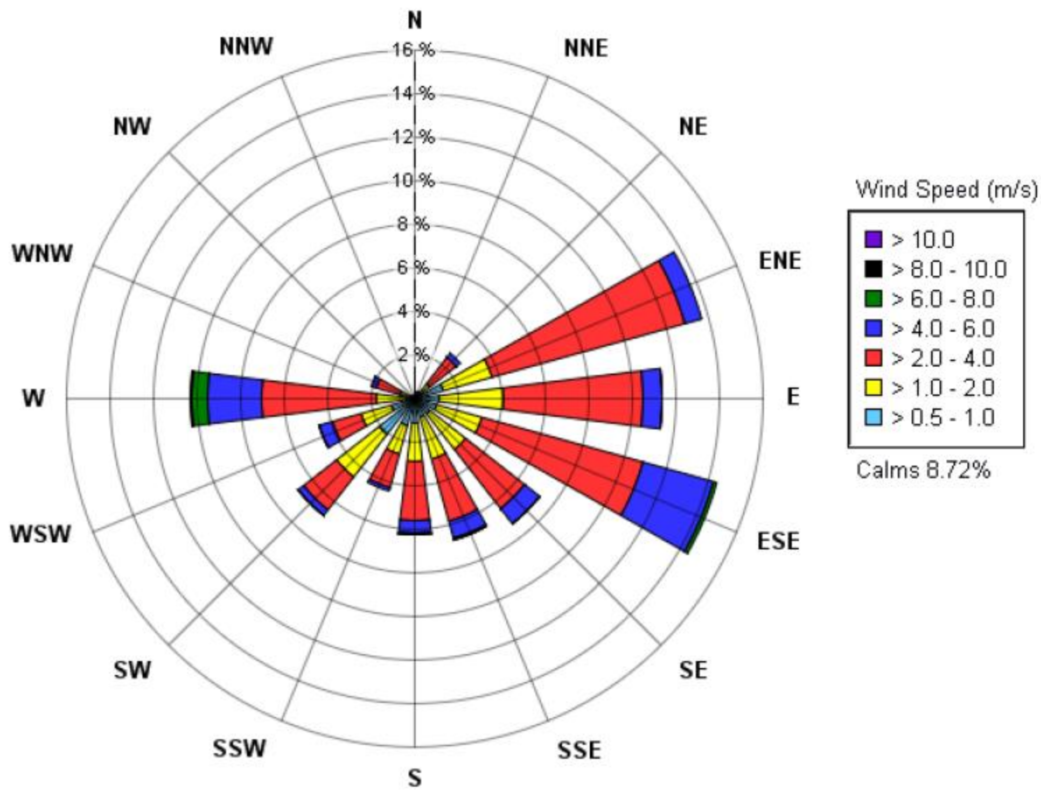


Figure 19: Wind rose centred at Westridge Terminal for the period from January 1, 2011 to December 31, 2011 [14].

3.0 REGULATORY FRAMEWORK

The regulatory framework identifies the applicable fire and life safety regulatory requirements for the design and operation of the WMT Facility. The intent of the regulatory framework is to identify the minimum expected level of performance of the safety features of the WMT Facility, and corresponding risk considered acceptable by applicable regulatory requirements. This "acceptable" level of risk is considered to be achieved if the Facility is designed in conformance with the applicable regulatory requirements.

The WMT Facility is located in a jurisdiction under the authority of the VFPA, and as noted earlier this report has been prepared in response to VFPA's request for a fire risk assessment to be conducted specific to the commodities proposed to be handled at the WMT Facility.

3.1 Applicable Regulatory Requirements

The design and construction of structures in Canada are governed by building and fire codes. These codes are complementary documents that contain provisions to address the safety of persons and protection of property from fire. The building code applies to the construction of buildings, whereas the fire code applies to the operation and maintenance of structures including buildings. However, the fire code contains provisions related to design and construction of facilities having certain risks associated with their operation, such as fuel storage facilities. In the case of the WMT Facility, the applicable Code for design, construction and operation is the Fire Code.

The Fire Code is developed and maintained federally in Canada as a model code, which is directly applicable to federally owned and operated properties/facilities. The 2015 National Fire Code of Canada (2015 NFCC) is the current model fire code.

The 2015 NFCC is composed of three divisions:

- Division A defines the scope of the Code and contains the objectives, the functional statements and the conditions necessary to achieve compliance;
- Division B contains acceptable solutions deemed to satisfy the objectives and functional statements listed in Division A; and
- Division C contains administrative provisions.

The objectives in Division A define overall goals that the applicable regulatory requirements, contained in Division B, are intended to achieve, and as noted in the Code, the applicable regulatory requirements:

> *define the boundaries between acceptable risks and the "unacceptable" risks referred to in the statements of the Code's objectives, i.e. the risk remaining once the applicable acceptable solutions in Division B have been implemented represents the residual level of risk deemed to be acceptable by the broad base of Canadians who have taken part in the consensus process used to develop the Code.*

Thus, a design that complies with the Division B requirements is a design that reduces the risk of harm to people and damage to property to an "acceptable level".

The following section of this report identifies high level 2015 NFCC requirements applicable to the design and construction of the WMT Facility and the intents of these requirements. This assessment is not intended to be a complete compliance assessment of the WMT Facility, but a summary of key requirements related to identification and mitigation of credible fire/deflagration scenarios, which will be discussed in more detail later in this report.

3.2 High Level 2015 NFCC Requirements

The 2015 NFCC contains provisions related to the design, construction and operation of industrial facilities that store and process hazardous materials. These requirements are based on the type of material stored and/or processed. The following sections of this report provide a summary of 2015 NFCC requirements associated with the considerations of the risk assessment of the new and upgraded aspects of the WMT Facility.

3.2.1 Commodity Hazard Classification

The 2015 NFCC requires certain design features and conditions corresponding with a liquids propensity to ignite. The greater the propensity for ignition, the greater the design measures to limit the risk of ignition, fire growth and fire spread. The 2015 NFCC categorizes liquids as either flammable or combustible, where the key differentiating factor is the propensity for the liquid to ignite and burn at normal working temperatures. This means that at temperatures that may occur normally (i.e., ambient environmental), flammable liquid has a higher propensity to give off enough vapour to form burnable mixtures with air.

The 2015 NFCC further subdivides liquids within each flammable/combustible category based on flash point (ignition temperature) and boiling point. The range of classifications are summarized in **Table 1**.

Table 1: Flammable and combustible liquid classification.

Category	Flash Point (°C)	Boiling Point (°C)	Class
Flammable	< 22.8	< 37.8	IA
	< 22.8	≥ 37.8	IB
	≥ 22.8 and < 37.8	N/A	IC
Combustible	≥ 37.8 and < 60	N/A	II
	≥ 60 and < 93.3	N/A	IIIA

The TMPL is intended to transport light and heavy crude oils (diluted bitumen), some may be mixed with a diluent to reduce the viscosity and density [9]. The properties of the crude oil vary as a function of type and diluent. The ranges of properties of the crude oils intended to be transported in the TMPL are listed in **Table 2**.

Table 2: Crude oil representative properties [10].

Property	Crude Oil
Specific Gravity (kg/m^3)	661 to 940
Flash Point (at 15 °C)	<-40 to 183
Boiling Point (°C)	-42 to 1100
Autoignition Temperature (°C)	220
Lower Flammability Limit (%)	0.31
Upper Flammability Limit (%)	15

Given the wide range of potential material properties for the various forms of crude that will be transported, it is assumed that the most severe classification should be considered. Therefore, for purposes of this analysis, the Crude is assumed to classified a Class IA flammable liquid. This is a conservative assumption since it is expected that not all of the crude products will have as high a propensity to ignite as assumed by the lower end of the flash point.

3.2.2 Fire Prevention and Protection

The 2015 NFCC requires the following general fire prevention and protection with respect to areas where flammable or combustible liquids are stored, handled or processed:

- Provision of additional fire protection equipment where special hazards are identified [Sentence 4.1.5.1.(1)].
- Unless controlled in a manner that will not create a fire or explosion hazard, a device or equipment is not permitted to produce open flame, sparks or heat [Sentence 4.1.5.2.(1)].
- Smoking is not permitted unless in designated areas [Sentence 4.1.5.3.(1) and Subsection 2.4.2.].
- Removal of accumulations of combustible material, control of vegetation [Article 4.1.5.4.], and appropriate handling [Article 2.4.1.3.] of used rags or similar materials contaminated with flammable or combustible liquids.
- Provision of emergency planning measures in accordance with Section 2.8. of the 2015 NFCC [Article 4.1.5.5. and Section 2.8.].
- Maintenance of access paths to permit the unobstructed movement of personnel and fire department apparatus so that firefighting operations can be carried out in any part of an area used for the storage, use or handling of flammable or combustible liquids [Sentence 4.1.5.6.(1)].
- Hot works performance in accordance with Section 5.2. of the 2015 NFCC [Sentence 4.1.5.7.(1)].

The intent of the requirements outlined above are to limit the probability of ignition of vapours and spread of fire, and facilitate fire service access to areas around the facility.

3.2.3 Electrical Installations

In accordance with Sentence 4.1.4.1.(1), where flammable or combustible liquids are present, electrical equipment is required to conform to CSA C22.1, “Canadian Electrical Code, Part I,” for hazardous locations. The design drawings included as **Appendix A** to this report identify hazardous locations on the WMT Facility site with respect to API RP 505 (2013), “Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1”.

The purpose of classifying hazardous location with respect to electrical installations where flammable or combustible liquid may be present is to limit the probability of ignition by provision of protective features for the electrical equipment. This protection includes special equipment and enclosures that reduce the probability of the electrical equipment generating sufficient ignition energy to cause a fire or explosion, and to limit the potential for interaction of an ignitable vapour and energized components of an electrical system.

The intent of these requirements is to limit the probability of ignition of vapours by energized electrical equipment. The drawings, included as **Appendix A** to this report, identify the hazard classification areas for the Facility electrical installations.

3.2.4 Spill Control and Drainage Systems

In accordance with Sentence 4.1.6.3.(1), maintenance and operating procedures are required to be established to limit the potential for escape of flammable or combustible liquids to locations where they could create a fire or explosion hazard.

In accordance with Sentence 4.1.6.3.(3), where a spill or leak does occur, a system is required to flush the flammable or combustible liquids to a location where they will not create a fire or explosion hazard.

The intent of these requirements is to limit the probability that flammable or combustible liquids will escape from process equipment, and lead to fire or explosion outside the spill area.

The valve manifold, metering, VRU area and berths will have spill control in the form of secondary containment.

3.2.5 Piping and Transfer Systems

In accordance with Sentence 4.5.1.1.(2), the requirements in the 2015 NFCC for piping and transfer systems does not apply to transmission pipelines. The 2015 NFCC notes that this is to limit the potential for overlap or inconsistency with other matters under provincial (or federal) jurisdiction.

3.2.6 Storage Systems

It is our understanding that no flammable or combustible liquid storage systems will be included in the upgrades to the WMT Facility.

3.2.7 Control of Static Electric Charge

In accordance with Sentence 4.1.8.2.(1), when Class I liquids are dispensed from or into a container or a storage tank, all metallic or electrically conducting material in the transfer system are required to be electrically bonded and grounded, or if the container or tank is made of non-electrically conducting material, measures are required to be taken to minimize the potential for static electric charge to develop.

The intent of these requirements is to limit the probability that static electric charges will build-up, which could lead to ignition of flammable or combustible liquid vapours.

3.2.8 Leak Detection

Subsection 4.4. of the NFCC has specific requirements for leak detection, testing and monitoring. The intent of these requirements is to limit the probability that defects in piping systems (including piping on piers and wharves) will go unnoticed, which limits remedial action and may lead to the spread of liquid and an increased risk of ignition of vapours should they encounter an ignition source. As outlined in **Section 2.3.3**, the facility will be provided with leak prevention, detection and response equipment and procedures.

3.2.9 Piers and Wharves

The following sections summarize the 2015 NFCC requirements for flammable and combustible liquid installations on piers and wharves.

3.2.9.1 Piping, Valves and Fittings

In accordance with Sentence 4.8.4., piping, valves and fittings require the following:

- Flexible connections or swing joints on piping between the shore and piers, designed in conformance with good engineering practice, to limit the probability of strain on the piping from movement of the pier or wharf [Sentence 4.8.4.4.(1)].
- A readily accessible valve to shut off the supply from shore is required to be provided in each pipeline within 7.5 m of piers and wharves [Sentence 4.8.4.5.(1)].
- Identification tags or labels of metal or other material impervious to water and to the flammable or combustible liquids being transferred are required to be attached to and maintained on all pipelines and control valves to designate their use [Sentence 4.8.4.7.(1)].

The intent of these requirements is to limit the probability that flammable or combustible liquids will escape from piping, valves and fittings, and lead to fire or explosion outside the spill area.

3.2.9.2 Portable Extinguishers

Portable extinguishers with a rating of 40-B:C are required in the vicinity of Class I liquid pumps/fuel dispensers and loading and unloading operations [Article 4.8.6.1.]. The intent of this requirement is to limit the probability that fire suppression operations using portable extinguishers will be delayed, or ineffective in controlling or suppressing a fire.

The Facility is intended to be equipped with 40-B:C rated sprinklers in the vicinity of any Class I liquid pumps/fuel dispensers and loading and unloading operations in the VRU area and the Berths.

3.2.9.3 Bulk Transfer Stations

The bulk transfer of flammable or combustible liquids is permitted only on piers and wharves used exclusively for that purpose, or where guards or fences are installed around valves or pumping equipment to prevent entry of unauthorized personnel [Article 4.8.7.1.]. Berth Nos. 1, 2 and 3 of the WMT Facility will be used exclusively for the purpose of transfer of combustible/flammable liquids.

The intent of these requirements is to limit the probability that other operations will create a fire or mechanical damage hazard to the liquid bulk transfer operations, hose connections will loosen from normal operations, and that marine vessels will impact and physically damage hose connections, which could all lead to escape and ignition of liquid from a nearby ignition source.

3.2.9.4 Transfer Operations

Transfer operations are required to be carried out only under the continuous supervision of a person qualified to supervise such operations, and Cargo is not permitted to be transferred to or from the tank of a marine vessel unless sufficient personnel are on board to control the operation [Sentences 4.8.11.1.(1) and (2)]. The person responsible for directing the operations is required to [Sentence 4.8.11.1.(3)]:

- prior to the transfer of cargo, ascertain that no unauthorized repair work is being carried out on the pier or wharf and that there are no open flames in the vicinity,
- during the transfer of cargo, monitor the progress of the loading and unloading to prevent overflow, and
- inspect the hose and connections for leakage and, if leakage occurs, stop the operations.

Tanks of marine vessels are required to be electrically connected to the shore piping prior to the connection of cargo hose, except when cathodic protection facilities are operating [Sentence 4.8.11.2.(1)]. Electrical connections to tanks of marine vessels are required to be maintained until the cargo hose has been disconnected and any spillage has been removed [Sentence 4.8.11.2.(2)].

Gaskets are required to be used in all hose joints and pipe couplings to prevent leakage [Sentences 4.8.11.3.(1) and (2)]. Flanged joints are required to be tightly bolted to prevent leakage, and drip pans are required to be placed under hose connections on piers and wharves, except where a sump pit or settling basin is provided [Sentences 4.8.11.3.(3) and (4)].

When transfer operations are completed, the valves on the hose connections are required to be closed, and unless the cargo hose is equipped with a device that automatically prevents liquid from draining from the hose upon its disconnection, the hose is required to be drained so as not to create a fire or explosion hazard [Sentence 4.8.11.4.(1)]. Care is required to be taken that no liquid is discharged on a pier or wharf or overboard during draining and emptying operations [Sentence 4.8.11.4.(2)].

The transfer operation equipment and procedures, outlined in **Section 2.3.2**, are arranged to comply with the transfer operation requirements outlined above.

The intent of these requirements is to limit the probability that during transfer operations, flammable or combustible liquid will escape from transfer equipment, which could lead to the spread of liquid, which could lead to the ignition of vapour from a nearby ignition source.

3.2.10 Process Plants

In accordance with Sentence 4.9.1.1.(1), Section 4.9. of the NFCC applies to process plants that contain industrial processes involving flammable or combustible liquids. The WMT Facility has a vapour recovery/ combustion area as shown in **Figure 5** and **Figure 14**. This area is intended to process the vapour recovered from the head-space of the marine vessels during transfer operations. Therefore, is required to comply with Section 4.9. of the 2015 NFCC.

The location of outdoor processing equipment in process plants is required to be based on its flammable or combustible liquid capacity [Sentence 4.9.2.1.(1)]. Outdoor processing equipment having emergency relief venting and a working pressure of not more than 17 kPa (gauge) is required to be separated from property lines and buildings on the same property by 3 m (assuming a capacity of 250,000 L or less in the processing area) [Sentence 4.9.2.1.(2) and Table 4.3.2.1.].

Outdoor processing equipment having emergency relief venting and a working pressure more than 17 kPa (gauge) is required to be separated from property lines and buildings on the same property by 4.5 m (assuming a capacity of 250,000 L or less in the processing area) [Sentence 4.9.2.1.(2) and Table 4.3.2.1.].

Processing equipment is required to be designed and arranged to prevent the unintentional escape of liquids and vapours, and minimize the quantity escaping in the event of accidental release [Sentence 4.9.4.1.(1)].

Processing equipment where an explosion hazard is present is required to be designed to withstand the explosion pressure without damage to the equipment, provided with explosion venting in conformance with NFPA 68, “Explosion Protection by Deflagration Venting,” or provided with an explosion prevention system in conformance with NFPA 69, “Explosion Prevention Systems” [Sentence 4.9.4.2.(1)].

The risks of fire and explosion at process plants are required to be evaluated based on material properties, material quantities, operating conditions, arrangement of stored materials, transportation of materials, process design, and operating and maintenance procedures [Sentence 4.9.4.3.(1)]. Based on this evaluation, measures to minimize the occurrence of fires and explosions and to mitigate their effects are required to be identified [Sentence 4.9.4.3.(2)]. Where the process warrants protection, process plants are required to be supplied with water supplies of adequate pressure and quantity to meet the probable fire demands, hydrants, hoses connected to a permanent water supply and located so that all equipment containing flammable liquids or combustible liquids, including pumps, can be reached with at least one hose stream, and fire protection systems conforming to Part 2 of the 2015 NFCC [Sentence 4.9.4.3.(3)]. The fire protection systems are required to be installed in conformance with Subsection 2.1.3. of the 2015 NFCC

In accordance with Sentence 4.9.4.4.(1), emergency procedures as outlined in **Section 3.2.2** of this report and conforming to Article 4.1.5.5. of the 2015 NFCC are required to be established for process plants.

The intent of these requirements is to limit the probability that during process operations, flammable or combustible liquid will escape from transfer equipment, which could lead to the spread of liquid, which could lead to the ignition of vapour from a nearby ignition source.

3.3 Summary

As outlined above, the 2015 NFCC is the code applicable to the construction, operation and maintenance of the WMT Facility. The requirements applicable to the WMT Facility summarized above are related to limiting the probability of the following risk factors:

- Release of flammable or combustible liquids,
- Spread of flammable or combustible liquids outside areas of containment,
- Ignition sources in proximity to areas that may contain flammable vapours,
- Explosive concentrations of flammable vapour, and
- Growth and spread of fire to buildings in the WMT Facility and areas adjacent to the WMT Facility.

The risk factors listed above are summarized in the following section of this report with respect to a hazard analysis of the WMT Facility.

4.0 HAZARD IDENTIFICATION AND QUANTIFICATION

Hazard identification involves consideration of sequences of events leading to undesirable consequences that can impact the safety of the general public, site personnel and responding fire service. The sequences include initiating events such as process vessel breakage or human error; intermediate events that escalate or mitigate the initial event; and undesirable consequences such as a large fire or explosion.

The following sections of this report summarize the hazards associated with the transmission of crude oil in the WMT Facility.

4.1 Commodity Characteristics

The TMPL will transfer heavy crude oil (diluted bitumen) [3] through the WMT Facility to the transport vessels as described in **Section 2.2**. Heavy crude oil is a hazardous material, based on its flammability characteristics outlined in **Section 3.2.1**.

4.2 Historical Incidents

A summary of historical incidents in US pipelines and associated facilities that have resulted in fires and/or explosions or deflagrations is included in **Table 3** below. While these incidents may not be directly related to the design and operation of the WMT Facility, they provide historic risk context to the bulk transfer of crude oil and facilitate the identification of events and consequences associated with the design and operation of the WMT Facility.

Table 3: Summary of US historical incidents – fires and explosions [DOT Database in the US].

Date	Location	Incident Summary
1939	Wichita Falls, Texas	Explosion in a 10 in. diameter crude oil pipeline. A 38-mile section of the line was emptied to locate and repair minor leaks. Odorized air was used to pass a series of scrapers through the line. The air was then to be displaced by oil and two scrapers collided causing a spark, ignition and explosion with the detonation traveled down the pipeline for over 26.8 miles, rupturing the line at intervals of about 80 ft.
1943	Lansdale, Pennsylvania	A pipeline ruptured and burned with burning crude oil spilling into a creek, and destroying over 100 trees. There were no injuries reported.
1951	Kansas City, Kansas	Two men welding on a crude oil pipeline were severely injured when a nearby valve failed, spraying them with crude oil that ignited. Both later died of their burns.
1963	Fostoria, Ohio	A crude oil pipeline was ruptured by an earth mover. The earth mover operator was seriously burned in the resulting fire.
1969	Lima, Ohio	A 22-inch crude oil pipeline ruptured due to cracks from welding, releasing 1,000 to 2,000 barrels of oil on a street and into the sewer system. The crude oil ignited, resulting in a fire that damaged the sewerage treatment plant.

Date	Location	Incident Summary
1972	Hearne, Texas	A rupture occurred on an 8 in. crude oil pipeline resulting in crude oil (10% of the oil was fractions lighter than hexane) being sprayed from a 6 in. split in the top of the pipe, showering the surrounding area with oil and formed a flammable gas cloud. The oil collected in a stock pond 1800 ft from the break, which was ignited by an unknown source, causing an explosion, one death and two injuries. The resulting fire several hundred feet high and 1800 ft. long burned on the surface of the oil. The quantity of oil that had escaped and burned was 7913 bbl (332,346 US gal).
1975	Lima, Ohio	A motor-operated valve within the terminal closed inadvertently and pressure built up in a pipe. When the pressure exceeded the 720 psig working pressure rating of a substandard flange, a 14-inch long crack developed. Crude oil was sprayed from the crack, which ignited and burned with flames more than 100 feet in height. It was determined that the incident was caused by the closing of a 12-inch motor-operated valve against the crude oil stream; this caused unrelieved pressure to build until a substandard flange in a low-pressure meter manifold ruptured. The oil was likely ignited when a truck in the meter building was started.
1976	Los Angeles, California	An explosion occurred aboard the tanker, which had just offloaded a cargo of light crude oil and was loading Bunker C oil. The terminal and ship did not have a vapor recovery or a cargo tank inerting system. The explosion is believed to have been initiated by a spark from a pump.
1979	Bantry Bay, Eire	Following the unloading of its cargo of heavy crude oil, a loud sound was heard at about 12:31 AM followed by observation of a small fire on deck of an oil tanker (No transfer operations were in progress at the time). Ten minutes later the fire had spread aft along the length of the ship. At approximately 1:08 AM, an explosion occurred resulting in complete damage to the vessel and extensive damage to the jetty. There were 50 deaths. The initiating event occurred as a result of the buckling of the hull, explosion in the permanent ballast tanks and subsequent simultaneous explosions in No. 5 center tank and all three No. 6 tanks. The buckling of the hull occurred because it had been weakened by inadequate maintenance and stress due to incorrect ballasting. The vessel was not equipped with a 'loadicator' computer system to indicate the loading stress, or an inert gas system to prevent or mitigate the explosions. The jetty had several modifications which had degraded the firefighting system as originally designed, including not keeping the fire mains pressurized, alteration to the fixed foam system to be manual and decommissioning of a remote control button for the foam to certain monitors. In addition, there was no dispatcher in the terminal control room at the time of the incident.

Date	Location	Incident Summary
1980	Berwick Louisiana	Crude oil leaked from a fractured 22-inch pipeline, and was ignited. One person was killed, one person was injured, and six homes were either destroyed or damaged. The pipeline's monitoring system did not detect release of over 1,800 barrels (290 m^3) of oil. It was determined that a defective sleeve weld caused the pipeline to fail.
1980	San Ysidro, New Mexico	A 16-inch crude oil pipeline was damaged by a bulldozer, resulting in a fire that killed the bulldozer operator.
1982	Norman, Oklahoma	A crude oil pipeline was cut into by a grader operator, resulting in a fire that severely burned the grader operator.
1983	Lima, Ohio	Crude oil pipeline exploded and burned at a pipeline terminal. The fire spread to a holding tank, resulting in the evacuation of 50 nearby homes.
1987	Odessa, Texas	A fire started under a mobile home, causing a pipeline below to split, fueling the fire and destroying 9 mobile homes and 2 cars.
1992	Leitchfield, Kentucky	A pipeline ruptured due to corrosion, resulting in release and ignition of crude oil. The resulting fire at a pump station resulted in the evacuation of 69 families. Approximately 3,780 barrels of crude were released.
2005	Lufkin, Texas	A bulldozer hit a pipeline resulting in the escape and ignition of crude oil. The bulldozer operator was injured and 18,500 gallons of oil escaped from the pipeline.
2007	Clearbrook, Minnesota	Pipeline repair resulting in an explosion and death of 2 workers. Ignition was attributed to not clearing sources of ignition from the designated work area and hiring improperly trained and qualified workers.
2012	New Lenox, Illinois	A pipeline was ruptured and crude oil ignited when damaged by 2 cars that left the road. Two men from the vehicles were killed, and three others seriously burned.
2015	Texas City, Texas	A crude oil pipeline pump station caught fire. The fire was under control within approximately 1 hour of its initiation.
2016	Nederland, Texas	Crude oil displaced a plug in the pipeline, resulting in the release and ignition of the oil. 7 contractors were injured from a fall and burns.

4.3 Event Tree Considerations

The risk associated with unintended consequences will be assessed using event trees, which are logic diagrams of success and failure combinations leading to all possible consequences of a given initiating event [23]. This approach allows for the logical combination of probabilities of the initiating event and intermediate events to determine the combined probability of the resulting undesirable consequences. The first event in a sequence is the initiating event for the sequence of interest, which is typically represented as a frequency of occurrence on a yearly basis.

The following sections summarize considerations associated with sources of data and consideration of events that lead to undesirable consequences.

4.3.1 Sources of Data

Frequencies and probabilities can be determined through analysis of historical incidents that have occurred at similar facilities, facilities and equipment transporting crude oil, and operation of equipment similar to that intended to be used at the WMT Facility. Frequencies and probabilities are provided for loss of containment in several reports and handbooks [11,13,23]. The data outlined in these documents is used in this section to quantify the frequencies and probabilities of events at the WMT Facility.

4.3.2 Loss of Containment

Loss of containment (LOC) can be characterized by a leak or spray from a small pinhole to a rapid discharge resulting from a major rupture [17]. The location, size, configuration and duration of the release will determine the interaction between the crude oil and the environment. The crude oil transfers through the WMT Facility from where the three pipelines enter the east side of the facility site by a subsurface tunnel, transits the facility as illustrated in **Section 2.2**, to ships on each of the three loading docks. A release can occur anywhere along the process pathway, and the resulting extent of the release will depend on the specific location, equipment involved and type of failure.

Material and equipment requirements and standards, some of which were identified in **Section 3.0** of this report, have been developed to limit the probability of failure of the system to safely convey crude oil. These requirements and standards have been developed following investigation of unintended incidents, such as those outlined in **Section 4.2**, to limit future similar occurrences.

A release is considered to be an initiating event, and can be characterized by historical frequencies. The historical frequencies are characteristic of past events, and given the development of requirements and standards that apply to current designs, these frequencies provide a conservative estimate of the potential for future events to occur.

The dispersion of the crude oil is a function of the nature of the loss of containment and can be characterized by outflow and pool evaporation. The quantity of crude oil released is a function of the size of the rupture in the pipe or vessel and the time from detection to initiation of the emergency shutdown (ESD) system. As outlined in **Section 2.3.1** in addition to manual shutdown capability, the WMT Facility will have an ESD that operates automatically in abnormal operating conditions indicated by the activation of:

- hydrocarbon and fire detectors,
- sump tank high level switch, or
- pressure transmitters.

The ESD system will initiate the immediate and automatic shutdown of all running pump units, the closing of the terminal ESD valves, the closing of the pump unit suction and discharge valves (if utility power is available), and the shutdown of waste oil sump lift/injection pumps.

In addition, the facility will be staffed 24 hours a day, seven days a week, all year. The facility will be visible from the control building, which will have direct sight lines to almost the entire length of pipeline from the point it enters the facility (See **Figure 9**), to the loading arms on the berths. Therefore, if a leak/rupture occurs and is indicated by activation of the devices noted above, the condition can be confirmed visually and events initiated to limit the extent of the release. The time associated with a release can be summarized in **Table 4** below.

Table 4: LOC Timeline.

LOC Event	Time for Each Event (s)	Considerations
Rupture of pipeline or vessel	Start	This is the initiating event
Automatic detection of the rupture	60	The WMT Facility will be equipped with automatic sensors to detect hydrocarbons, fire, tank high level and pressure. It is anticipated that a loss of containment will result in an immediate change of pressure in the system that will activate the pressure transmitter. The WMT Facility will also be equipped with hydrocarbon detectors throughout the facility, which are anticipated to operate in addition to the pressure transmitters once a detectable concentration (usually a very small amount) of hydrocarbons interfaces with the detector(s). In addition, if a rupture and release occurs at the valve manifold, metering, VRU and berth loading arm areas, it is anticipated that the material will be partially captured in the sumps, which will activate the sump high level switch.
Operator detection and recognition of an event	60	This event involves notification of an operator that an event may have occurred and initiation of the actions or decisions required to confirm that the notification is an actual event that requires intervention. The WMT Facility is visible from the control room building; therefore, it is anticipated that confirmation of an event would occur in a reasonably short period of time, and this period of time would decrease with increasing event size due to a higher probability of direct observation of the event from the control room building.
Operator response and initiation of ESD if not initiated automatically	30-90	This event follows confirmation that an event is occurring and initiation of the emergency shutdown (ESD) actions, which is intended to shut down the pumps that transmit the crude oil. These pumps are located at the Burnaby Terminal and can be operated directly from the WMT Facility.
Completion of ESD procedures	30	This event is intended to address the time required from initiation of the ESD system to complete cessation of transmission of the crude oil in the system.

The total time estimated from event occurrence to system shut down is approximately 3-4 minutes (180 to 240 seconds). It is anticipated that a larger loss of containment, such as a pipeline rupture, will be identified and ESD initiated more quickly than a smaller loss of containment (i.e., 180 seconds).

Following the loss of containment event, ignition of the crude oil depends on its proximity to sources of ignition, which are discussed in more detail in the following section of this report.

4.3.3 Ignition Events

Ignition is an energy initiated process that results in the sustained burning of a fuel. For ignition to occur, the following is required:

1. The device or equipment involved in the ignition resulting in a competent ignition source,
2. The type and form of material first ignited, and
3. The circumstance, activity, failure that bring the above factors together to allow a fire to occur.

These are discussed in more detail in the following sections of this report.

4.3.3.1 Ignition Source

The mode of ignition is difficult to predict or simulate, but can be characterized through statistical analysis of fire incidents.

The WMT Facility will be fenced, have staff onsite, and security monitoring 24 hours a day. In addition, the site staff will conduct regular inspections of the site, which will limit the potential for unintended access to the site and intentional damage resulting in fire or deflagration. In addition, site security and staff inspections will increase the probability of identification of conditions that may result in fire or early detection of fire events.

In an industrial setting, there are a number of possible ignition sources including energized electrical equipment, static discharge, hot work operations, smoking, mechanical failure/friction. Some of these modes of ignition were identified in the previous section of this report relative to historical incidents. Each of these potential ignition mechanisms and mitigation is discussed in more detail in the context of the proposed upgrades and operation of this facility as follows:

- **Energized Electrical Equipment**: Energized equipment is intended to be provided with protection from potential flammable environments in accordance with CSA C22.1 as outlined in **Section 3.2.3**. Protection strategies include enclosures that limit the interaction between energized electrical components and potential flammable environments, and equipment that limits the potential for high temperature or localized electrical discharge energy.

- **Static:** The WMT Facility equipment will be designed to limit the potential for static discharge including grounding systems (**Section 3.2.7**), and use of non-sparking metals and materials in system components.

- **Hot Work Operations:** The WMT Facility will develop a program for control of hot work operations through procedures and training in compliance with the 2015 NFCC and other applicable codes/standards (**Section 3.2.2**). This will reduce the probability of ignition by hot work operations.

- **Smoking:** Smoking will not be permitted on the WMT Facility property (**Section 3.2.2**).

- **Mechanical Failure/Friction:** The WMT Facility will have limited mechanical components, which will be designed specific to hazards associated with the transport of crude oil. The facility does not have any pumps for the delivery of crude oil to tankers, all delivery pumps are located at the Burnaby Terminal.

The proposed design and intended operation of the WMT Facility, as noted above, will limit the probability of ignition, likely below the levels reflected in the statistical data derived from historical incidents and intended to be used to characterize the probability of ignition in this report. Therefore, the use of these probabilities of ignition will be conservative.

4.3.3.2 Crude Oil as the Material First Ignited

As outlined in **Section 3.2.1**, the crude oil that will be transported through the WMT Facility has a flash point ranging between -40 and 183 °C. The daily ambient temperatures in Burnaby will be within this range; therefore, with loss of containment, a flammable concentration, adequate oxygen, presence of an adequate ignition source, the spilled crude oil will have a propensity to ignite and sustain burning.

Depending on the amount of vapour that develops (i.e., due to a release of crude oil vapour cloud) and local conditions, ignition can result in either a fire or a deflagration. These are discussed in more detail in the following sections of this report.

4.3.4 Deflagration

A deflagration can occur where a flammable vapour is present within its explosive limits (lower and upper) and comes into contact with an ignition source. A flame front develops and propagates outward from the point of ignition and in combination with burning gases behind the flame front creates a pressure wave that if confined in an enclosure can result in structural damage and failure. If unconfined, the resulting pressure wave can still result in damage due to the pressure differential.

Propagation of the flame front through the flammable vapour at a speed lower than the speed of sound is characterized as a deflagration. When the flame front speed exceeds the speed of sound, it is characterized as a detonation. Where containment of the crude oil vapour cloud is not present, ignitions would more likely result in deflagrations [17].

As outlined in **Section 3.2.1**, crude oil is a flammable liquid and therefore has the potential to result in a deflagration if an flammable concentration (0.31% to 15% vol.) of vapour with adequate oxygen (> 10% vol.) comes in contact with an energy source sufficient to cause ignition. However, the fractions of volatiles in crude oil are limited and tend to produce vapour that is denser than air [10,18]. This means that the flammable vapours are likely to move towards low lying areas in relatively calm conditions. The wind rose for the WMT Facility, provided in **Section 2.4**, indicates calm winds for approximately 9% of the time, and wind speeds up to 8 m/s, but only for short relative durations. The predominant wind direction is from the ENE to ESE, as well as W. There is little relative wind from the north. These wind conditions align with the topography surrounding the WMT Facility, which as shown in **Figure 20**, contours toward the WMT Facility site and specifically the foreshore section of the site.

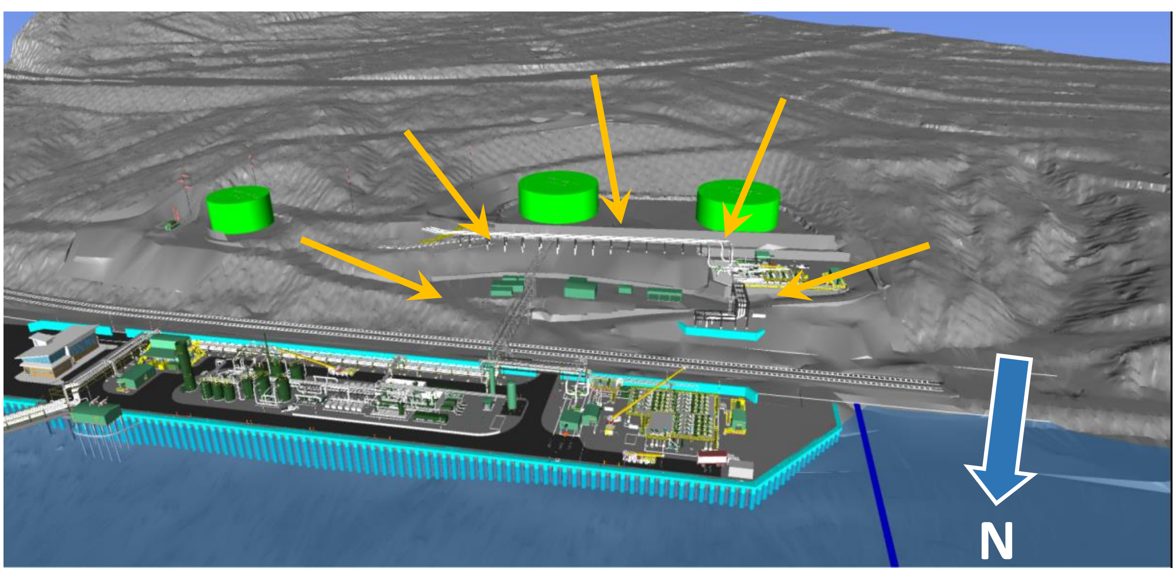


Figure 20: Topography surrounding the WMT Facility site [8].

Therefore, the limited fraction of volatiles in crude oil, vapours denser than air, predominant wind conditions and topography of the site support limited movement of any vapour that may develop from a leak and any movement of the vapour is likely to be towards the foreshore area of the facility. It is expected that ignition of the crude oil pool will follow a deflagration.

4.3.5 Fire Growth

Fire growth can occur once sustained burning is attained, and sufficient fuel and oxygen are available. The rate of fire growth depends on the configuration of the fuel and can be characterized as a jet flame or pool fire. A jet flame can result from ignition of a pressurized release of liquid from a small opening, and has a geometry that is a function of release pressure, liquid combustion characteristics and wind. A pool fire can result from the ignition of an accumulation of flammable/combustible liquid and has a geometry that is a function of the liquid release area, combustion characteristics and wind [20].

It is anticipated that the consequences from a large pool fire at the same location as a jet fire will have a greater impact on the potential exposure of persons and structures. Therefore, the consequences associated with a jet fire resulting from a release of crude oil are considered to be adequately addressed through the assessment of a large pool fire in the same location.

4.4 Sequences

The sequence of events from the initiating event to the undesirable consequences were summarized in the previous sections of this report, and include the probability of:

1. Component failure or human action (or inaction) that results in release of crude oil from the WMT Facility systems, the loss of containment and time to mitigate the release.
2. Ignition of the crude oil or flammable vapour.
3. Pool fire, deflagration, a pool fire following a deflagration, or no ignition.
4. Impact on adjacent spaces.

These events leading from release to fire/deflagration are characterized by the event tree included in **Figure 21** below. This tree does not follow all possible events, but the key events that lead to undesirable consequences.

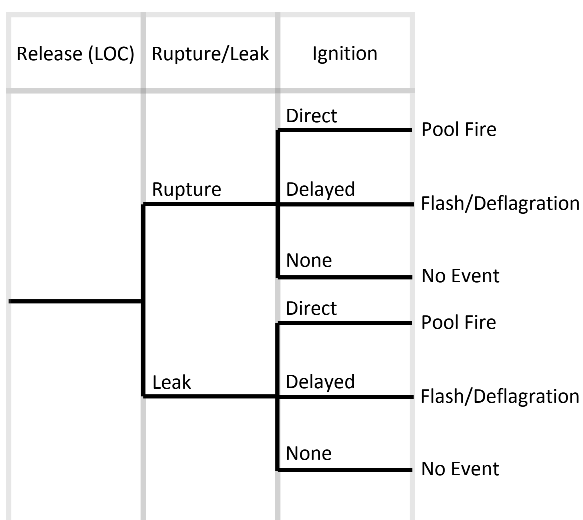


Figure 21: Event tree for release of crude oil to a fire/deflagration event.

The events associated with event tree above are included in the following sections of this report. These trees include probabilities based on available data as outlined in **Section 4.3.1**.

4.4.1 Events Following Rupture of the Pipeline to Fire/Deflagration

This event considers the loss of containment (LOC) of crude oil from one of the three NPS 30 pipelines within the WMT Facility boundaries, development of a crude oil pool with base area that is a function of the release location and whether containment is provided (i.e., a bund), ignition of the crude oil pool and subsequent fire/deflagration, impact of the radiant heat or pressure differential from the fire/deflagration on the area proximal to the event. The likelihood, frequencies and probabilities associated with these events are summarized in the following sections of this report.

4.4.1.1 Rupture/Leak

The frequency of a release from an onshore oil pipeline and the probability of that release being a rupture or leak is published by the International Association of Oil & Gas Producers (OGP) in "Risk Assessment Data Directory on Riser & pipeline release frequencies," (RPRF) [13] and is based on these "379 failures on pipelines with a total exposure for pipelines containing crude oil and products of approximately 667,000 km-years". The OGP RPRF recommends a failure frequency of 2.5 x 10^{-4} per km-year for onshore oil pipelines with a diameter greater than 28 inches.

The WMT Facility has three NPS 30 pipelines and a total combined pipeline length of approximately 2.5 km from the point of entry on the WMT Facility site to the loading arms on the berths, and includes the valve manifold and metering areas. The extent of the pipelines is shown in green in **Figure 5**. This results in a failure frequency of 6.25 x 10^{-4} for the pipeline, including valves and metering, on the WMT Facility site.

The OGP RPRF provides a percentage breakdown of leak hole sizes for onshore oil pipelines, shown in **Table 5** below.

Table 5: Hole Size Distributions – Onshore Oil Pipelines [13].

Hole Size	Percentage
Small (< 20 mm)	23
Medium (20 to 80 mm)	33
Large (> 80 mm)	15
Full Rupture	29

The hole size distributions for small to large are combined for a total percentage of 71% and assumed to have a combined hole size of 80 mm to represent a "leak". This is a conservative assumption, given that only 15% of the total LOC's had a hole size greater than 80 mm.

The OGP RPRF data also is categorized as a function of failure mechanism, which includes failures that are unlikely for a site such as the WMT Facility that is staffed 24 hours a day and 7 days a week. However, the distribution of losses as a function of the failure mechanism has not been considered in this analysis as they are not categorized as a function of hole size. This is a conservative approach to the application of the frequency of leak or rupture as outlined above.

4.4.1.2 Ignition

Ignition probabilities are provided by the OGP in "Risk Assessment Data Directory on Ignition Probabilities," (IP) [13]. The data and models are specific to onshore and offshore scenarios, and provide ignition probabilities as a function of release rate (kg/s). The total ignition probabilities (i.e., immediate + delayed) for release from an onshore cross-country pipeline running through industrial or urban areas are summarized in **Table 6** below.

Table 6: Ignition Probabilities [13].

Release Rate	Ignition Probability
0.1	0.0010
0.2	0.0016
0.5	0.0028
1	0.0045
2	0.0070
5	0.0126
10	0.0198
20	0.0311
50	0.0563
100	0.0700
200	0.0700
500	0.0700
1000	0.0700

As noted in the OGP IP, the direct and delayed ignition probabilities are included in the ignition probability. The direct ignition is 0.001 and the delayed ignition is the ignition probability in the table above minus 0.001. Since the ignition probabilities are a function of the release rate, the probabilities will be determined later in this report following the assessment of the spill rate/quantity.

4.4.1.3 Event Tree

The event tree with the sequence of events from rupture of the pipeline to pool fire, flash fire/deflagration or no event is included in **Figure 22** below.

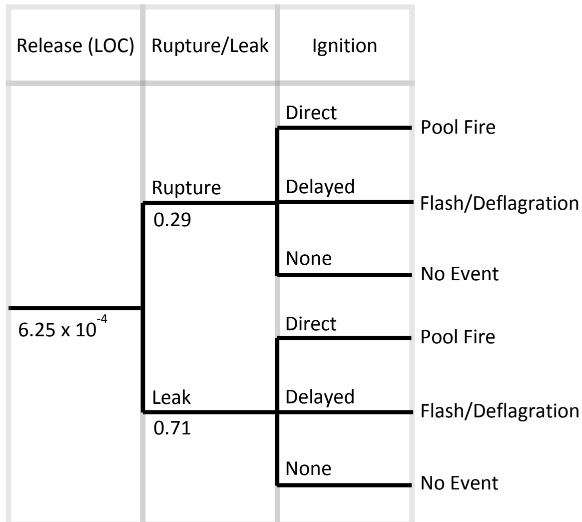


Figure 22: Event tree for a fire/deflagration event following LOC of one line of the pipelines.

4.4.2 Loading Arm Rupture and Fire/Deflagration

This event considers the loss of containment (LOC) of crude oil from one of the three loading arms on the berths, development of a crude oil pool with base area that is a function of the release location and whether containment is provided (i.e., a bund), ignition of the crude oil pool and subsequent fire, impact of the radiant heat from the fire on the area proximal to the fire. The probabilities associated with these events are summarized in the following sections of this report.

4.4.2.1 Rupture/Leak

The frequency of a release from a loading arm is published in CPR 18E, "Guideline for quantitative risk assessment (the 'Purple Book')," [13], and is 6 x 10^{-5} per operation with for a full-bore rupture (both sides of full bore), and 6 x 10^{-4} per operation for a leak (10% of nominal diameter of the arm with a maximum of 50 mm).

Each berth will be equipped with three 406 mm diameter (NPS 16) loading arms. It is anticipated that the WMT Facility will support up to 408 transfer operations per year. This results in a full bore failure frequency of 0.07344 per year (6 x 10^{-5} per operation, 3 loading arms operating per operation, 408 total operations per year), and a leak frequency of 0.7344 per year (6 x 10^{-4} per operation, 3 loading arms operating per operation, 408 total operations per year).

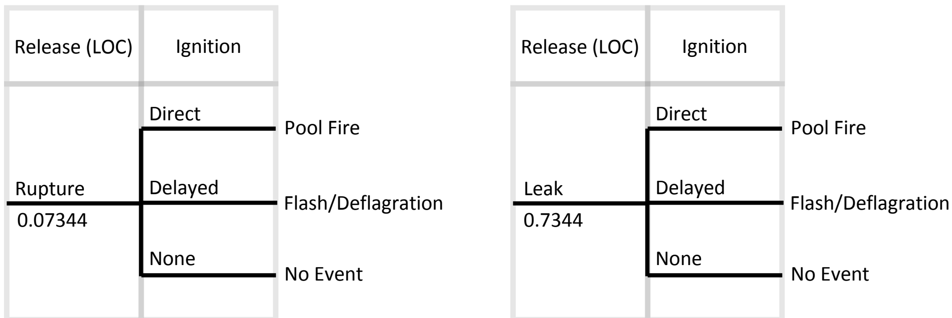
4.4.2.2 Ignition

The probability of ignition for a release from the loading arms is the same as outlined in **Section 4.4.1.2** of this report. However, the actual probability of ignition is expected to be lower where the quantity of crude oil spilled is greater than the berth holding capacity (secondary containment) and the excess spills to the water level. Fewer possible ignition sources are expected at the water level than may be on the berth level. Therefore, the ignition hazard is expected to be localized to the spill area on the berth.

Similar to the ignition probability of a pipeline rupture/spill, since the ignition probabilities are a function of the release rate, the probabilities will be determined later in this report following the assessment of the spill rate/quantity.

4.4.2.3 Event Tree

The event tree with the sequence of events from rupture of a loading arm to pool fire, flash fire/deflagration or no event is included in **Figure 22** below. Since there are two frequencies associated with a release as a function of the type of release (LOC), these are illustrated as two event trees, shown in **Figure 23(a)** and **(b)** below.



(a) **(b)**

Figure 23: Event trees for a fire/deflagration event following LOC of any one line of the loading arms for a (a) rupture, and (b) a leak.

4.4.3 Vapour Recovery Unit Process Area Fire/Deflagration

The vapour recovery unit (VRU) process area, located north of the pipeline, is shown in **Figure 14**. The VRU area will process and recover the vapour from the ship holds during a transfer operation. Light gases such as nitrogen, carbon dioxide and light hydrocarbon vapours that can’t be captured will be combusted or vented to atmosphere. The recovered crude oil is intended to be reinjected back to the pipeline system.

The quantity of flammable liquids/gases within the process unit will be minimal relative to the quantity within the pipelines immediately south. Therefore, a fire/deflagration that may occur within the VRU process area is not expected to result in a consequence greater than that resulting from a rupture/leak in the pipeline south of that location. Because analysis of a failure of the pipeline (outlined in **Section 4.4.1**) located immediately south of the VRU process area is included within this report, the probability of failure of the equipment within the VRU process area, subsequent release of flammable liquid/vapour, and consequence associated with that release is not calculated as part of this report.

4.5 Probability Criteria (MIACC)

A guide developed under the auspices of the Major Industrial Accidents Council of Canada (MIACC) [19] for analyzing major accident risks from hazardous substances provides risk acceptability guidelines for “facilities with a single hazardous material that might impact the public”. These guidelines define annual individual risk with respect to adjacent allowable land uses, as shown in **Figure 24** below.

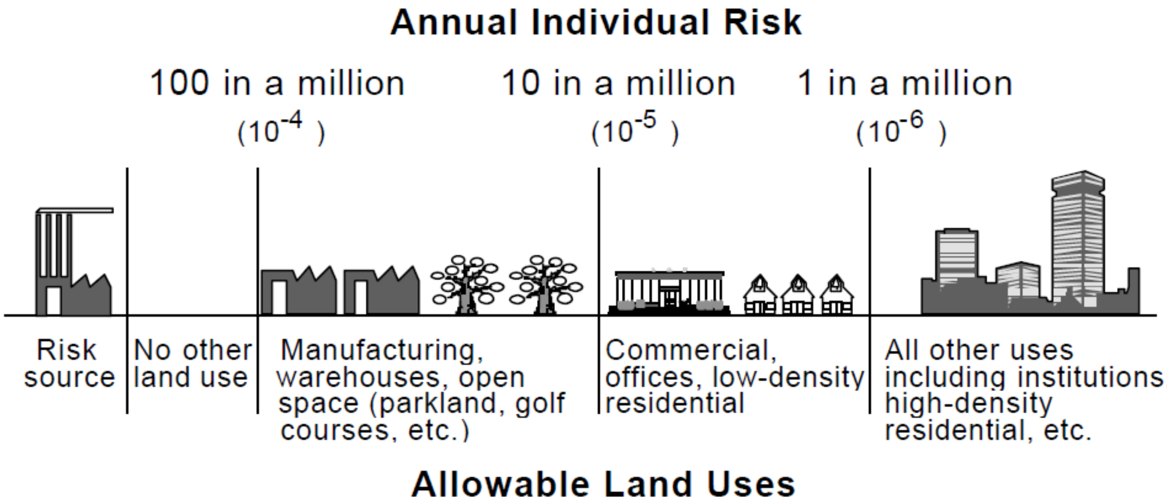


Figure 24: Annual Individual risk for allowable land uses [19].

The MIACC acceptable risk approach defined individual risk as "the chance (in any year) that a person near a hazardous facility might die due to potential accidents in that facility" [19]. The MIACC risk levels provide a quantitative framework by which to establish an acceptable level of risk associated with the design and operation of the WMT Facility, and will be used to examine the resulting risk levels based on the analyses in this report.

The probabilities calculated based on the event trees outlined in the previous section of this report will be examined relative to the MIACC criteria to determine acceptable levels of risk. Where the probability of an event occurring, is below the acceptable limit outlined in the MIACC criteria, the consequence following such an event does not require quantification.

The area adjacent to the WMT Facility is zoned as parkland, which is flanked by low-density residential as shown in **Figure 25** and **Figure 26** below. In addition, **Figure 25** shows the distances between the site boundary and the next closest low density residential area. Therefore, the MIACC annual individual risk criteria of 10^{-4} will be applied to the interface between the WMT Facility site and the parkland (blue line) and 10^{-5} to the interface between the low density residential areas and the parkland (purple line).

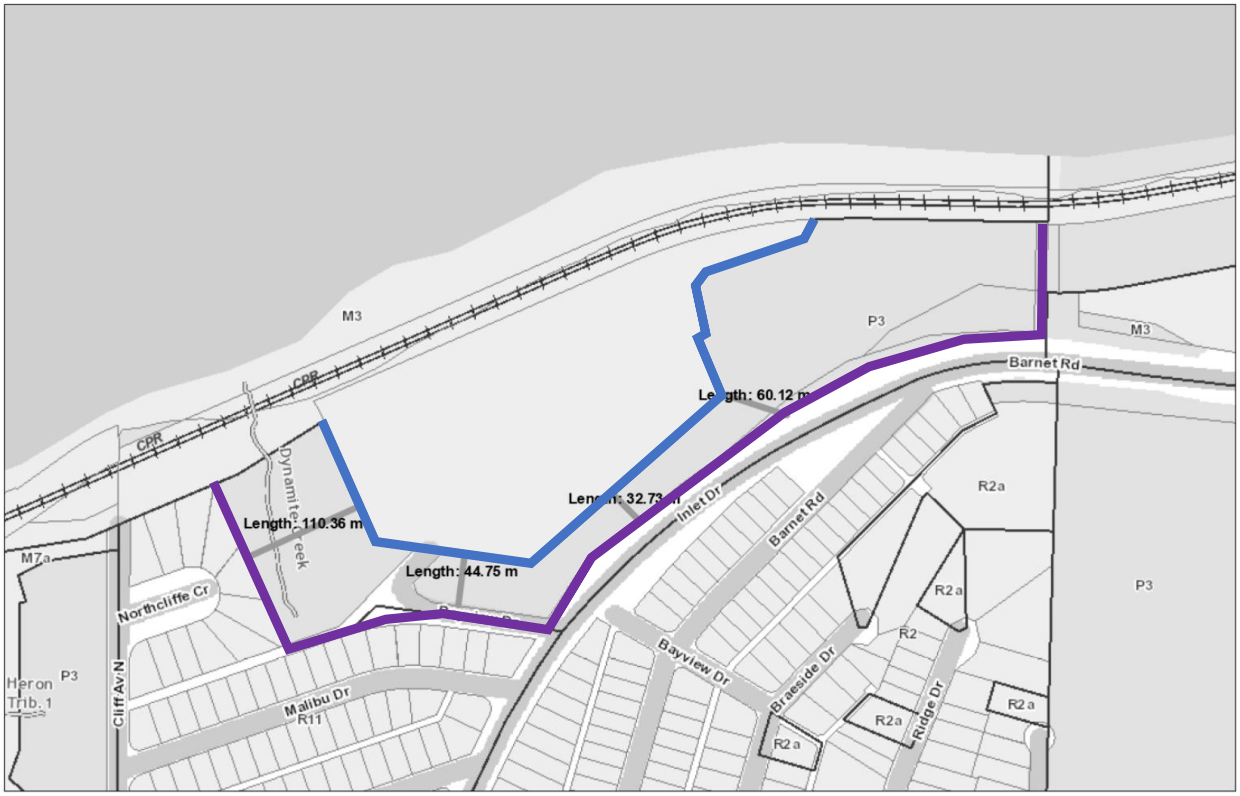


Figure 25: Zoning adjacent to the WMT Facility and distances to residential.

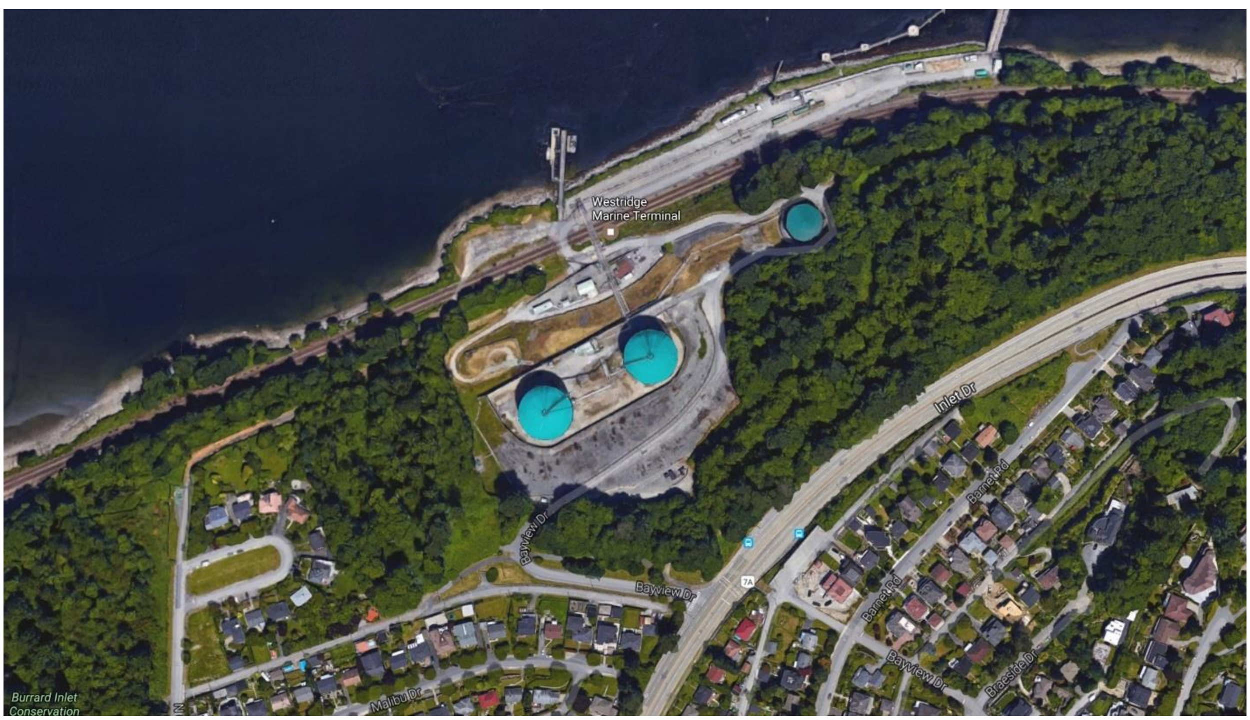


Figure 26: Aerial of the WMT Facility showing the adjacent parkland.

The following section of this report details the methodologies proposed for establishing the risk associated with the consequences outlined in the sections above.

5.0 ANALYSIS METHODOLOGY

As outlined in **Section 4.2** of this report, fires incidents that have occurred at facilities and pipelines have ranged in size from relatively small to significantly large. The purpose of the following sections of this report is to detail the methodology used to characterize the credible fires/deflagrations in terms of phenomena of interest, characterization of the exposing source, and radiant heat transfer model.

5.1 Phenomena of Interest

The principal means by which fires can impact persons and adjacent structures or facilities is by radiative heat transfer, products of combustion or deflagration pressure wave. Therefore, the analysis and associated discussion in this report is related to these phenomena, as well as quantification of the release of crude oil from the WMT Facility process.

5.2 Quantification of Crude Oil Release

As noted in **Section 3.2.1**, crude oil is classified by the 2015 NFCC as a flammable liquid. Light components of crude oil produce a flammable vapour at ambient conditions while heavy component remain in a liquid state. Therefore, a release from a pipe is expected to pool and the light ends evaporate in proximity to the release. The size of the resulting pool and extent of vapour development can be used to quantify the relative impact of a pool fire or vapour cloud deflagration. The release can be characterized by calculating the spill rate, liquid pool distribution and pool evaporation.

Upon release, it is anticipated that the light components of the crude oil will evaporate and may ignite. Early ignition of the vapour is expected to result in a pool fire that will result in the additional heating and evaporation (pyrolyzation) of heavier components of the crude oil supporting continuation of the pool fire until the spilled crude oil is depleted. Later ignition of the vapour may result in a deflagration, depending on the extent of delay, degree of evaporation, local topography and wind conditions. It is expected that a pool fire will follow a deflagration and as noted above, and will continue to burn until the spilled crude oil is depleted. These concepts outlined above are detailed in the following sections.

5.2.1 Spill Rate

The spill rate depends on the type of release, and can be characterized as a function of breach size, liquid density and release pressure and can be characterized as follows [20]:

$$\dot{m} = CA\sqrt{2\rho(P_1 - P_a + \rho g h)}$$

Where:
$\dot{m}$ = Spill mass flow rate (kg/s)
C = Discharge coefficient (0.6)
A = Orifice opening area (m^2)
ρ = Liquid density (kg/m^3)
P_1 = Vessel pressure (kPa)
P_a = Ambient pressure (kPa)
g = Acceleration due to gravity (9.81 m/s^2)
h = Height of vessel pressure above orifice (m)

5.2.2 Liquid Pool Area

The size of the liquid pool depends on the spill rate, ground surface material and geometry and whether any containment is provided. The liquid pool growth can be expressed as follows [20]:

$$A = \min\left(\frac{V_{Spill}}{h_{min}}, A_c\right)$$

$$h_{min} = \max\left(\sqrt{\frac{2\sigma(1-\cos\theta)}{g\rho}}, \varepsilon\right)$$

Where:
- A = Pool area (m^2)
- V_{Spill} = Spill volume (m^3)
- h_{min} = Minimum pool thickness (m)
- A_c = Containment area (m^2)
- σ = Surface tension at air/liquid interface (N/m)
- θ = Contact angle of liquid at the substrate
- g = Acceleration due to gravity (9.81 m/s^2)
- ρ = Liquid density (kg/m^3)
- ε = Roughness of the substrate

5.2.3 Pool Evaporation

Evaporation can be calculated as a function of the liquid temperature and time as follows [16]:

$$\%Ev = (-0.16 + 0.013 \cdot T)\sqrt{t}$$

Where:
- $\%Ev$ = Percentage evaporated (by mass)
- T = Temperature (15 °C)
- t = Time (min)

The constants in the equation above are empirically correlated relative to 15 °C. The total mass of crude oil evaporated can be calculated as a function of the total mass of the released material. This is a conservative estimate assuming that all of the vapour evaporated from the crude oil pool will be within the flammable limit; however, the actual volume within the flammable limit is expected to be lower.

5.3 Quantification of Explosive Pressure - Unobstructed

Once the evaporation rate from a crude oil spill is determined as outlined in **Section 5.2.3** of this report, the probability of a deflagration can be estimated based on the propensity for the evolution of flammable vapours. As outlined in **Section 4.3.4** of this report, due to the topography of the WMT Facility and surrounding area, traditional Gaussian plume analysis is not appropriate, given the non-flat ground, surface roughness and proximal obstacles. In addition, recent studies have shown that some Canadian crude oils are not air boundary-layer regulated [16]. This means that wind has limited impact on the evaporation of crude oil.

In the case of the WMT Facility and the considerations related to local topography and wind conditions (discussed in **Section 4.3.4**), the development of a flammable vapour cloud is likely to be localized to the area of release and since the vapour mass is dominated by evaporation, it is reasonable to assume a flammable vapour cloud localized to the area of the spill. The flammable volume of the vapour cloud can be estimated from an analysis of the evaporation rate of crude oil over time and the spill area.

Once the flammable volume is known, it can be used to calculate the energy of the source as follows [17]:

$$E = \sum_{i=1}^{n} \frac{m_n \cdot H_{c,n}}{MW_n}$$

Where: E = Energy of the source (MJ)
n = Number of light end components
i = Each light end component
m = Mass of vapour (kg)
H_c = Heat of combustion (MJ/mol)
MW = Molecular weight (kg/mol)

Calculation of the radius as follows [17]:

$$r_0 = \left(\frac{3E}{2\pi E_v}\right)^{1/3}$$

Where: r_0 = radius for the blast source (m)
E_v = Average hydrocarbon energy at stoichiometric concentration (3.5 MJ/m^3)

Calculation of dimensionless peak side-on overpressure as follows [17]:

$$P_s' = \frac{P_s}{p_a}$$

Where: P_s' = Dimensionless peak side-on overpressure
P_s = Overpressure (kPa)
p_a = Ambient pressure (kPa)

Determine the scaled radius (r’) based on the diagram included as **Figure 27**.

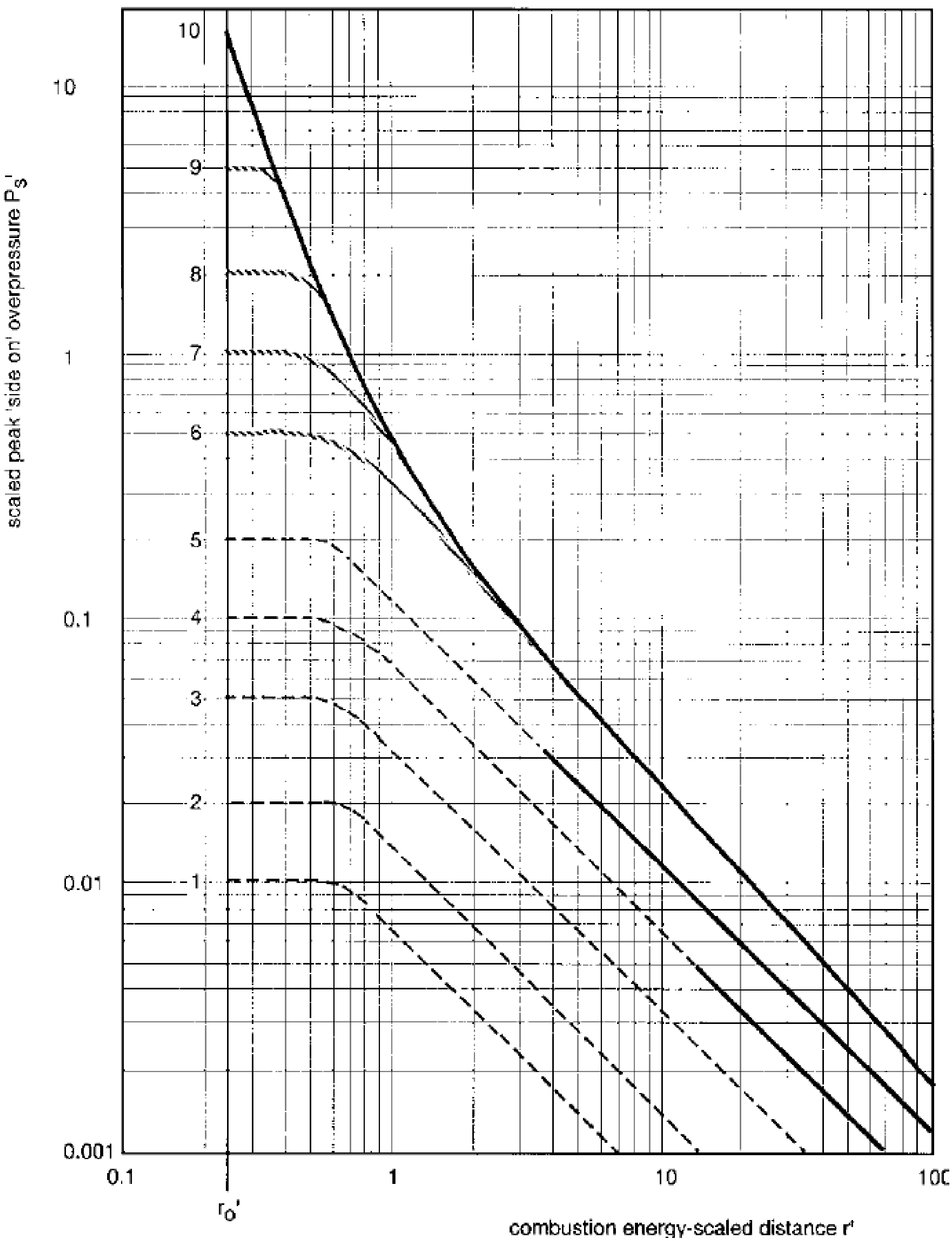


Figure 27: TNO multienergy model for vapor cloud explosions [**17**].

Calculate the radius at which the overpressure is attained as follows [17]:

$$r = r' \left(\frac{E}{p_a}\right)^{1/3}$$

The radius at which the overpressure is attained can be used to establish exposure.

5.4 Quantification of Radiative Heat Transfer

Radiant heat transfer is expressed as a function of the source emissive energy, attenuating factors, and the geometrical relationship between the source and target(s). The methodology outlined in the following sections of this report quantify the radiant heat from pool fire events.

5.4.1 Radiative Heat Flux Equation

The radiant heat from a pool fire can be expressed in terms of the emissive energy, which is the emissive power at the flame surface, and view factor. The expression for radiant heat is as follows [21]:

$$\dot{q}" = \phi_{total} \, E_f$$

Where: $\dot{q}"$ = Thermal radiation flux (kW/m^2)
ϕ_{total} = View (configuration) factor
E_f = Emissive power of the flame at the flame surface (kW/m^2)

Emissivity (ε) and transmissivity (β) are also factors that influence total radiated heat. However, they have been discounted from this analysis as their impact is considered to be relatively minimal at close distances. This is a conservative assumption, resulting in predicted radiant heat at a distance that will be higher than actual values.

5.4.2 View Factor (ϕ_{total})

The view factor is the geometrical relationship between the source (fire) and target (person, building) and considers the size, shape, distance between, and relative angle of incidence of the source and the target. Where the target is considered a point, its size and shape is unimportant. This geometrical relationship is called the view factor, and is defined as the proportion of radiant heat from the source that reaches the target. The view factor is illustrated as follows:

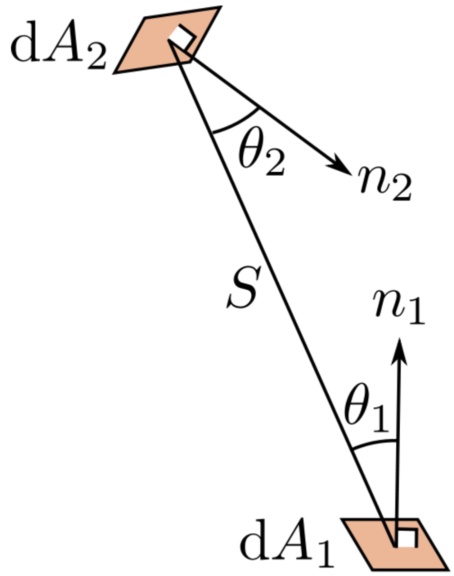


Figure 28: Illustration of view factor.

The relationship for determining the view factor is expressed as follows:

$$d\phi_{d1-d2} = \frac{\cos\theta_1 \ \cos\theta_2}{\pi \, S_{1-2}^2} dA_2$$

$$\phi_{d1-d2} = \int_{A_1} \left(\int_{A_2} \frac{\cos\theta_1 \ \cos\theta_2}{\pi \, S_{1-2}^2} dA_2 \right) dA_1$$

Where: ϕ = View (configuration) factor
θ = Angle between plane normal and line of sight to other plane
S = Distance between planes (m)
dA = Differential area element (m^2)

The shape of the source determines the solution to the equation above. The shape of a pool fire depends on whether containment is provided and the shape of the containment. Where containment isn't provided, the shape of the luminous portion of flame can be established as cylindrical, as shown in **Figure 29**.

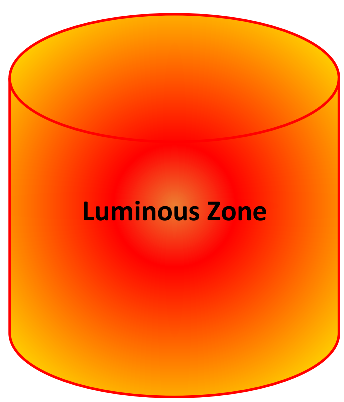


Figure 29: Cylindrical source - pool.

Wind can have an impact on the shape of the flame, and can be represented by a tilted cylinder. The wind conditions are established from the wind rose for the WMT Facility site included in **Figure 19**, **Section 2.4**, and are summarized in **Table 7**. These frequencies are used to establish the impact of radiant heat on adjacent areas relative to a tilted flame. The wind speeds assumed in the analysis are the peak average speeds for each direction, which in reality will not be constant. Therefore, the assumption for purposes of the analysis in this report that these wind speeds are at their peak and constant is conservative.

Table 7: Wind directions, speeds and frequencies.

Wind Direction	Peak Average Wind Speed (m/s)	Frequency
Calm	0	0.0872
N	0	0.0000
NNE	0	0.0000
NE	6	0.0250
ENE	6	0.1380
E	6	0.1150
ESE	8	0.1430
SE	6	0.0700
SSE	8	0.0700
S	8	0.0600
SSW	6	0.0450
SW	6	0.0700
WSW	6	0.0500
W	8	0.1060
WNW	6	0.0210
NW	0	0.000
NNW	0	0.000

The wind tilted geometry produces conservative view factor values as a result of the oversimplified fire shape. Actual fire shape, which it is much more difficult to predict the view factor for, would produce a lower view factor value. The result of conservative view factors is conservative target values.

The view factor calculations, including modifications as a result of wind, are included in **Appendix B** to this report.

5.4.3 Large Pool Fire Concept

Quantification of radiative heat from hydrocarbon pool fires is a function of the type of fuel burning, the area of the fuel surface, and the location of the fire relative to persons and adjacent structures/facilities.

Large pool fires emit heat, smoke and other combustion products. The heat emitted is a function of visible luminous flame. Correlations exist for estimating luminous flame height as a function of the width of the fire base. However, these correlations are typically for smaller fires that produce limited smoke. As fires increase in size, combustion becomes increasingly inefficient, producing more smoke. This condition is augmented by hydrocarbon fuel that has a high heat of combustion and greater sooting potential than cellulosic fueled fires. The result is a fire with much of the luminous zone, which is the source of most of the radiant heat, obscured by smoke.

These concepts are illustrated below for a relatively small pool fire in **Figure 30(a)** versus a larger hydrocarbon pool fire in **Figure 30(b)**.

(a) **(b)**

Figure 30: (a) relatively small pool fire, **(b)** larger hydrocarbon pool fire.

The magnitude of thermal radiation and separation distances has been quantified for large pool fires by McGrattan, et al [22] in a report based on a literature review of published data and theory of heat transfer. This methodology is used to define the radiant heat transfer for larger hydrocarbon pool fires with respect to smoke obscuration as outlined in the following sections of this report.

5.4.4 Flame Height

The emissive power of the flame surface is determined as a function of the pool fire shape, which can be estimated as a vertical or tilted cylinder representing the luminous flame zone, as noted in **Section 5.4.3**. This requires determination of fire diameter and luminous zone height. A correlation to establish mean fire height in absence of wind is provided as follows [21]:

$$\frac{H}{D} = 42\left(\frac{\dot{m}''_\infty}{\rho_a\sqrt{gD}}\right)^{0.61}$$

Where:	H	=	Fire height (m)
	D	=	Pool diameter (m)
	$\dot{m}''_\infty$	=	Mass burning rate per unit pool area (kg/m^2·s)
	ρ_a	=	Ambient air density (1.225 kg/m^3)
	g	=	Gravitational acceleration (9.81 m/s^2)

Irregular shaped pools have an effective diameter calculated as follows:

$$D = \left(\frac{4 \cdot A_p}{\pi}\right)^{1/2}$$

Where: D = Effective pool diameter (m)
A_p = Surface area of the pool (m^2)

In the presence of wind, the flame height is as follows [21]:

$$\frac{H}{D} = 55\left(\frac{\dot{m}''_\infty}{\rho_a\sqrt{gD}}\right)^{0.67}(u^*)^{-0.21}$$

Where u* is the nondimensional wind velocity given by the following [21]:

$$u^* = \frac{u_w}{\left(g\dot{m}''_\infty\frac{D}{\rho_a}\right)^{1/3}}$$

Where: u_w = Wind speed at 10 meters (m/s)
ρ_a = Ambient air density (kg/m^3)

The fire tilt angle due to wind is given as follows:

$$Fr_{10} = \frac{u_w^2}{g \cdot D}$$

$$Re = \frac{u_w \cdot D}{v}$$

$$\theta = \sin^{-1}\left[\frac{\sqrt{4 \cdot c^2 + 1} - 1}{2 \cdot c}\right]$$

$$c = \frac{2}{3} \cdot Fr_{10}^{1/3} \cdot Re^{0.117}$$

Where: Fr_{10} = Froude number for wind velocity at a height of 10 meters
Re = Reynolds number
v = Kinematic velocity of air (m^2/s)
θ = Tilt angle of the flame (degrees)

5.4.5 Emissive Power

The emissive power for luminous spots for flammable liquid fires has been measured at 100 kW/m^2 to 140 kW/m^2 [22], and smoke at 20 kW/m^2. The fire height includes both luminous and smoke covered areas. A correlation by Mudan [21] can be used to establish the emissive power (E) of hydrocarbon fires as a function of pool fire diameter as follows:

$$E = E_{max}e^{-sD} + E_s[1 - e^{-sD}]$$

Where: E_{max} = Equivalent blackbody emissive power (140 kW/m^2)
s = extinction coefficient (0.12 m^{-1})
D = Equivalent pool diameter (m)
E_s = Emissive power of smoke (20 kW/m^2)

This correlation addresses the concept summarized in **Section 5.4.3** of this report that as the fire diameter increases, the combustion process becomes inefficient and the flames become shielded by smoke. At a certain point the fire has the emissive characteristics of smoke (i.e., 20 kW/m^2). This correlation predicts emissive power averaged over the height of the fire.

5.5 Quantification of Products of Combustion

The potential fires/deflagrations to be addressed in this report are all outside of buildings/enclosures. Therefore, products of combustion that may immediately impact tenability are expected to have diffused at-length scales corresponding to the locations of people not directly adjacent to the incident (i.e., beyond the WMT Facility boundaries). This is supported by research of in-situ burning of crude oil pools conducted by Fingas [27] and Ross [28], which showed that emissions from the burning pools are below "health concern" levels beyond 60 to 200 m from the fire. At closer distances emission exposure is limited to within or near the plume which is primarily buoyancy driven. Therefore, the products of combustion from potential pool fires are not expected to be of sufficient concentration to adversely impact persons required to evacuate away from an immediate incident location to a point of safety.

The nature of these incidents will provide obvious visual identifiers in the form of flame plumes and smoke, allowing workers and other persons to evacuate to safety areas and minimize the probability of exposure for an extended duration outside the immediate threat area.

6.0 EVALUATION CRITERIA

The evaluation criteria are established from the objective of the risk analysis, which in this case is the risk of injury to the public as a result of exposure to the effects of undesirable fire or deflagration events that may occur at the WMT Facility. Establishment of the evaluation criteria involves identification and quantification of the key physical phenomena of the undesirable events that has an impact on the public. With respect to fire and deflagrations, these criteria include heat effects (radiation, convection) and pressure waves from deflagrations.

The evaluation criteria included consideration of the key physical phenomena associated with the impact to persons (i.e., radiated heat, pressure wave). The impact of the physical phenomena also relates to the receiver (person). Receiver characteristics significant to the analysis contained in this document are:

- receiver configuration, and
- receiver response.

Receiver configuration defines the angle of incidence and distance of the target surface to the source. Target response defines a set of values that represent thresholds of importance to the phenomena of interest. These thresholds are values at which the incident heat flux is expected to cause certain undesirable conditions such as ignition or pain over certain periods of time. The target configuration and response are discussed in more detail in the following sections.

6.1 Location of Persons

The objective of the applicable regulatory requirements, outlined in **Section 3.0**, is to limit the probability of harm to persons and fire spread to adjacent buildings and facilities. The purpose of the analysis outlined in this report is to assess the impact of fire/deflagrations on persons, which requires an understanding of their locations relative to fires. This further requires consideration of who may be in proximity to the WMT Facility at the time of an incident. The following summarizes the assumptions relative to potential locations of persons during an incident:

- **Public:** The WMT Facility will be fenced with no public access. Therefore, it is assumed that public may be in proximity to the WMT property at the time of a fire, but not within the property boundary.
- **Staff:** The WMT Facility will be occupied by 3 to 16 personnel at any one time, depending on the time of day. The staff will access different parts of the facility to perform operations activities, and conduct maintenance and repair work, but will primarily be located in the Control Centre Building, located at the approximate centre of the foreshore area as shown in outlined red in **Figure 5** and illustrated in **Figure 7** of this report.
- **Fire Service:** The WMT Facility has a site access road located north of the site as shown in **Figure 18**, and a secondary site access road to the foreshore area from Cliff Avenue. It is our understanding that during a fire, the responding fire service will assess the best direction and access point to approach a fire and appropriate location to establish suppression/exposure protection operations.

6.2 Heat Effects (Pain and Burns)

There is significant variation of correlations relating radiant heat flux to time to pain or burn. These correlations have been developed over the last 30-40 years by numerous researchers under varying experimental conditions and for different purposes and has been limited to healthy average sub-sections of the population. The SFPE Fire Protection Engineering Handbook provides a summary of the research results of some of the methods as shown in the table and diagram included below [26]:

Table 2-6.18 ***Data on the Effects of Exposure to Radiant Heat***

Reference Source	Heat Flux W/cm²	Time to Effect(s): Erythema (or pain)	Burn	Full Burn	Letter in Figure 2-6.28
Perkins et al.[124]	15	1	2.5	4	
	10	2	4	6	
	5	4	7	>15	
	4	4.5	9	>15	A
	3.5	5	9.5	>15	A
	3	6	10	>15	A
Buettner[119]	2.35	1.6			B
	1.05	5			B
	0.25	40			B
Veghte[115]			Blisters		
	0.42		30		C
Simms and Hinkley[112]		Unbearable pain			
	0.126	600			
	0.252	30 to 60			D
Dinman[125]	0.24	Lower limit for pain after a long period			
	0.82	5			E
	0.48	10			E
Berenson and Robertson[111]	0.34	Limit for blood to carry away heat			
Babrauskas[56]	0.25	Tenability limit			

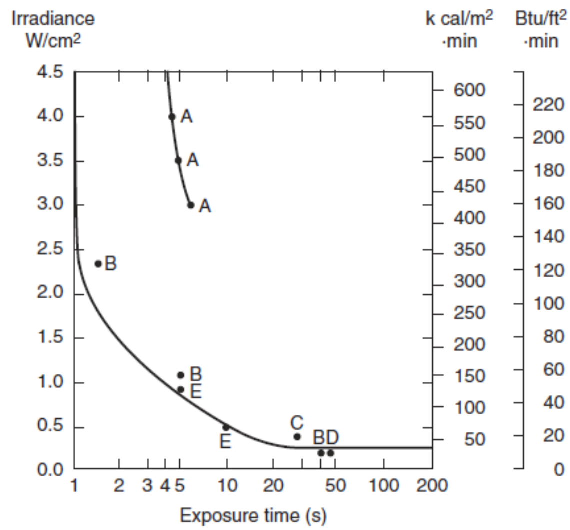


Figure 2-6.28. ***Time to severe skin pain from radiant heat. Adapted from Berenson and Robertson.[111] See text and Table 2-6.18 for discussion of data points A to E.[56,112,115,118,124,125]***

The variation of results complicates practical application for design purposes. A paper by Wieczorek and Dembsey [29] takes a more fundamental approach in considering a variation in skin properties for a diverse population in developing corrective factors to simplify correlations to predict skin response to radiant heat flux. Their results suggest the following:

6.2.1 No Pain Threshold

1.7 kW/m² is the critical heat flux below which no pain is experienced no matter how long the duration of exposure [29]. Note that the heat flux on a sunny summer day is approximately 1 kW/m².

6.2.2 Pain Threshold

The time to experience pain from incident radiant heat fluxes between 1.7 kW/m² and 20 kW/m² can be expressed as follows [29]:

$$t_p = 125\, q^{-1.9}$$

Where: t_p = Time to pain (s)
q = Heat flux (kW/m²)

Given the conservative assumptions associated with rapid growth of a fuel fire, and the potential fire size, it is anticipated the occupants within a hazardous proximity to the fire will be aware and able to react by moving away from the fire. The time to pain is calculated assuming occupants will not begin to move until the fire has reached its peak (i.e., steady burning phase) and 30 seconds is assumed to be sufficient to move away from hazardous conditions. Based on this period of time, the calculated heat flux criteria is 2.1 kW/ m².

6.2.3 Second Degree Burn Threshold

The time to second degree burns from incident radiant heat fluxes between 2 kW/m^2 and 50 kW/m^2 can be expressed as follows [29]:

$$t_{2b} = 260\, q^{-1.56}$$

Where: t_{2b} = Time to second degree burn (s)
q = Heat flux (kW/m^2)

Similar assumptions for the time to pain criteria are made for the time to second degree burn (i.e., 30 seconds). Based on this period of time, the calculated heat flux criteria is 4 kW/m^2.

6.2.4 Firefighting Criteria

The correlations above are relative to bare skin exposure. A different set of criteria have been developed for firefighters considering protective clothing. Similar to skin response models, firefighter tenability also varies as a function of the research conducted. The results of several studies is included below:

Table 8: Abbott. [30]

	Routine	Ordinary	Emergency
Heat Flux (kW/m^2)	up to 1.7	1.7 to 12.5	over 12.5
Time	1 - 5 minutes	10 - 20 minutes	15 – 20 seconds

Table 9: Foster and Roberts. [31]

	Routine	Hazardous	Extreme	Critical
Heat Flux (kW/m^2)	up to 1	1 to 4	4 to 10	over 10
Time	indefinite	5 minutes	75 seconds	0 seconds

Table 10: Department of Fire & Emergency Services – Australia. [32]

	Routine	Hazardous	Extreme
Heat Flux (kW/m^2)	up to 1	1 to 3	4 to 4.5
Time	25 minutes	10 minutes	1 minute

Foster and Abbott both considered an exposure to a heat flux of 5 kW/m^2 as hazardous [31] and it has been shown that at that heat flux, pain is experienced after approximately 5 minutes [33]. This is the criteria used in this analysis.

A summary of the heat flux receiver criteria, based on the previous sections, are summarized in **Table 11** below.

Table 11: Receiver Criteria: Life Safety.

Criteria	Target Value (kW/m^2)
No Pain (Unlimited Time)	1.7
Pain (30 seconds)	2.1
Second Degree Burn (30 seconds)	4
Firefighter Pain (5 minutes)	5

Quantification of the exposure risk is based on the probability of death as a result of exposure and is calculated based on a probit function, expressed as follows [11]:

$$P(Q,t) = 0.5 \cdot \left[1 + erf\left(\frac{Pr - 5}{\sqrt{2}}\right)\right]$$

$$\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

Where: P = Probability of death
P_r = Probit function
t = Time (s)

The probit function for radiant heat exposure is expressed as follows [11]:

$$Pr = -36.38 + 2.56 \cdot \ln\left(t \cdot Q^{4/3}\right)$$

Where: Q = Heat flux (W/m^2)
t = Time (s)

The probability of death as a result of pressure effects us a function of the peak pressure from the deflagration and can be expressed as shown in **Table 12**.

Table 12: Probability of death for radiant heat [11].

Heat Flux (kW/m^2)	P_E
Within Flame Envelope	1
≥ 35	1
< 35	$P(Q,t)$

6.3 Pressure Effects

The probability of death as a result of pressure effects us a function of the peak pressure from the deflagration and can be expressed as shown in **Table 13**.

Table 13: Probability of death for pressure [11].

Peak Pressure	P_E
> 0.3 bar_g (> 30 kPa)	1
0 to 0.3 bar_g (10 to 30 kPa)	0

6.4 Individual Annual Risk

The results of the risk analysis of the WMT Facility will be presented as individual annual risk values. The individual annual risk, which is the risk of a person dying as a result of an incident on a yearly basis, will be presented as probability of death, calculated as follows [11]:

$$R_I = \sum_{i=i}^{n} \sum_{j=1}^{m} F_i \cdot P_j$$

Where:

Where:	R_I	=	Individual Risk
	F	=	Frequency of release (LOC)
	P	=	Probability of each ignition event
	m	=	Total number of cumulative events from each LOC sequence
	n	=	Total number of independent LOC sequences
	i	=	A number representing each LOC sequence
	j	=	A number representing each sub-event for a LOC sequence

The individual annual risk is assessed at the WMT Facility boundaries, as noted by the MIACC criteria outlined in **Section 4.5** of this report. Since the individual annual risk is spatially dependant, event location will be selected based on proximity to the site boundary.

7.0 EVALUATION

The following sections of this report detail the application of the analysis methodologies outlined in **Section 5.0** of this report to the sequence of events outlined in **Section 4.0** of this report, based on the evaluation criteria outlined in **Section 6.0** of this report.

7.1 Approach to Cumulative Individual Annual Risk

As outlined in **Section 6.4** of this report, the total individual annual risk is the risk for each LOC event and ignition sub-event. In addition, the individual annual risk is spatial dependent as a function of the proximity of each event and associated impact of the consequences at the WMT Facility site boundaries and beyond.

The two LOC events considered for this analysis are rupture/spill of the pipeline and loading arms respectively. The total individual annual risk is based on the cumulative individual annual risks of each of these LOC events. The frequency of a pipeline rupture/spill has been determined in **Section 4.4.1.1** of this report is based on the entire pipeline on the WMT Facility site. Similarly, the frequency of a loading arm rupture/spill is based on operation of all the loading arms. Therefore, the contribution to the total annual individual risk for each LOC event can be based on the worst-case proximity to the WMT Facility site boundary. The worst-case proximity for both LOC events is the combination of the worst-case proximity for each event relative to each-other and the site boundary.

With the exception of the north site boundary, where to magnitude of the risk is considered to be inconsequential due to the adjacency to the inlet, the main site boundaries are located on the east, south and west side of the WMT Facility site, as shown in **Figure 25**. Therefore, the total annual individual risk at the WMT Facility will be based on each boundary analysis independently.

7.2 Pipeline Rupture/Spill

The following sections characterize the LOC events for pipeline rupture/spill.

7.2.1 Spill Rate and Volume

As outlined in **Section 4.4.1.1** of this report, two LOC events are considered including full rupture and an 80 mm diameter hole. The spill rates associated with these LOC events are calculated in the following sections of this report based on the methodology outlined in **Section 5.2.1**.

7.2.1.1 Full Rupture

A full rupture of one of the pipeline delivery lines is assumed to result in release crude oil based on the pipe diameter and system pressure. As noted in **Section 2.2** of this report, the pipeline flow rate is 4,635 m^3/hour. Based on this information, the mass flow rate of the crude oil from a rupture of the pipeline is:

$$\dot{m} = \left(4{,}635\ {}^{m^3}\!/_{h}\right)\left(940\ {}^{kg}\!/_{m^3}\right)$$

$$\dot{m} = 1{,}210\ {}^{kg}\!/_{s}$$

$$\dot{V} = 1.29\ {}^{m^3}\!/_{s}$$

Following the LOC timeline outlined in **Section 4.3.2** of this report, the total expected volume as a result of a hole and spill will be as follows:

$$V = \left(1.29\ {m^3}/{s}\right)(180\ s)$$
$$V = 232\ m^3$$

7.2.1.2 Spill

The highest expected operating pressure for the WMT Facility piping (upstream of the last valve prior to the loading arms) [2] is anticipated to be 4,960 kPag. The mass flow rate based on an 80 mm hole is as follows:

$$\dot{m} = (0.6)[\pi(0.5 \cdot 0.08\ m)^2]\sqrt{2\left(940\ {kg}/{m^3}\right)(4{,}960\ kPa)}$$
$$\dot{m} = 291\ {kg}/{s}$$
$$\dot{V} = 0.31\ {m^3}/{s}$$

Following the LOC timeline outlined in **Section 4.3.2** of this report, the total expected volume as a result of a hole and spill will be as follows:

$$V = \dot{V} \cdot t$$
$$V = \left(0.31\ {m^3}/{s}\right)(240\ s)$$
$$V = 74\ m^3$$

7.2.2 Liquid Pool Area and Shape

As outlined in **Section 5.2.2** of this report, the size of the liquid pool depends on the spill rate, ground surface material and geometry and whether any containment is provided. These factors vary as a function of the location of the rupture. A rupture or spill along the south section of the pipeline and valve manifold area, highlighted green in **Figure 31**, is likely to spread to the northeast as a result of the retaining wall and ground slope toward the northeast, as shown in **Figure 32** and **Figure 33**.

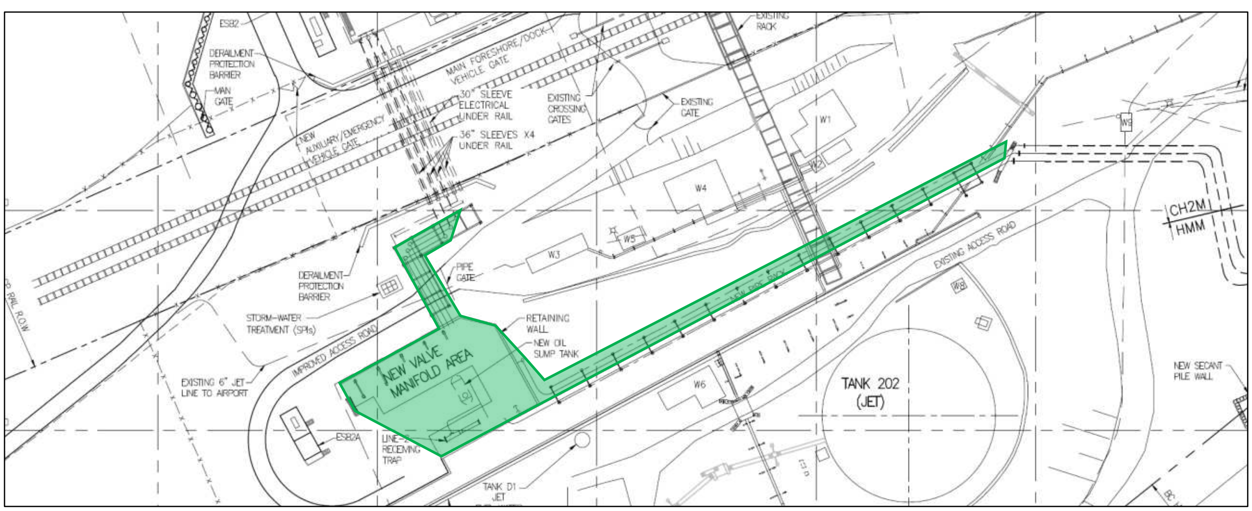


Figure 31: South section of pipeline [5].

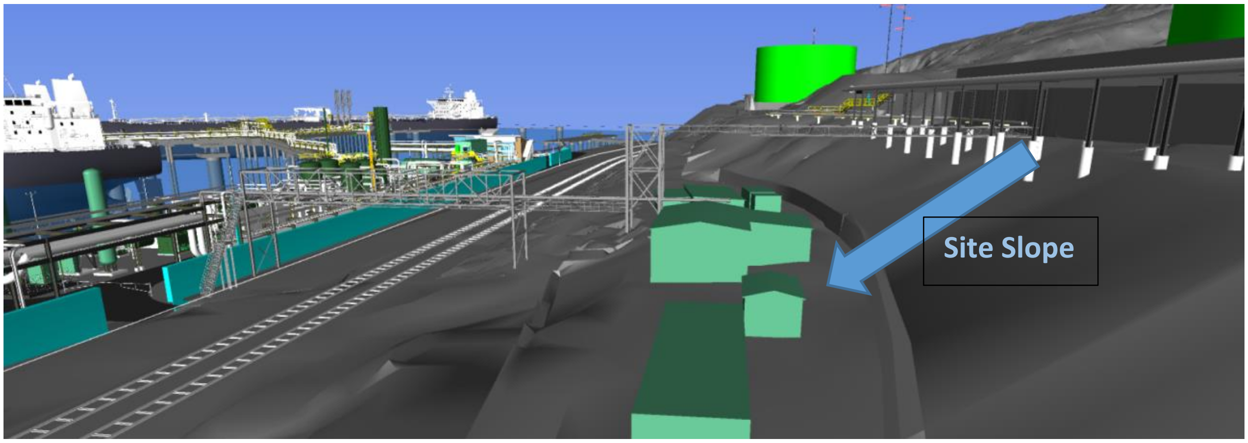


Figure 32: Looking east at the site slope north of the south section of pipeline [8].

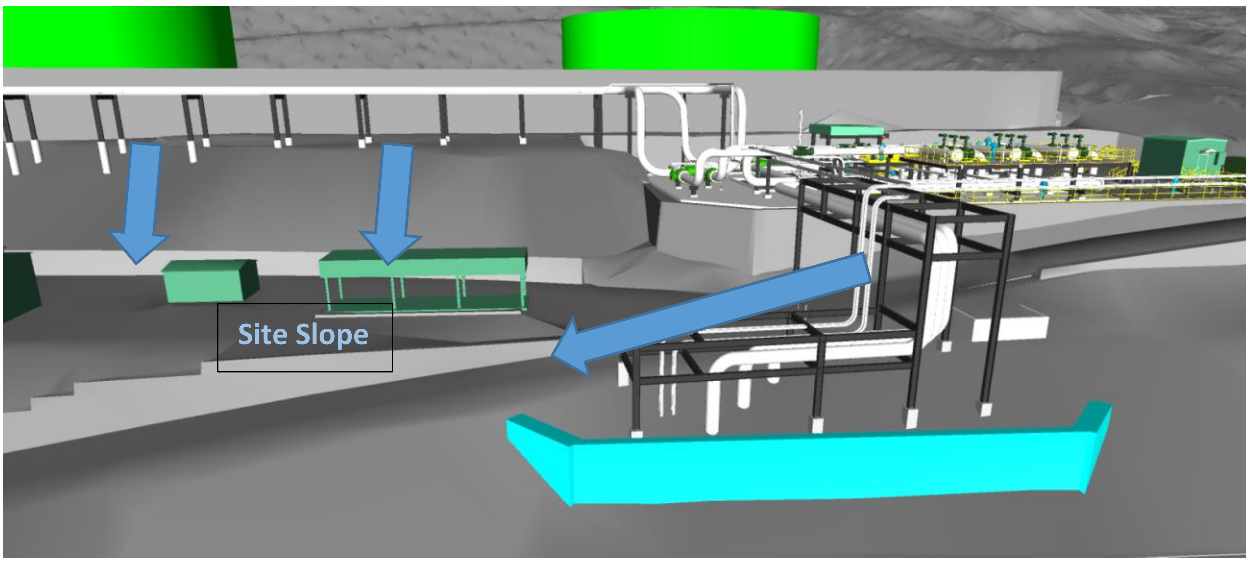


Figure 33: Looking south at the site slope north of the south section of pipeline and east of the valve manifold area [8].

Following a rupture or spill of the pipeline along this section, the site slope will facilitate flow and pooling of the crude oil toward the buildings and railroad tracks north of the pipeline.

A rupture or spill along the north foreshore section of the pipeline, in the metering area and adjacent to the vapour recovery area, is expected to be mostly contained by the derailment protection barrier and bulkhead wall. The derailment protection barrier and bulkhead wall are shown in blue in **Figure 34**. A liquid pool at this location is expected to have a shape that can be characterized by the partial containment boundaries.

A rupture or spill along the section of pipeline on the dock and berths is anticipated to spill to the surface of the water below. A liquid pool on the surface of the water can be characterized by as a circular pool by establishing an effective diameter as outlined in **Section 5.4.4** of this report.

The area of the pool is a function of the volume of oil and thickness of the spill. The thickness of the pool has been estimated to be from 0.005 to 1.0 m [18,20] for the land-based spills based on the ground substrate roughness (i.e., concrete, soil, absorption, topography etc.) and assumption that additional containment may be provided by the site landscape and barriers. The ground of the WMT Facility will be a combination of gravel, asphalt, soil, vegetation and concrete; and several locations where liquid can pool and be contained by barriers. Therefore, the pool thickness is conservatively estimated to be towards the lower end of the range at approximately 0.10 m.

A spill on water is anticipated to have a thickness on the lower end of the noted range (i.e., 0.01 m). This estimate is based on a combination of the momentum of the spilled liquid to penetrate the water surface as a function of the height of the surface of the water from the dock and the potential for emulsification of the oil with water.

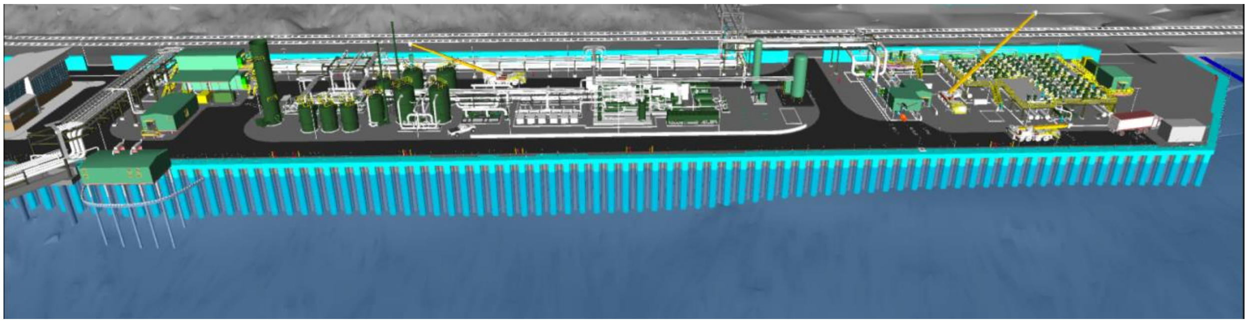


Figure 34: Looking south at the metering and vapour recovery areas [8].

The liquid pool areas for a pipeline rupture and spill are detailed in the following sections of this report for the locations noted above.

7.2.2.1 Full Rupture

The volume for a full rupture, calculated in **Section 7.2.1.1** of this report, is 232 m^3. This spill volume at a depth of 0.10 m has a total area of 2,318 m^2 for a land-based spill and at a depth of 0.01 m has a total area of 23,175 m^2 for a spill on water.

As outlined earlier, the shape of the spill area depends on whether the spill is contained or not. A spill from the land-based section of the pipeline is expected to be partly contained by the surrounding landscape/barriers and can be characterized as a circular pool by establishing an effective diameter as outlined in **Section 5.4.4** of this report, and calculated as follows:

$$D = \left[\frac{4 \cdot (2{,}318\ m^2)}{\pi}\right]^{1/2}$$

$$D = 54\ m$$

An uncontained spill on water can be characterized using the same method, with an effective diameter as follows:

$$D = \left[\frac{4 \cdot (23{,}175\ m^2)}{\pi}\right]^{1/2}$$

$$D = 172\ m$$

7.2.2.2 Spill

The volume for a spill, calculated in **Section 7.2.1.2** of this report, is 74 m^3. This spill volume at a depth of 0.10 m has a total area of 743 m^2 for a land-based spill and at a depth of 0.01 m has a total area of 7,430 m^2.

Similar to a rupture, the partially contained spill area is calculated as follows for a land-based spill and water-based spill respectively:

Land-based spill:

$$D = \left[\frac{4 \cdot (743\ m^2)}{\pi}\right]^{1/2}$$

$$D = 31\ m$$

Water-based spill:

$$D = \left[\frac{4 \cdot (7{,}430\ m^2)}{\pi}\right]^{1/2}$$

$$D = 97\ m$$

7.3 Loading Arm Rupture/Spill

The following sections characterize the LOC events for a loading arm rupture/spill.

7.3.1 Spill Rate and Volume

As outlined in **Section 4.4.2.1** of this report, two LOC events are considered including full rupture and a 50 mm diameter hole. Each loading platform will be provided with a storm water sump with capacities equal to 30 seconds of full flow from one loading arm in case of a leak [2].

The spill rates associated with these LOC events are calculated in the following sections of this report based on the methodology outlined in **Section 5.2.1**, and do not consider a reduction in the spill quantity in consideration of the capacity of the storm water sumps provided at each loading platform. This results in a conservative estimate of the spill volume as a result of a failure of the loading arms.

7.3.1.1 Full Rupture

A full rupture of one of the delivery arms is assumed to result in release crude oil based on the pipe diameter and system pressure. Each of the three berths will be equipped with three 406 mm diameter (NPS 16) loading arms to deliver a maximum crude oil flow rate of 4,140 m^3/hr to each vessel. The peak flow rate per loading arm will be 1,545 m^3/h [34]. Based on this information, the mass flow rate of the crude oil from a rupture of one of the loading arms is:

$$\dot{m} = \left(1{,}545\ {}^{m^3}\!/_{h}\right)\left(940\ {}^{kg}\!/_{m^3}\right)$$

$$\dot{m} = 403\ {}^{kg}\!/_{s}$$

$$\dot{V} = 0.43\ {}^{m^3}\!/_{s}$$

Following the LOC timeline outlined in **Section 4.3.2** of this report, the total expected volume as a result of a hole and spill will be as follows:

$$V = \left(0.43\ {}^{m^3}\!/_{s}\right)(240\ s)$$

$$V = 103\ m^3$$

7.3.1.2 Spill

The highest expected operating pressure for the WMT Facility piping (upstream of the last valve prior to the loading arms) [2] is anticipated to be 4,960 kPag. This pressure is assumed to also apply to the loading arms. Therefore, the mass flow rate based from a 50 mm hole is calculated as follows:

$$\dot{m} = (0.6)[\pi(0.5 \cdot 0.05\ m)^2]\sqrt{2\left(940\ {}^{kg}/_{m^3}\right)(4{,}960\ kPa)}$$

$$\dot{m} = 113.7\ {}^{kg}/_{s}$$

$$\dot{V} = 0.1210\ {}^{m^3}/_{s}$$

Following the LOC timeline outlined in **Section 4.3.2** of this report, the total expected volume as a result of a hole and spill will be as follows:

$$V = \left(0.1210\ {}^{m^3}/_{s}\right)(240\ s)$$

$$V = 29\ m^3$$

7.3.2 Liquid Pool Area

It is assumed that the majority of crude oil resulting from a rupture or spill from a loading arm will spread to the water level. Therefore, the pool area on water is calculated consistent with a spill from the pipeline as noted in **Section 7.2.2**. This approach assumes an oil thickness of approximately 0.01 m, and radial spread of the oil consistent with characterization as a circular pool.

7.3.2.1 Rupture

The rupture of a loading arm is estimated to result in a total volume of 103 m^3 spilling to the water surface below. The boom that will be deployed around each vessel during loading is intended to contain up to 1,500 m^3 of oil [9]; therefore, a spill of 103 m^3 is expected to be retained within the boom area, and at a depth of 0.01 m will have a total area of 10,300 m^2.

The effective diameter of the spill, based on the methodology outlined in **Section 5.4.4**, is calculated as follows:

$$D = \left[\frac{4 \cdot (10{,}300\ m^2)}{\pi}\right]^{1/2}$$

$$D = 114\ m$$

7.3.2.2 Spill

The volume for a spill from a loading arm is 9.24 m^3. This spill volume at a depth of 0.10 m has a total area of 743 m^2 for a land-based spill and at a depth of 0.01 m has a total area of 924 m^2.

Similar to a rupture, the partially contained spill area is calculated as follows:

$$D = \left[\frac{4 \cdot (924\ m^2)}{\pi}\right]^{1/2}$$

$$D = 61\ m$$

7.4 Pool Evaporation

Pool evaporation is summarized in **Section 5.2.3** of this report, and is a function of temperature and time. Given the pool sizes determined in the previous sections, it is assumed that if ignition is going to occur it will be within the first 5 minutes from the occurrence of the spill. This assumption is supported by data outlined in Table 4.A.1 of the “Purple Book”, which indicates a relatively high probability of ignition within the first minute for various sources. The percent by mass of crude oil evaporated within the first minute following a spill is as follows:

$$\%Ev(Alberta\ Sweet\ Mixed\ Blend) = [3.24 + 0.054 \cdot (15\ °C)] \cdot \ln(5\ min)$$

$$\%Ev = 6.52$$

Crude oil is a complex hydrocarbon mixture with light to heavy ends. Early evaporation involves the light ends of the liquid, which can contain butane, pentane, hexane, heptane, octane, nonane, decane, etc. A summary of the percentage by volume (%vol). of the light ends for several crude oil samples are summarized in **Table 14** below.

Table 14: Light end component percentages by vol. of liquid [9].

Component	Access Western Blend	Cold Lake	Statoil Cheecham Blend	Surmount Heavy Blend	Albian Heavy Synthetic	Average
Butanes	0.64 ± 0.18	0.91 ± 0.27	0.94 ± 0.28	0.73 ± 0.27	1.16 ± 0.46	0.88 ± 0.29
Pentanes	8.52 ± 1.34	6.19 ± 1.10	5.71 ± 1.54	3.75 ± 2.65	5.82 ± 1.09	6.00 ± 1.54
Hexanes	6.86 ± 0.55	5.46 ± 0.50	5.36 ± 0.52	3.67 ± 1.91	5.48 ± 0.48	5.37 ± 0.79
Heptanes	4.32 ± 0.65	3.51 ± 0.50	3.61 ± 0.61	2.64 ± 0.89	3.62 ± 0.60	3.54 ± 0.65
Octanes	2.40 ± 0.58	2.29 ± 0.55	2.83 ± 1.41	2.33 ± 0.51	2.74 ± 0.86	2.52 ± 0.78
Nonanes	1.16 ± 0.33	1.42 ± 0.42	1.94 ± 1.24	1.85 ± 0.66	1.78 ± 0.69	1.63 ± 0.67
Decanes	0.53 ± 0.15	0.70 ± 0.22	0.98 ± 0.63	0.99 ± 0.39	0.86 ± 0.32	0.81 ± 0.34

Table 15: Properties of light end components.

Component	Relative % by vol. of liquid from Table 14*	Relative % by mass of liquid	MW (kg/mol)	Heat of Combustion (MJ/mol)	Density (kg/m^3)
Butanes	5	4	0.05812	2.878	579
Pentanes	29	28	0.07215	3.510	626
Hexanes	24	24	0.08618	4.180	655
Heptanes	16	17	0.10021	4.825	680
Octanes	13	14	0.11423	5.53	703
Nonanes	9	10	0.12820	6.125	718
Decanes	4	5	0.14229	6.779	730

* Assuming upper end of the ± range

Therefore, based on the evaporation of 6.52% of liquid in the first minute from the spill, 1 kg of spilled liquid will have 0.0652 kg of vapour. The energy of the vapour associated with the spill of 1 kg of liquid can be calculated as follows:

$$E = 0.0652 \cdot \left\{ \left[\frac{(0.04)\cdot(2.878)}{(0.05812)}\right] + \left[\frac{(0.28)\cdot(3.510)}{(0.07215)}\right] + \left[\frac{(0.24)\cdot(4.180)}{(0.08618)}\right] + \left[\frac{(0.17)\cdot(4.825)}{(0.10021)}\right] + \left[\frac{(0.14)\cdot(5.530)}{(0.11423)}\right] + \left[\frac{(0.10)\cdot(6.125)}{(0.12820)}\right] + \left[\frac{(0.05)\cdot(6.779)}{(0.14229)}\right] \right\}$$

$$E = (0.0652)\cdot(49.37)$$

$$E = 3.22\ {}^{MJ}/_{kg}$$

7.5 Ignition

Given the extent of spread and area of crude oil pools for the scenarios outlined above, ignition is expected to be relatively direct. As outlined in **Section 4.4.1.2** of this report, the probability of ignition is a function of the release rate and whether ignition is direct or delayed.

The probability of ignition of the crude oil from rupture and spill events is summarized in the following sections of this report.

7.5.1 Pipeline - Full Rupture and Spill, Loading Arm – Full Rupture

The calculated flow rate of crude oil from a pipeline rupture, pipeline spill and loading arm rupture is 1,210 kg/s, 291 kg/s and 403 kg/s respectively. Based on the values in **Table 6** of this report, the probability of ignition is 0.07 for all of these events. As noted in **Section 4.4.1.2** of this report, the probability of ignition is a combination of the direct and delayed ignition, with the direct ignition being 0.001. Therefore, the probability of delayed ignition for these events is 0.069.

7.5.2 Loading Arm - Spill

The calculated flow rate of crude oil from a pipeline spill is 36.2 kg/s. Based on the values in **Table 6** of this report, the probability of ignition is 0.0563. As noted in **Section 4.4.1.2** of this report, the probability of ignition is a combination of the direct and delayed ignition, with the direct ignition being 0.001. Therefore, the probability of delayed ignition for this event is 0.0553.

7.6 Quantification of Impact of Radiated Heat from a Pool Fire

Quantification of the radiant heat impact from a pool fire depends on the location of the fire relative to the exterior boundaries of the WMT Facility and beyond. The rationale for the locations of the pool fires resulting from a rupture or spill from a pipeline is outlined in **Section 7.2.2** of this report. This rationale was used in conjunction with location of the LOC events within close proximity to the WMT Facility site boundaries. The specific fire locations are shown in **Figure 35**. The selected event locations are summarized in **Table 16**.

Table 16: Fire/deflagration locations for a pipeline LOC event.

Event	Location Description
A1	This location was selected based on its proximity to the west and southwest site boundaries and assumes a LOC at the valve manifold area (**Figure 10**) resulting in pooling of crude oil in this general area and subsequent ignition and fire/deflagration. This area is relatively flat with a gradual slope toward the northeast. A LOC at this location is expected to generally flow in a northeast direction; however, is conservatively assumed to be concentrated to the

Event	Location Description
	valve manifold area. Therefore, the rupture and spill pools are centred at the same location assuming radial spread of the oil outward from the approximate centre of the valve manifold pad.
A2	This location was selected based on its proximity to the west site boundary and assumes a LOC at the west end of the metering area (**Figure 13**) resulting in pooling of crude oil in this general area and subsequent ignition and fire/deflagration. This location is flat; therefore, the rupture and spill pools are centred at the same location assuming radial spread of the oil outward from the approximate west end of the metering area.
A3	This location was selected based on its proximity to the south site boundary and assumes a LOC where the pipeline enters the WMT Facility site, as shown in **Figure 9**. This location has a significant slope toward the north as shown in **Figure 32** and **Figure 33**, which is expected to result in flow of any released oil toward the north. Therefore, the edges of both the rupture and spill pools have been located at the location of the LOC event location.
A4	This location was selected based on its proximity to the southeast site boundary and assumes a LOC at the section of pipeline transitioning from the foreshore to the dock area (**Figure 15**) resulting in pooling of crude oil in this general area and subsequent ignition and fire/deflagration. This location is flat; therefore, the rupture and spill pools are centred at the same location assuming radial spread of the oil outward from the approximate east end of the vapour recovery area.
A5	This location was selected based on its proximity to the southeast site boundary and assumes a LOC from a section of pipeline on the dock, near the foreshore area. A loss at this location is assumed to spread on the water surface toward the north. The spread of the pool in this direction will potentially be limited by the protective boom surrounding the vessels, which is expected to impact the shape of the pool. However, the pool has been conservatively assumed to retain a circular shape, which would result in the highest expected radiant heat to the most proximal site boundary. Therefore, the edges of both the rupture and spill pools have been located at the location of the LOC event location, assuming they both spread outward from this location.
B1	This location was selected based on its proximity to the west site boundary and assumes a LOC from a loading arm on Berth 1. Similar to the pipeline LOC at A5, A loss at this location is assumed to spread on the water surface, but toward the south. The spread of the pool in this direction will potentially be limited by the vessels and protective boom surrounding the vessels, which is expected to impact the shape of the pool. However, the pool has been conservatively assumed to retain a circular shape, which would result in the highest expected radiant heat to the most proximal site boundary. Therefore, the edges of both the rupture and spill pools have been located at the location of the LOC event location, assuming they both spread outward from this location.
B2	This location was selected based on its proximity to the southeast site boundary and assumes a LOC from a loading arm on Berth 3. The rationale for the selection of this site is the same as for B1.

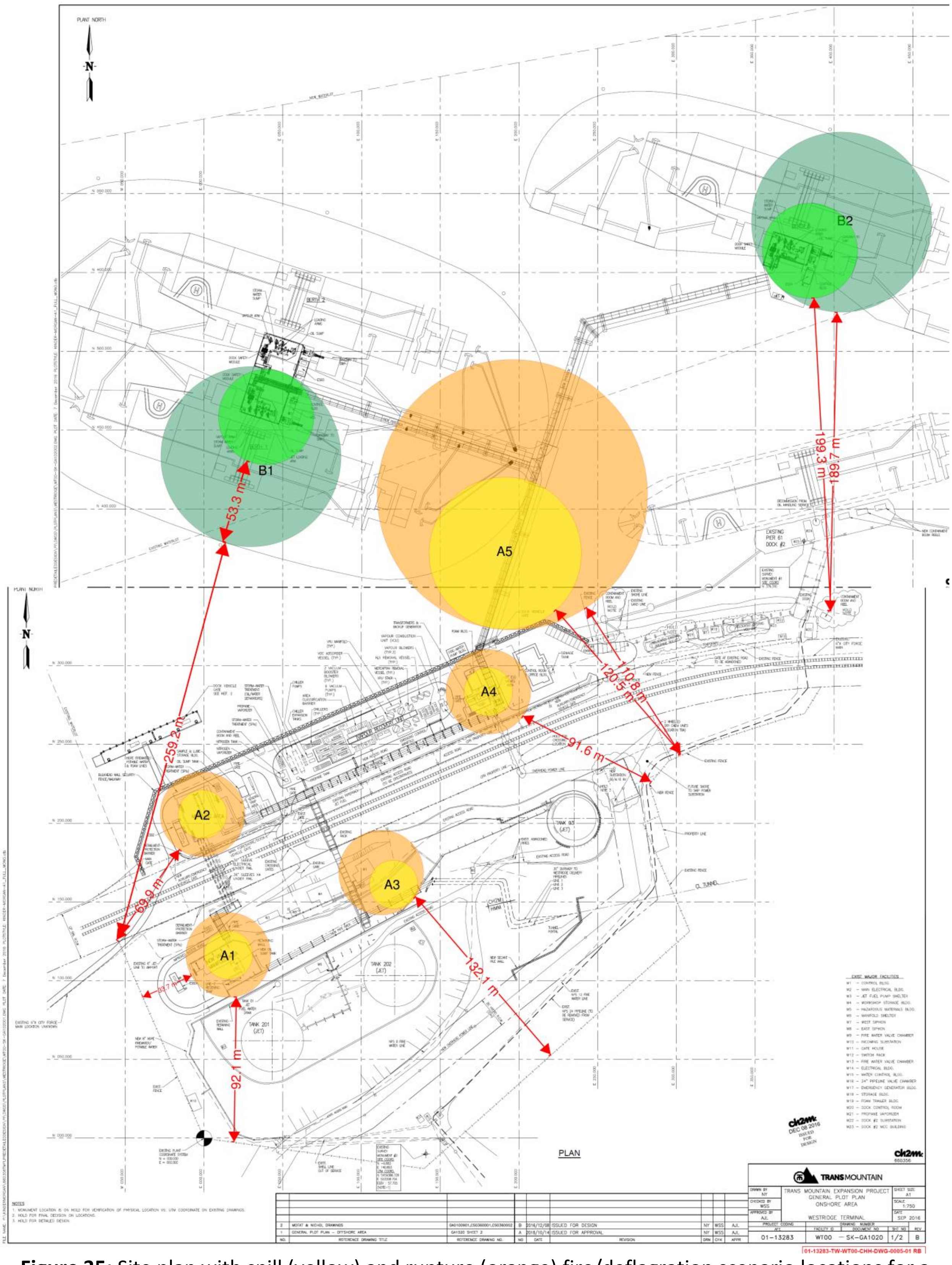


Figure 35: Site plan with spill (yellow) and rupture (orange) fire/deflagration scenario locations for a pipeline LOC event.

Based on the event location summarized above, the calculations characterizing the potential radiant heat from these events is summarized in **Table 17**.

Table 17: Fire Characteristics.

Event	Type of LOC	Effective Diameter (m)	Characteristic Fire Length (m)	Closest Boundary	Distance from Edge to Closest Site Boundary (m)
A1	Rupture	54.3	43.72	West	33.68
	Spill	30.8	29.44	West	45.43
A2	Rupture	54.3	43.72	West	69.91
	Spill	30.8	29.44	West	81.66
A3	Rupture	54.3	43.72	South	132.11
	Spill	30.8	29.44	South	132.11
A4	Rupture	54.3	43.72	Southeast	91.62
	Spill	30.8	29.44	Southeast	103.4
A5	Rupture	171.8	97.31	Southeast	110.75
	Spill	97.3	65.53	Southeast	120.53
B1	Rupture	114.5	73.41	West	259.18
	Spill	60.8	47.3	West	312.50
B2	Rupture	114.5	73.41	Southeast	189.71
	Spill	60.8	47.3	Southeast	199.30

The impact of the radiated heat to the closest site boundary is calculated based on the methodology outlined in **Section 5.4**, and probability of death as a result of exposure to the radiative heat based on the methodology outlined in **Section 6.0**. Based on these methodologies, a summary of the probability of death for each of the events identified above is provided in **Table 18**.

Table 18: Probability of Death Based on Identified Fire Events.

Event	Type of LOC	Closest Boundary	Probability of Death at Boundary
A1	Rupture	West	3.66×10^{-4}
	Spill	West	2.35×10^{-16}
A2	Rupture	West	4.90×10^{-17}
	Spill	West	Near 0
A3	Rupture	South	Near 0
	Spill	South	Near 0
A4	Rupture	Southeast	Near 0
	Spill	Southeast	Near 0
A5	Rupture	Southeast	1.21×10^{-7}
	Spill	Southeast	Near 0
B1	Rupture	West	Near 0
	Spill	West	Near 0
B2	Rupture	Southeast	Near 0
	Spill	Southeast	Near 0

For information purposes, the impact of radiant heat from the LOC events on the jet fuel storage tanks, shown in green in **Figure 36**, has been examined and the results summarized in **Table 19**.

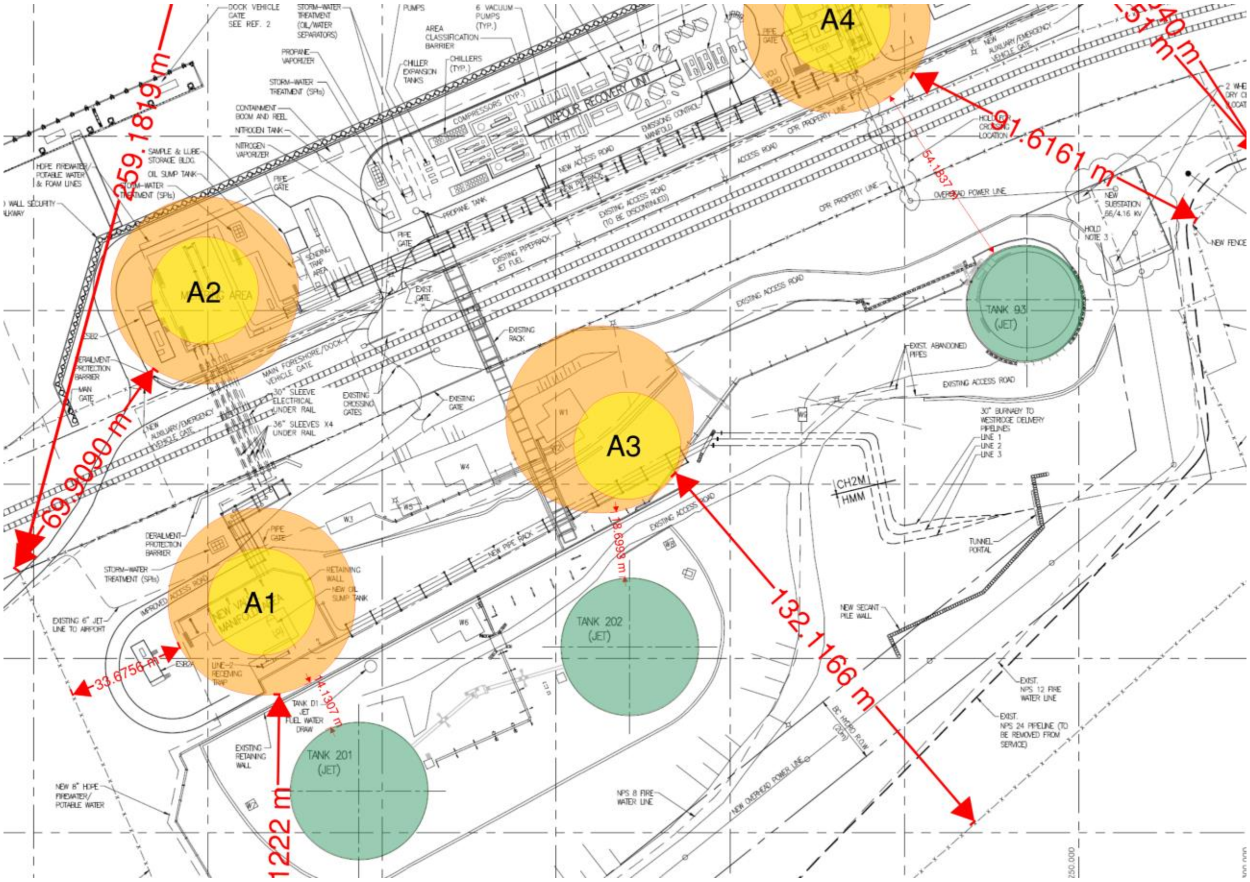


Figure 36: Site plan with fire locations for a pipeline LOC event relative to the jet fuel storage tanks.

Table 19: Heat flux at Jet Fuel Tank Surfaces.

Event	Closest Jet Fuel Tank	Distance (m)	Radiant Heat at Exterior Surface (kW/m^2)
A1	201	15.0	7.41
A3	202	19.0	6.53
A4	93	54.0	2.54

The radiant heat calculated at the exterior surface of the jet fuel tanks is less than that assumed by the 2015 National Building Code of Canada relative to the acceptable heat flux criteria for ignition of adjacent combustible structures (< 12.5 kW/m^2). Based on these results, the fires considered in this risk assessment are not considered to adversely impact the existing jet fuel storage tanks on the WMT Facility site.

7.7 Quantification of Potential for Deflagration and Impact of Pressure Wave

The following sections of this report calculate the impact of the deflagration wave pressure at the WMT Facility site boundaries and beyond for rupture and spill events for the pipeline and loading arms respectively. The proximity of the events to the site boundaries is based on the event initiation location shown in **Figure 35**.

7.7.1 Pipeline - Full Rupture

As outlined in **Section 7.2.1.1** of this report, the total mass of crude oil estimated to be released from a rupture of the pipeline is (1,210 kg/s)(180 s) = 217,800 kg. As outlined in **Section 7.4**, the amount of crude oil light end components estimated to evaporate is (0.0652)(217,800 kg) = 14,201 kg. The energy associated with this quantity of vapour is (14,201 kg)(3.22 MJ/kg) = 45.73 GJ.

The radius (r_o) can be calculated as follows:

$$r_0 = \left(\frac{3 \cdot 45{,}730\ MJ}{2\pi \cdot 3.5\ MJ/m^3}\right)^{1/3}$$

$$r_0 = 18.41\ m$$

The dimensionless peak side-on pressure (P_s') for an overpressure (P_s) of 30 kPa is as follows:

$$P_s' = \frac{30\ kPa}{100\ kPa}$$

$$P_s' = 0.3$$

Based on the chart in **Figure 27**, a dimensionless peak side-on pressure of 0.3 corresponds to a combustion energy-scaled distance (r’) of 1.0. The radius at which an overpressure of 30 kPa is attained is as follows:

$$r = \left(\frac{45.73\ GJ}{100\ kPa}\right)^{1/3}$$

$$r = 77.0\ m$$

As outlined in **Section 6.3** of this report, the probability of death based on an overpressure of 30 kPa or greater is 1, and for a rupture of the pipeline and subsequent deflagration, the distanced at which this overpressure is reached is 77.0 m.

7.7.1.1 Pipeline - Spill

As outlined in **Section 7.2.1.2** of this report, the total mass of crude oil estimated to be released from a hole in the pipeline is (291 kg/s)(240 s) = 69,840 kg. As outlined in **Section 7.4**, the amount of crude oil light end components estimated to evaporate is (0.0652)(69,840 kg) = 4,554 kg. The energy associated with this quantity of vapour is (4,554 kg)(3.22 MJ/kg) = 14.66 GJ.

The radius (r_o) can be calculated as follows:

$$r_0 = \left(\frac{3 \cdot 14{,}660\ MJ}{2\pi \cdot 3.5\ MJ/m^3}\right)^{1/3}$$

$$r_0 = 12.60\ m$$

The dimensionless peak side-on pressure (P_s') for an overpressure (P_s) of 30 kPa is as follows:

$$P_s' = \frac{30\ kPa}{100\ kPa}$$

$$P_s' = 0.3$$

Based on the chart in **Figure 27**, a dimensionless peak side-on pressure of 0.3 corresponds to a combustion energy-scaled distance (r') of 1.0. The radius at which an overpressure of 30 kPa is attained is as follows:

$$r = \left(\frac{14.66\ GJ}{100\ kPa}\right)^{1/3}$$

$$r = 52.7\ m$$

As outlined in **Section 6.3** of this report, the probability of death based on an overpressure of 30 kPa or greater is 1, and for a rupture of the pipeline and subsequent deflagration, the distanced at which this overpressure is reached is 52.7 m.

7.7.2 Loading Arm - Full Rupture

As outlined in **Section 7.3.1.1**, the total mass of crude oil estimated to be released from a rupture of the a loading arm is (403 kg/s)(240 s) = 96,720 kg. As outlined in **Section 7.4**, the amount of crude oil light end components estimated to evaporate is (0.0652)(96,720 kg) = 6,306 kg. The energy associated with this quantity of vapour is (6,306 kg)(3.22 MJ/kg) = 20.305 GJ.

The radius (r_o) can be calculated as follows:

$$r_0 = \left(\frac{3 \cdot 20{,}305\ MJ}{2\pi \cdot 3.5\ MJ/m^3}\right)^{1/3}$$

$$r_0 = 14.04\ m$$

The dimensionless peak side-on pressure (P_s') for an overpressure (P_s) of 30 kPa is as follows:

$$P_s' = \frac{30\ kPa}{100\ kPa}$$

$$P_s' = 0.3$$

Based on the chart in **Figure 27**, a dimensionless peak side-on pressure of 0.3 corresponds to a combustion energy-scaled distance (r') of 1.0. The radius at which an overpressure of 30 kPa is attained is as follows:

$$r = \left(\frac{20.305\ GJ}{100\ kPa}\right)^{1/3}$$

$$r = 58.8\ m$$

As outlined in **Section 6.3** of this report, the probability of death based on an overpressure of 30 kPa or greater is 1, and for a rupture of a loading arm and subsequent deflagration, the distanced at which this overpressure is reached is 58.8 m.

7.7.3 Loading Arm - Spill

As outlined in **Section 7.3.1.2** of this report, the total mass of crude oil estimated to be released from a 50 mm hole in a loading arm of the pipeline is (36.2 kg/s)(240 s) = 8,688 kg. As outlined in **Section 7.4**, the amount of crude oil light end components estimated to evaporate is (0.0652)(8,688 kg) = 566 kg. The energy associated with this quantity of vapour is (566 kg)(3.22 MJ/kg) = 1.823 GJ.

The radius (r_o) can be calculated as follows:

$$r_0 = \left(\frac{3 \cdot 1{,}823\ MJ}{2\pi \cdot 3.5\ MJ/m^3}\right)^{1/3}$$

$$r_0 = 6.29\ m$$

The dimensionless peak side-on pressure (P_s') for an overpressure (P_s) of 30 kPa is as follows:

$$P_s' = \frac{30\ kPa}{100\ kPa}$$

$$P_s' = 0.3$$

Based on the chart in **Figure 27**, a dimensionless peak side-on pressure of 0.3 corresponds to a combustion energy-scaled distance (r') of 1.0. The radius at which an overpressure of 30 kPa is attained is as follows:

$$r = \left(\frac{1.823\ GJ}{100\ kPa}\right)^{1/3}$$

$$r = 26.32\ m$$

As outlined in **Section 6.3** of this report, the probability of death based on an overpressure of 30 kPa or greater is 1, and for a rupture of the pipeline and subsequent deflagration, the distanced at which this overpressure is reached is 26.32 m.

7.7.4 Summary of Results for Deflagration

The results of the analysis of the impact of the deflagration events at the site boundaries as a function of the probability of death, based on the methodology outlined in **Section 6.3**, are summarized in **Table 20**.

Table 20: Probability of Death Based on Identified Deflagration Events.

Event	Type of LOC	Radius (r_o)	Radius Where Overpressure = 30 kPa	Closest Boundary	Distance from Event Epicentre to Closest Boundary (m)	Probability of Death at Boundary
A1	Rupture	18.41	77.0	West	60.88	1.0
	Spill	12.60	52.7	West	60.88	1.0
A2	Rupture	18.41	77.0	West	97.11	Near 0
	Spill	12.60	52.7	West	97.11	Near 0
A3	Rupture	18.41	77.0	South	159.31	Near 0
	Spill	12.60	52.7	South	147.51	Near 0
A4	Rupture	18.41	77.0	Southeast	118.82	Near 0
	Spill	12.60	52.7	Southeast	118.82	Near 0
A5	Rupture	18.41	77.0	Southeast	196.65	Near 0
	Spill	12.60	52.7	Southeast	169.13	Near 0
B1	Rupture	14.04	58.8	West	316.48	Near 0
	Spill	6.29	26.3	West	342.90	Near 0
B2	Rupture	14.04	58.8	Southeast	247.01	Near 0
	Spill	6.29	26.3	Southeast	229.70	Near 0

7.8 Annual Individual Risk at the WMT Facility Boundaries

The general approach to calculating the individual risk for the WMT Facility is outlined in **Section 6.4**, and is based on the probability of events occurring and the probability of death as a result of the impact of those events. The actual combination of events occurring is a function of the event independence, how the event frequencies were treated in the analysis, and the magnitude of the impact of certain events at the WMT Facility boundaries.

The first consideration is the frequency of LOC events. Two LOC events were considered: pipeline and loading arm. The frequency of each of these LOC events was calculated such that it was representative of the entire pipeline on the WMT Facility site, and all loading arms during all transfer operations. This assumption then accounts for the whole system based on consideration of the most significant single LOC event for the pipeline and loading arms respectively, and cumulative consideration of both these events.

The second consideration is the type of release for each LOC event. Both events consider a rupture and leak. These events are considered to be **Figure 37**.

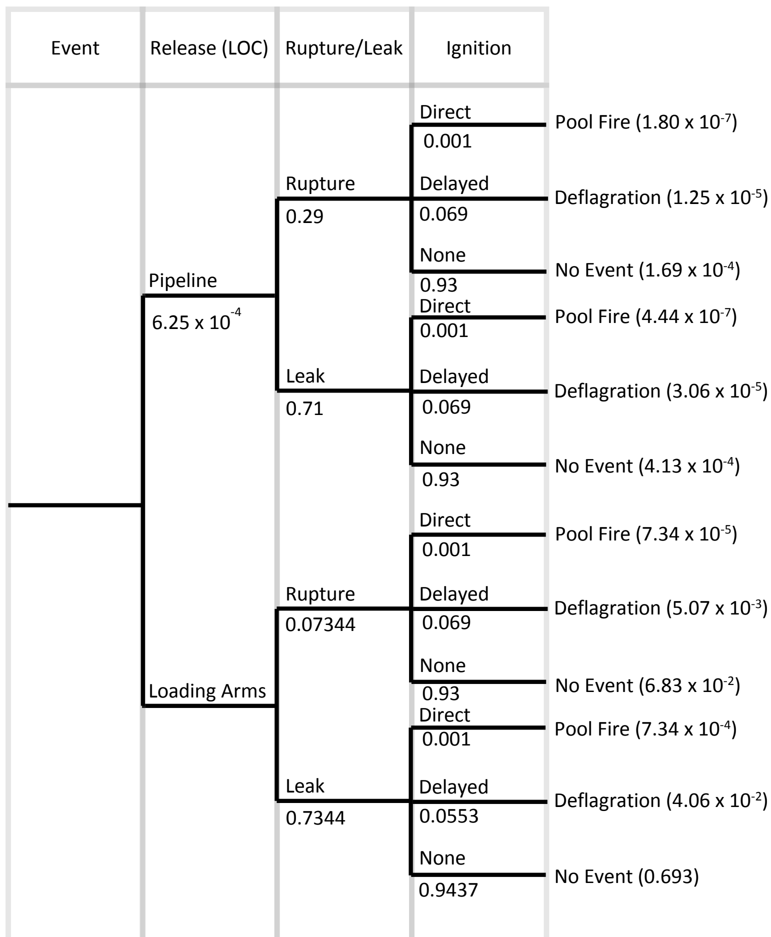


Figure 37: Combined LOC event tree.

The impact of these events in terms of probability are summarized in **Table 21**. Note that the most significant event relative to proximity to the site boundary was Event A1 and the LOC events associated with the loading arms do not have an impact on the site boundaries; therefore, are not factored into the total individual risk.

Table 21: Probability of Death Based on Identified Deflagration Events – Site Boundary.

Release (LOC)	Rupture/ Leak	Ignition	Consequence	Frequency of Event	Impact at Closest Boundary	Result at Closest Site Boundary
Pipeline	Rupture	Direct	Pool Fire	1.80×10^{-7}	3.66×10^{-4}	6.59×10^{-11}
		Delay	Deflagration	1.25×10^{-5}	1.0	1.25×10^{-5}
			Pool Fire	1.25×10^{-5}	3.66×10^{-4}	4.58×10^{-9}
	Spill	Direct	Pool Fire	4.44×10^{-7}	2.35×10^{-16}	1.04×10^{-22}
		Delay	Deflagration	3.06×10^{-5}	1.0	3.06×10^{-5}
			Pool Fire	3.06×10^{-5}	2.35×10^{-16}	7.19×10^{-21}
Loading Arm	Rupture	Direct	Pool Fire	7.34×10^{-5}	0.0	0.0
		Delay	Deflagration	5.07×10^{-3}	0.0	0.0
			Pool Fire	3.06×10^{-5}	0.0	0.0
	Spill	Direct	Pool Fire	7.34×10^{-4}	0.0	0.0
		Delay	Deflagration	4.06×10^{-2}	0.0	0.0
			Pool Fire	3.06×10^{-5}	0.0	0.0
Total Individual Risk at the WMT Facility West Site Boundary						**4.31×10^{-5}**

Therefore, as shown in **Table 21**, the total individual risk at the WMT west site boundary is 4.31×10^{-5}, and is expected to be significantly lower at the other boundaries. This level of risk is less than the criteria identified by MIACC in **Section 4.5** relative to the boundary between the WMT Facility site and the interface with the adjacent parkland.

The impact of the risk at the boundary between the parkland and the low density residential is calculated based on the event closest to that interface (i.e., Event A1) and the results summarized in **Table 22** to **Table 25** below.

Table 22: Fire Characteristics.

Event	Type of LOC	Effective Diameter (m)	Characteristic Fire Length (m)	Closest Boundary	Distance from Edge to Closest Site Boundary (m)
A1	Rupture	54.3	43.72	West	144.04
	Spill	30.8	29.44	West	155.79

Table 23: Probability of Death Based on Identified Fire Events.

Event	Type of LOC	Closest Boundary	Probability of Death at Boundary
A1	Rupture	West	Near 0
	Spill	West	Near 0

Table 24: Probability of Death Based on Identified Deflagration Events.

Event	Type of LOC	Radius (r_o)	Radius Where Overpressure = 30 kPa	Closest Boundary	Distance from Event Epicentre to Closest Boundary (m)	Probability of Death at Boundary
A1	Rupture	18.41	77.0	West	171.24	Near 0
	Spill	12.60	52.7	West	171.24	Near 0

Table 25: Probability of Death Based on Identified Deflagration Events – Boundary at Low Density Res.

Release (LOC)	Rupture/ Leak	Ignition	Consequence	Frequency of Event	Impact at Closest Boundary	Result at Closest Site Boundary
Pipeline	Rupture	Direct	Pool Fire	1.80×10^{-7}	0.0	0.0
		Delay	Deflagration	1.25×10^{-5}	0.0	0.0
			Pool Fire	1.25×10^{-5}	0.0	0.0
	Spill	Direct	Pool Fire	4.44×10^{-7}	0.0	0.0
		Delay	Deflagration	3.06×10^{-5}	0.0	0.0
			Pool Fire	3.06×10^{-5}	0.0	0.0
Loading Arm	Rupture	Direct	Pool Fire	7.34×10^{-5}	0.0	0.0
		Delay	Deflagration	5.07×10^{-3}	0.0	0.0
			Pool Fire	3.06×10^{-5}	0.0	0.0
	Spill	Direct	Pool Fire	7.34×10^{-4}	0.0	0.0
		Delay	Deflagration	4.06×10^{-2}	0.0	0.0
			Pool Fire	3.06×10^{-5}	0.0	0.0
					SUM	**0.0**

Therefore, as shown in **Table 25**, the total individual risk at the boundary between the parkland adjacent to the WMT Facility site and the low density residential area is near 0, and is expected to be the same at the other boundaries. This level of risk is significantly less than the criteria identified by MIACC in **Section 4.5** from the WMT Facility to the nearest low density residential area.

8.0 CONCLUSIONS

This report has summarized the analysis results for the proposed approach to quantifying the fire risk associated with the proposed expansion to the Westridge Marine Terminal Facility (WMT Facility), and the proposed increase in transport of crude petroleum product from 47,690 m^3/d (300,000 bbl/d) to 141,500 m^3/d (890,000 bbl/d) by twinning the existing pipeline. The report responds to a requirement by the Vancouver Fraser Port Authority that a fire risk assessment be conducted for the expanded WMT Facility. The upgrades to the WMT Facility to support the additional transfer of crude oil will include:

1. Expanded/upgraded foreshore process and transfer area; and
2. Expanded/upgraded dock transfer area.

The upgraded WMT facility components are required to be designed in conformance with current applicable regulations and standards, including the 2015 National Fire Code of Canada (2015 NFCC). The requirements in the 2015 NFCC are intended to limit the probability of:

- Release of flammable or combustible liquids;
- Spread of flammable or combustible liquids outside areas of containment;
- Ignition sources in proximity to areas that may contain flammable vapours;
- Explosive concentrations of flammable vapour; and
- Growth and spread of fire to buildings in the WMT Facility and areas adjacent to the WMT Facility.

A hazard analysis of the WMT Facility based on the risk factors outlined above and conditions associated with historical incidents was conducted to determine possible undesirable events that could impact the safety of areas surrounding the facility. The hazard analysis considered:

- Key characteristics of crude oil associated with the risk of fire;
- The potential loss of containment (LOC), ignition, fire, and deflagration events for the upgrades to the WMT Facility; and
- The impact of the undesirable events on the areas adjacent to the WMT Facility.

Two key LOC events were identified from the hazard analysis: a pipeline failure and a loading arm failure. The LOC for each failure included consideration of rupture and leakage scenarios. Event trees were developed to represent the sequence of events resulting in undesirable consequences, and frequencies/probabilities attributed to those events based on data from statistical analyses of historical incidents and published industry values.

The impact of fire and deflagration events was quantified using representative models and attributed probabilities of impact on public safety using probit functions. The cumulative probability of the risk of the sequence of events impacting the safety of the public was expressed as an individual annual risk of death at the site boundaries based on acceptability criteria associated with the design and operation of the WMT Facility.

The results of the analysis indicate that the total individual risk at the WMT Facility site boundaries is at most 4.31×10^{-5}, and near zero at the nearest residential development for the scenarios considered. These values are well within the limits considered to be acceptable in the MIACC criteria.

9.0 SOURCES OF INFORMATION

The following sources of information have been considered:

1. Kinder Morgan Canada Inc., "Summary," Vol. 1, Trans Mountain Expansion Project, An Application Pursuant to Section 52 of the National Energy Board Act, December 2013.
2. Kinder Morgan Canada Inc., "Project Overview, Economics & General Information," Vol. 4a, Trans Mountain Expansion Project, An Application Pursuant to Section 52 of the National Energy Board Act, December 2013.
3. Kinder Morgan Canada Inc., "Project Design & Execution - Engineering," Vol. 2, Trans Mountain Expansion Project, An Application Pursuant to Section 52 of the National Energy Board Act, December 2013.
4. Trans Mountain Expansion Project, "General Plot Plan – Onshore Area," September 2016, AFE 01-13283, Facility WT00, Document No. SK-GA102, Sheet No. 001.
5. Trans Mountain Expansion Project, "General Plot Plan – Onshore Area," September 2016, AFE 01-13283, Facility WT00, Document No. SK-GA102, Sheet No. 002.
6. Kinder Morgan Canada Inc., "Public Consultation," Vol. 3a, Trans Mountain Expansion Project, An Application Pursuant to Section 52 of the National Energy Board Act, December 2013.
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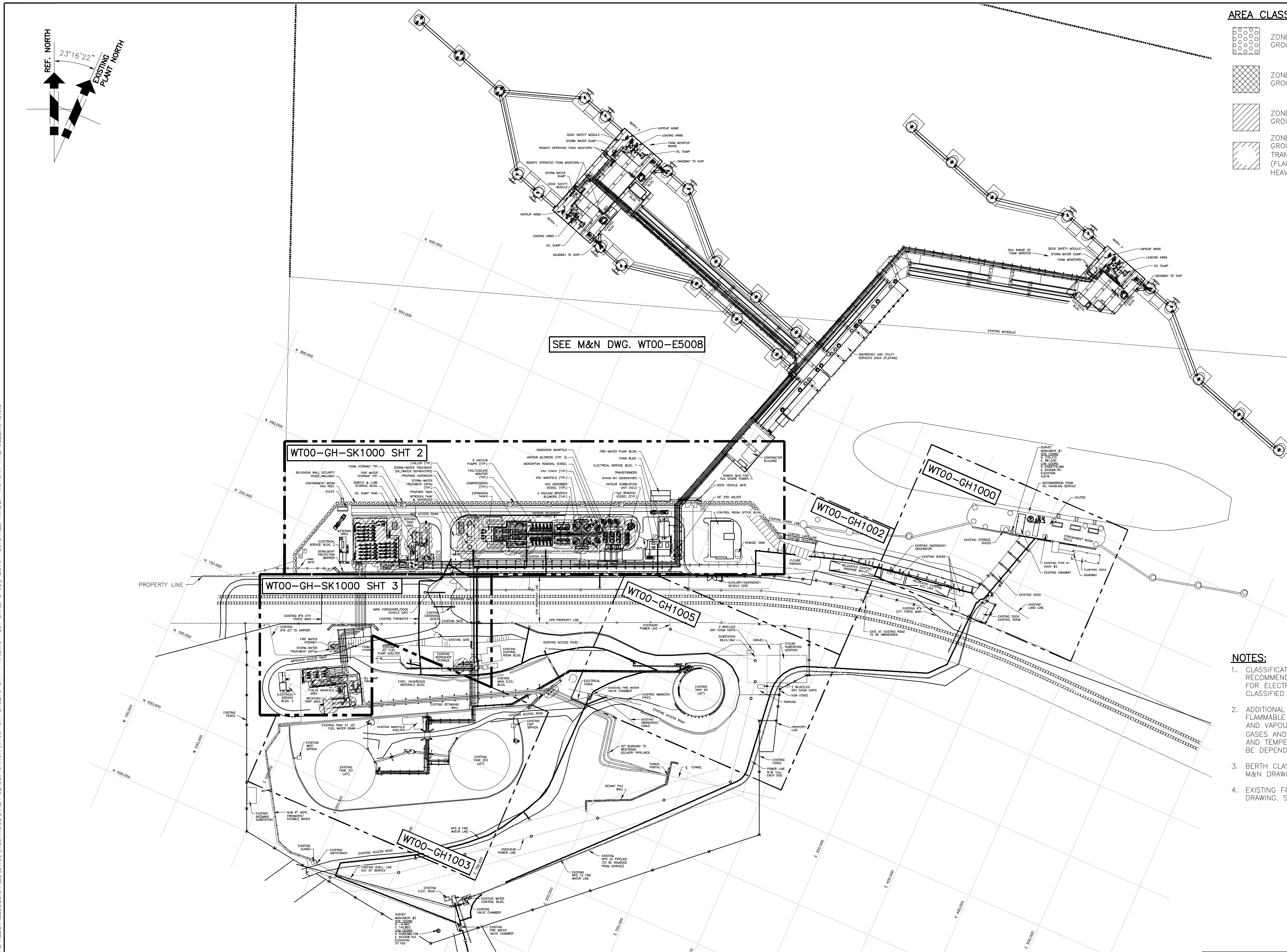
APPENDIX A ELECTRICAL ZONE DRAWINGS



AREA CLASSIFICATION LEGEND

- ZONE 0 — GROUP IIA AND IIB, TEMPERATURE CODE T3
- ZONE 1 — GROUP IIA AND IIB, TEMPERATURE CODE T3
- ZONE 2 — GROUP IIA AND IIB, TEMPERATURE CODE T3
- ZONE 2 — GROUP IIA AND IIB, TEMPERATURE CODE T3 TRANSIENT LEVEL 600mm ABOVE GRADE (SEE NOTE 1) (FLAMMABLE LIQUIDS OR FLAMMABLE HEAVIER-THAN-AIR GASES AND VAPOURS)

NOTES:

1. CLASSIFICATION IN ACCORDANCE WITH API RP 505 (2013), RECOMMENDED PRACTICE FOR CLASSIFICATION OF LOCATIONS FOR ELECTRICAL INSTALLATIONS AT PETROLEUM FACILITIES CLASSIFIED AS CLASS 1, ZONE 0, ZONE 1, AND ZONE 2.
2. ADDITIONAL TRANSIENT VAPOUR LEVEL REQUIRED WHEN FLAMMABLE LIQUIDS OR FLAMMABLE HEAVIER-THAN-AIR GASES AND VAPOURS ARE PRESENT. FLAMMABLE HEAVIER-THAN-AIR GASES AND VAPOURS WOULD BE TYPICAL FOR H_2S (SOUR) GAS AND TEMPERATURE CODE FOR ELECTRICAL EQUIPMENT WOULD BE DEPENDANT ON THE FLAMMABLE MATERIAL BEING HANDLED.
3. BERTH CLASSIFICATION IS NOT SHOWN ON THIS DRAWING. SEE M&N DRAWING WT00-E5008.
4. EXISTING FACILITIES CLASSIFICATION IS NOT SHOWN ON THIS DRAWING. SEE TMPL DRAWINGS WT00-GH1000 TO GH1005.

10 0m 10 20 30 40 50

ch2m:
PROJECT # 660356

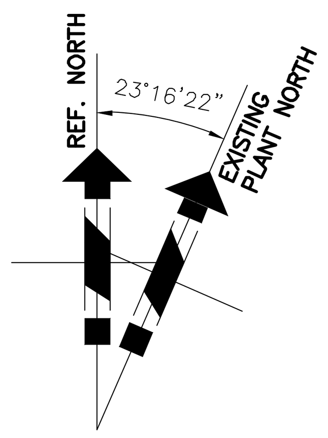
TRANSMOUNTAIN

NO.	REFERENCE DRAWING TITLE	REFERENCE DRAWING NO.	NO	DATE	REVISION	DRN	CHK	APPR
			A	2016/07/11	ISSUED FOR REVIEW	DM	JE	PH

DRAWN BY DM	TRANS MOUNTAIN EXPANSION PROJECT HAZARDOUS AREA KEY PLAN FORESHORE AND BERTHS 1, 2 & 3 WESTRIDGE TERMINAL	SHEET SIZE A1
CHECKED BY JE		SCALE 1:1250
APPROVED BY		DATE 2016/02/04

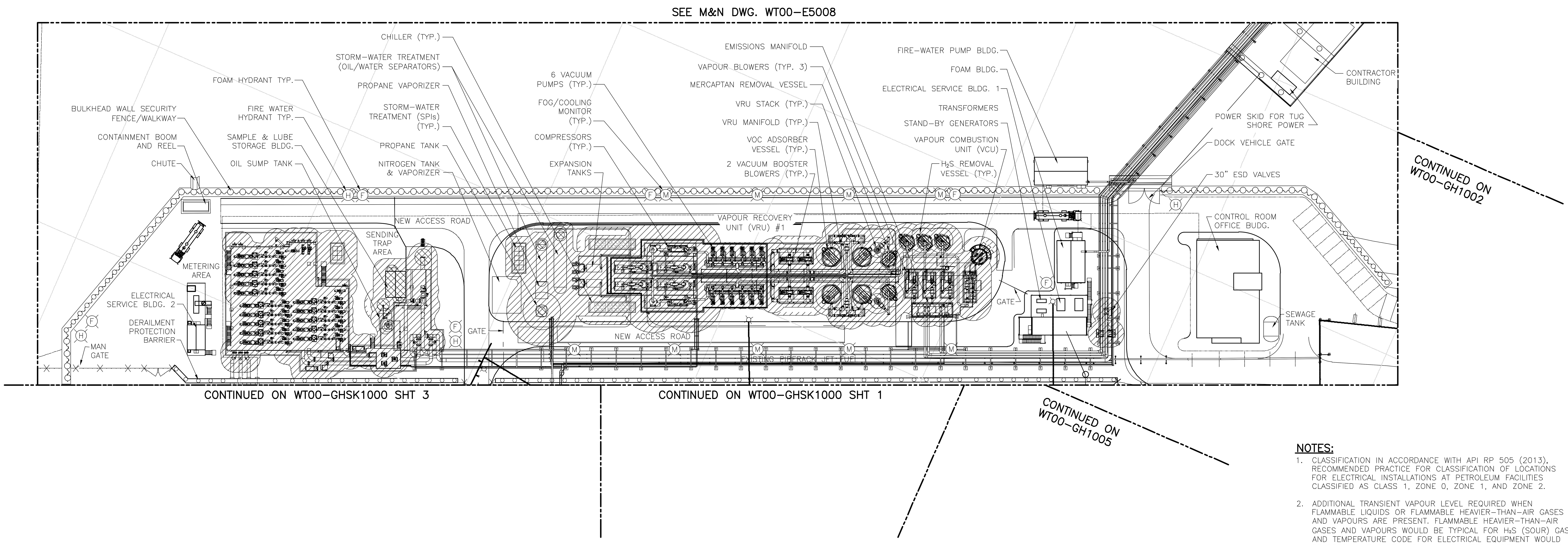
PROJECT CODING: AFE	DRAWING NUMBER: FACILITY ID	DOCUMENT NO	SHT NO	REV
SKT	WT00	GH-SK0210	1of3	A

FILE NAME: P:\KINDERMORGAN\660356TMPLPREDETAILEDDESIGN\EL\DWGS\WESTRIDGE\AREA CLASSIFICATION\WT00-GH-SK0210 SHT 1 RA.DWG PLOT DATE: 8 July 2016 PLOTSTYLE: KINDER-MORGAN-A1_FULL_MONO.ctb



AREA CLASSIFICATION LEGEND

- ZONE 0 — GROUP IIA AND IIB, TEMPERATURE CODE T3
- ZONE 1 — GROUP IIA AND IIB, TEMPERATURE CODE T3
- ZONE 2 — GROUP IIA AND IIB, TEMPERATURE CODE T3
- ZONE 2 — GROUP IIA AND IIB, TEMPERATURE CODE T3 TRANSIENT LEVEL 600mm ABOVE GRADE (SEE NOTE 1) (FLAMMABLE LIQUIDS OR FLAMMABLE HEAVIER–THAN–AIR GASES AND VAPOURS)



NOTES:

1. CLASSIFICATION IN ACCORDANCE WITH API RP 505 (2013), RECOMMENDED PRACTICE FOR CLASSIFICATION OF LOCATIONS FOR ELECTRICAL INSTALLATIONS AT PETROLEUM FACILITIES CLASSIFIED AS CLASS 1, ZONE 0, ZONE 1, AND ZONE 2.
2. ADDITIONAL TRANSIENT VAPOUR LEVEL REQUIRED WHEN FLAMMABLE LIQUIDS OR FLAMMABLE HEAVIER–THAN–AIR GASES AND VAPOURS ARE PRESENT. FLAMMABLE HEAVIER–THAN–AIR GASES AND VAPOURS WOULD BE TYPICAL FOR H_2S (SOUR) GAS AND TEMPERATURE CODE FOR ELECTRICAL EQUIPMENT WOULD BE DEPENDANT ON THE FLAMMABLE MATERIAL BEING HANDLED.

5 0m 5 10 15 20 25

ch2m:
PROJECT # 660356

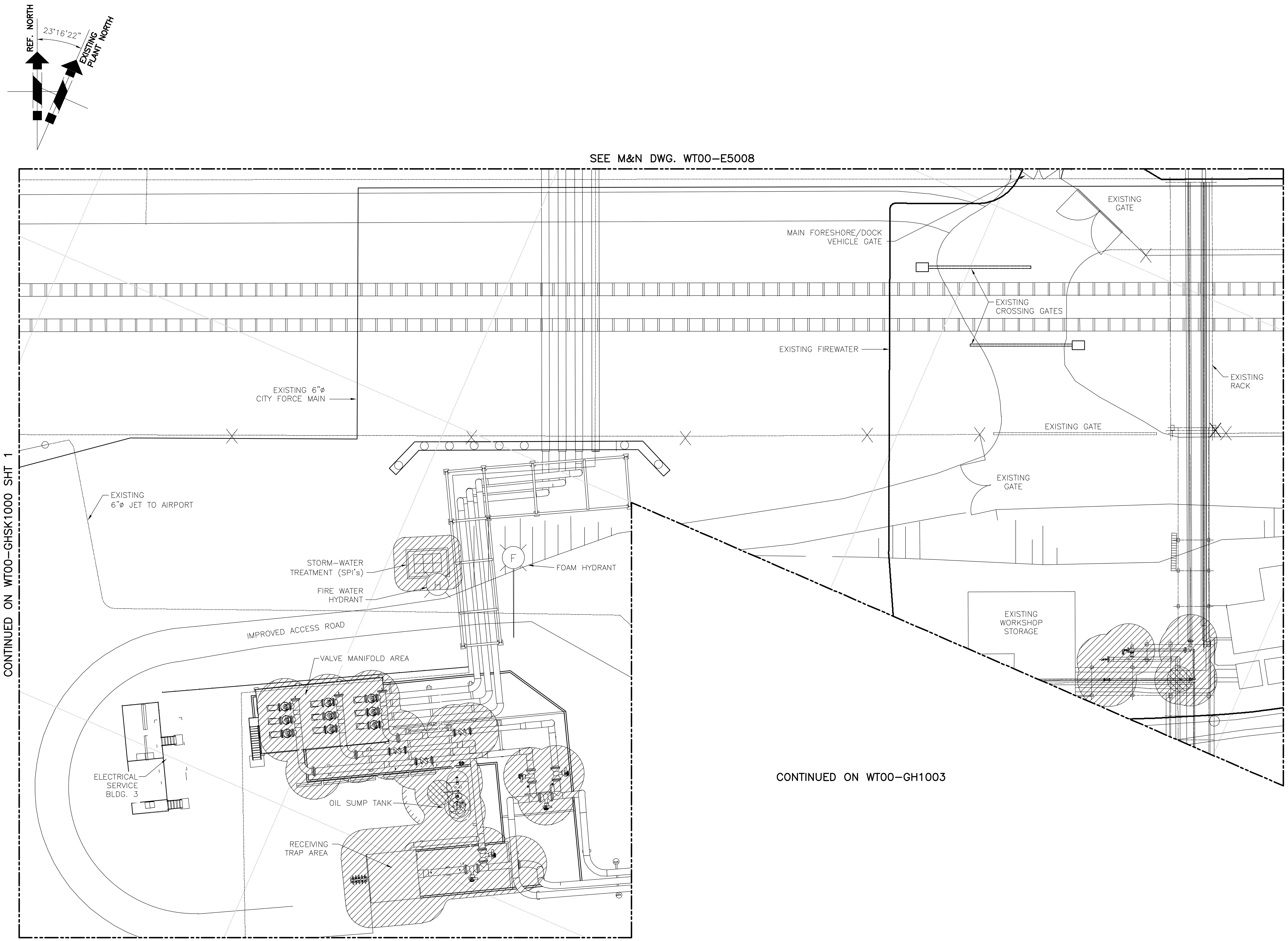
TRANS MOUNTAIN

NO.	REFERENCE DRAWING TITLE	REFERENCE DRAWING NO.	NO	DATE	REVISION	DRN	CHK	APPR
			A	2016/07/11	ISSUED FOR REVIEW	DM	JE	PH

DRAWN BY DM	TRANS MOUNTAIN EXPANSION PROJECT HAZARDOUS AREA PLAN METERING, SENDING TRAP & VAPOUR RECOVERY UNIT AREA WESTRIDGE TERMINAL	SHEET SIZE A1
CHECKED BY JE		SCALE 1:500
APPROVED BY		DATE 2016/02/04

PROJECT CODING AFE	FACILITY ID	DOCUMENT NO	SHT NO	REV
SKT	WT00	GH–SK0210	2of3	A

FILE NAME: P:\KINDERMORGAN\660356TMPLPREDETAILEDDESIGN\EL\DWGS\WESTRIDGE\AREA CLASSIFICATION\WT00–GH–SK0210 SHT 2 RA.DWG PLOT DATE: 8 July 2016 PLOTSTYLE: KINDER–MORGAN–A1_FULL_MONO.ctb



AREA CLASSIFICATION LEGEND

ZONE 0
GROUP IIA AND IIB, TEMPERATURE CODE T3

ZONE 1
GROUP IIA AND IIB, TEMPERATURE CODE T3

ZONE 2
GROUP IIA AND IIB, TEMPERATURE CODE T3

ZONE 2
GROUP IIA AND IIB, TEMPERATURE CODE T3
TRANSIENT LEVEL 600mm ABOVE GRADE (SEE NOTE 1)
(FLAMMABLE LIQUIDS OR FLAMMABLE HEAVIER-THAN-AIR GASES AND VAPOURS)

NOTES:

1. CLASSIFICATION IN ACCORDANCE WITH API RP 505 (2013), RECOMMENDED PRACTICE FOR CLASSIFICATION OF LOCATIONS FOR ELECTRICAL INSTALLATIONS AT PETROLEUM FACILITIES CLASSIFIED AS CLASS 1, ZONE 0, ZONE 1, AND ZONE 2.
2. ADDITIONAL TRANSIENT VAPOUR LEVEL REQUIRED WHEN FLAMMABLE LIQUIDS OR FLAMMABLE HEAVIER-THAN-AIR GASES AND VAPOURS ARE PRESENT. FLAMMABLE HEAVIER-THAN-AIR GASES AND VAPOURS WOULD BE TYPICAL FOR H_2S (SOUR) GAS AND TEMPERATURE CODE FOR ELECTRICAL EQUIPMENT WOULD BE DEPENDANT ON THE FLAMMABLE MATERIAL BEING HANDLED.

ch2m:
PROJECT # 660356

TRANS MOUNTAIN

NO.	REFERENCE DRAWING TITLE	REFERENCE DRAWING NO.	NO	DATE	REVISION	DRN	CHK	APPR
			A	2016/07/11	ISSUED FOR REVIEW	DM	JE	PH

DRAWN BY DM	TRANS MOUNTAIN EXPANSION PROJECT HAZARDOUS AREA PLAN VALVE MANIFOLD & RECEIVING TRAP AREA WESTRIDGE TERMINAL	SHEET SIZE A1
CHECKED BY JE		SCALE 1:250
APPROVED BY		DATE 2016/02/04

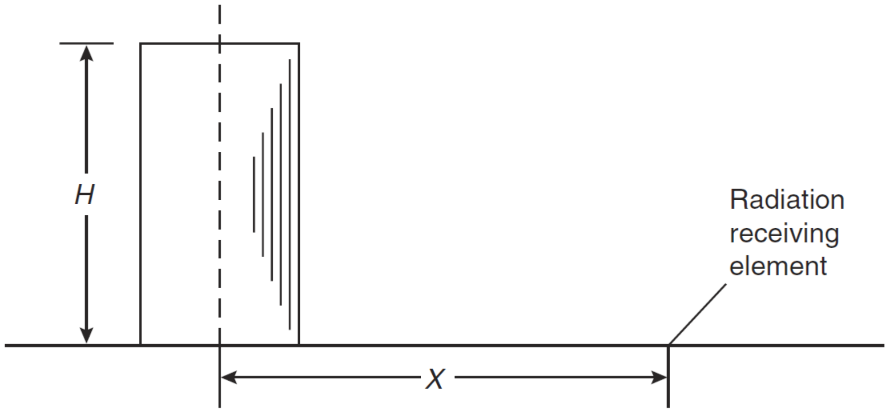
PROJECT CODING AFE	FACILITY ID	DOCUMENT NO	SHT NO	REV
SKT	WT00	GH-SK0210	3of3	A

FILE NAME: P:\KINDERMORGAN\660356TMPLPREDETAILEDDESIGN\EL\DWGS\WESTRIDGE\AREA CLASSIFICATION\WT00-GH-SK0210 SHT 3 RA.DWG PLOT DATE: 8 July 2016 PLOTSTYLE: KINDER-MORGAN-A1_FULL_MONO.ctb

APPENDIX B CONFIGURATION FACTOR EQUATIONS

Cylindrical Source

For cylindrical sources, the finite configuration factor is determined by integrating over the area of the exposing cylinder. A simplified version of the result for a finite element parallel to a cylindrical surface is as follows:



Vertical receiving element:

$$\phi_{1-2,V} = \frac{1}{\pi}\left[\frac{1}{x_r}\tan^{-1}\left(\frac{h_r}{\sqrt{x_r^2-1}}\right) + \frac{h_r(A-2\cdot x_r)}{x_r\sqrt{A\cdot B}}\tan^{-1}\left(\sqrt{\frac{A(x_r-1)}{B(x_r+1)}}\right) - \left(\frac{h_r}{x_r}\right)\tan^{-1}\left(\sqrt{\frac{x_r-1}{x_r+1}}\right)\right]$$

Horizontal receiving element:

$$\phi_{1-2,H} = \frac{1}{\pi}\left[\tan^{-1}\left(\sqrt{\frac{x_r+1}{x_r-1}}\right) - \left(\frac{x_r^2-1+h_r^2}{\sqrt{A\cdot B}}\right)\tan^{-1}\left(\sqrt{\frac{A(x_r-1)}{B(x_r+1)}}\right)\right]$$

Where:

$$h_r = \frac{H}{R}$$

$$x_r = \frac{X}{R}$$

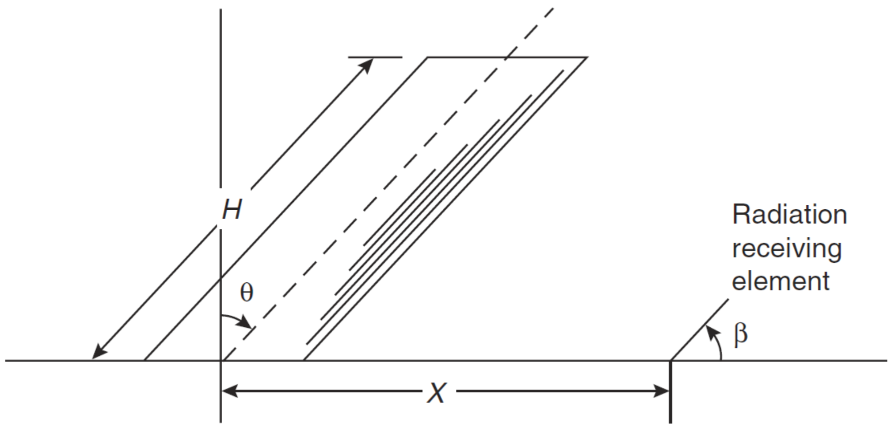
$$A = (x_r+1)^2 + h_r^2$$

$$B = (x_r-1)^2 + h_r^2$$

Where: X = Distance between the centre of the pool fire and the target (m)
H = Height of the pool fire (m)
R = Pool fire radius (m)

Where the flame base is above the target base, the view factor of the flame can be represented by two cylinders and view factor subtraction.

A simplified version of the result for a finite element relative to a tilted cylinder is as follows:



Vertical receiving element:

$$\pi\phi_{1-2,V} = E\left[\frac{a^2+(b+1)^2-2b(1+\sin\theta)}{A\cdot B}\right]\tan^{-1}\left(\frac{A\cdot D}{B}\right)$$
$$+\frac{\cos\theta}{C}\left[\tan^{-1}\left(\frac{ab-F^2\sin\theta}{F\cdot C}\right)+\tan^{-1}\left(\frac{F\sin\theta}{C}\right)\right]-E\tan^{-1}D$$

Horizontal receiving element:

$$\pi\phi_{1-2,H} = \tan^{-1}\left(\frac{1}{D}\right)-\left[\frac{a^2+(b+1)^2-2(b+1+ab\sin\theta)}{A\cdot B}\right]\tan^{-1}\left(\frac{A\cdot D}{B}\right)$$
$$+\frac{\sin\theta}{C}\left[\tan^{-1}\left(\frac{ab-F^2\sin\theta}{F\cdot C}\right)+\tan^{-1}\left(\frac{F\sin\theta}{C}\right)\right]$$

Where:

$$a=\frac{H}{R}$$

$$b=\frac{X}{R}$$

$$A=\sqrt{a^2+(b+1)^2-2a(b+1)\sin\theta}$$

$$B=\sqrt{a^2+(b-1)^2-2a(b-1)\sin\theta}$$

$$C=\sqrt{1+(b^2-1)\cos^2\theta}$$

$$D=\sqrt{\frac{b-1}{b+1}}$$

$$E=\frac{a\cos\theta}{b-a\sin\theta}$$

$$F=\sqrt{b^2-1}$$

$$2\pi\phi_{1-2,H} = 2\tan^{-1} D + \left(\frac{F\sin\theta}{I}\right)\left[\tan^{-1}\left(\frac{\frac{a\cdot b}{F} + \sin\theta}{I}\right) - \tan^{-1}\left(\frac{\frac{a\cdot b}{F} - \sin\theta}{I}\right) - 2\tan^{-1}\left(\frac{\sin\theta}{I}\right)\right]$$
$$- \left(\frac{a^2+b^2-1}{G}\right)\left[\tan^{-1}\left(\frac{H\cdot D - 2a\sin\theta}{G}\right) + \tan^{-1}\left(\frac{H\cdot D + 2a\sin\theta}{G}\right)\right]$$

$$2\pi\phi_{1-2,H} = -\left[\frac{a^2\sin\theta\cos\theta}{2(a^2\sin\theta + b^2)}\right]\ln\left[\frac{a^2+b^2-1-2a\frac{F}{b}\sin\theta}{a^2+b^2-1+2a\frac{F}{b}\sin\theta}\right]$$
$$+ \left(\frac{\cos\theta}{I}\right)\left[\tan^{-1}\left(\frac{\frac{a\cdot b}{F} + \sin\theta}{I}\right) + \tan^{-1}\left(\frac{\frac{a\cdot b}{F} - \sin\theta}{I}\right)\right]$$
$$+ \left(\frac{ab\cos\theta}{b^2 + a^2\sin^2\theta}\right)\left(\frac{a^2+b^2+1}{G}\right)\left[\tan^{-1}\left(\frac{H\cdot D - 2a\sin\theta}{G}\right)\right.$$
$$\left. + \tan^{-1}\left(\frac{H\cdot D + 2a\sin\theta}{G}\right)\right] - \left(\frac{2ab\cos\theta}{b^2 + a^2\sin^2\theta}\right)\tan^{-1} D$$

Where:

$G = \sqrt{(a^2+b^2+1)^2 - 4(b^2 + a^2\sin^2\theta)}$

$H = a^2 + (b+1)^2$

$I = \sqrt{b^2 - \sin^2\theta}$

The maximum configuration factor at a given point is a function of the vertical and horizontal receiving elements as follows:

$$\phi_{1-2,max} = \sqrt{\phi_{1-2,V}^2 + \phi_{1-2,H}^2}$$