Global Leaders in
Fire Engineering

SERECA

Vancouver Airport Fuel Delivery Project

Risk and Hazard Analysis for
Fuel Receiving Facility

Our File Number: DV150848
Date of Report: August 5, 2015

Prepared for: Mr. Adrian Pollard
FSM Management Group
108-12300 Horseshoe Way
Richmond, BC
V7A 4Z1

Prepared by: Sereca Consulting Inc.

Keith D. Calder, M.Eng., P.Eng.   Peter Senez, M.Eng., P.Eng.

Table of Contents

1.0 Introduction and Scope 1
2.0 Facility Description 2
 2.1 General Facility Layout 2
 2.2 Storage Configuration 2
 2.3 Facility Operation 3
 2.4 Jet A1 Characteristics 4
3.0 Regulatory Framework 5
 3.1 Applicable Regulatory Requirements 5
 3.2 2010 NFC Requirements 5
 3.3 NFPA 30, "Flammable and Combustible Liquids Code" 8
 3.4 Regulatory Summary 9
 3.5 Comparative Risk Discussion 10
4.0 Hazard Analysis And Risk Ranking 12
 4.1 Hazard/Risk Assessment Objectives and Approach to Analysis 12
 4.2 Historical Incident Data 12
 4.3 Propensity for Ignition 15
 4.4 Identification of Fire Scenarios of Concern (Possible) 18
 4.5 Risk Ranking and Credible Scenarios 18
 4.6 Summary of Scenarios and Credibility Assessment 25
 4.7 Design Fire Locations 26
5.0 Analysis Methodology 28
 5.1 Phenomena of Interest 28
 5.2 Quantification of Radiative Heat Transfer 28
 5.3 Target Characteristics 32
 5.4 Location of Persons and Structures 35
 5.5 Method of Comparative Analysis 38
6.0 Analysis and Discussion 39
 6.1 Comparative Scenarios 39
 6.2 Process Area Fire 41
 6.3 Tank Head Fire 43
 6.4 Tank Release and Bund Fire 45
 6.5 Life Safety 48
7.0 Discussion and Conclusion 49
8.0 Sources of Information 50

Appendix A - View Factor Calculations

1.0 INTRODUCTION AND SCOPE

A Jet A/A1 aviation fuel receiving and storage facility is proposed to be constructed on the Fraser River in Richmond, BC as part of the Vancouver Airport Fuel Delivery Project proposed by the Vancouver Airport Fuel Facilities Corporation. The facility is intended to consist of two major components:

- A marine terminal where tanker ships will be unloaded; and
- A storage tank farm where fuel will be retained temporarily before transportation through a pipeline to the Vancouver International Airport.

Due to the nature of the Project, there are multiple jurisdictions that will/may require building and fire code approvals, and currently there is limited risk assessment or quantification/qualification of the design standards relative to risk of fire and explosion completed for the facility. The project has undergone a harmonized federal/provincial Environmental Assessment which included descriptive analysis on fire preparedness, prevention, and emergency response. The Vancouver Fraser Port Authority (VFPA or PMV) issued an Environmental Assessment Certificate for the project on the basis that further fire risk assessment and hazard analysis would be completed at the construction permit stage.

Accordingly, this fire hazard/risk analysis outlines the codes and standards framework, compared and quantified relative to the defined regulatory objectives as a benchmark in addressing safety for the facility. The purpose of this analysis is to address safety related issues with the various agencies involved to demonstrate that the design, construction and operation of the facility will afford the appropriate level of fire safety to the community and responding fire service.

The analysis will include an assessment of potential hazards (possible fire scenarios), establishment of design fire scenarios and details of the methodology to quantify the consequences associated with the design fire scenarios. The intent of the work is to facilitate interface and approvals with the various jurisdictions in quantifying the approach, addressing concerns, and facilitating the necessary fire and life safety approvals in order to allow the Project to proceed. The analysis is specific to the storage area located north of the intersection of Williams and Dyke roads, and west of the Canadian National Railway R.O.W. in Richmond, BC.

2.0 FACILITY DESCRIPTION

The following sections of this report describe the Fuel Receiving Facility layout/operation, and the quantity and properties of fuel to be stored. For the purposes of this report, Jet A and Jet A1 have identical characteristics and from herein will only be referred to as Jet A1. Jet A1 is Jet A with additives to lower the fuel's freezing temperature for winter use.

2.1 GENERAL FACILITY LAYOUT

The proposed Jet A1 Fuel Receiving Facility is intended to be located north of the intersection of Williams and Dyke roads, and west of the Canadian National Railway R.O.W. in Richmond, BC. A site schematic is included in **Figure 1**. The proposed site is approximately 11.75 acres, will have a security fence (highlighted in green) and three points of access off Dyke road to the south (highlighted in red). The facility will have parking, an operations trailer and an equipment pad at the south end. The majority of the north area of the site will be used for the 6 fuel storage tanks and associated containment area (bunded area). A 6.5 m wide perimeter access/fire road will be provided around the site. A foam storage and distribution building will be located to the west of the tanks storage area. Locations A and B identify potential command centers or locations of primary fire system controls where responders can establish operations.

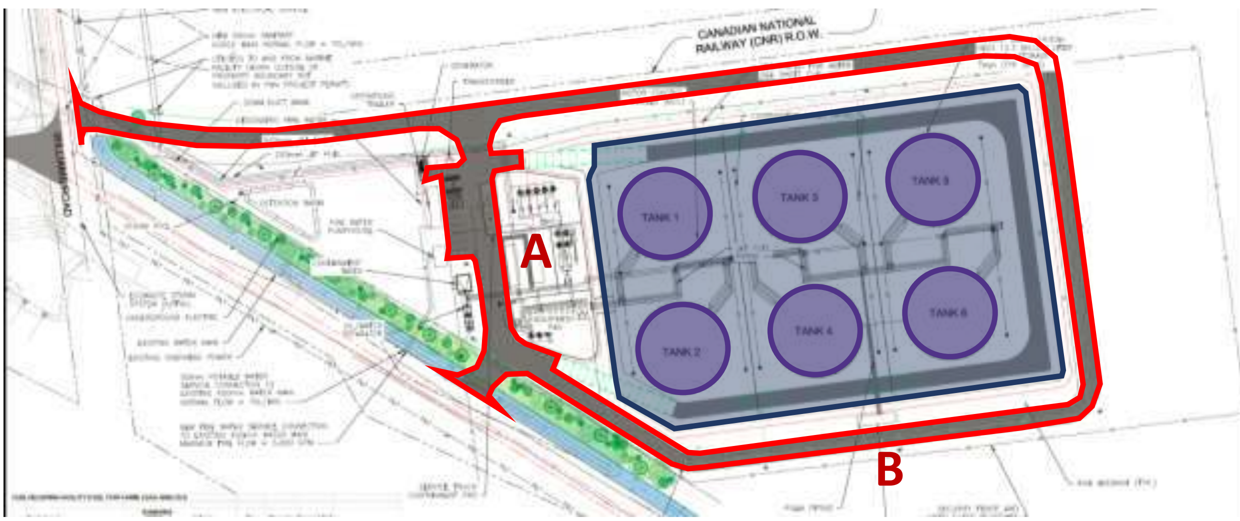


Figure 1: Facility overview.

2.2 STORAGE CONFIGURATION

The Fuel Receiving Facility is intended to have 6 storage tanks, highlighted in purple in **Figure 1**. Each tank will have:

a) a shell capacity of 14.1 million litres and a maximum usable capacity of 13.3 million litres,

b) a diameter of 35.05 m, and

c) a shell height of 14.63 m.

The total working capacity for all 6 tanks is approximately 80,000,000 litres. The tanks will be located in a containment bund with a capacity of 22,891,000 litres, highlighted in blue in **Figure 1**. The containment bund is approximately 166 m long by 106 m wide. The tanks will be at least 19.5 m from the property line, will be separated shell-to-shell from adjacent tanks by at least 17.5 m, and will be at least 36 m from the foam storage and distribution building.

The storage tanks will be equipped with an exterior shell and an interior floating roof to limit gaseous headspace above the Jet A1 liquid within. The tanks will be accessed in the containment area by raised catwalks and will have stairs on the exterior providing access to the top of the tanks. Side and end storage tank elevations are provided in **Figure 2** and **Figure 3**.

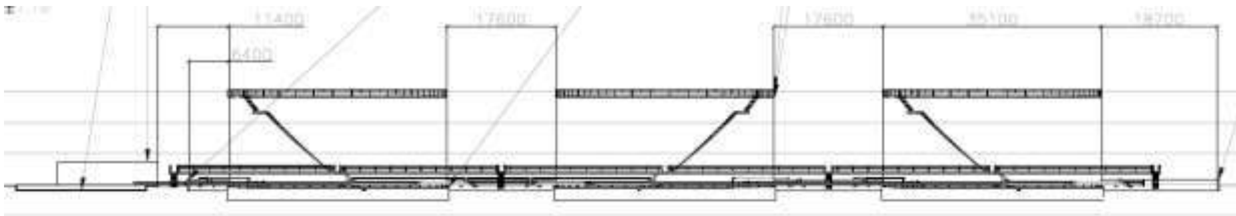


Figure 2: Storage area side elevation (Looking West).

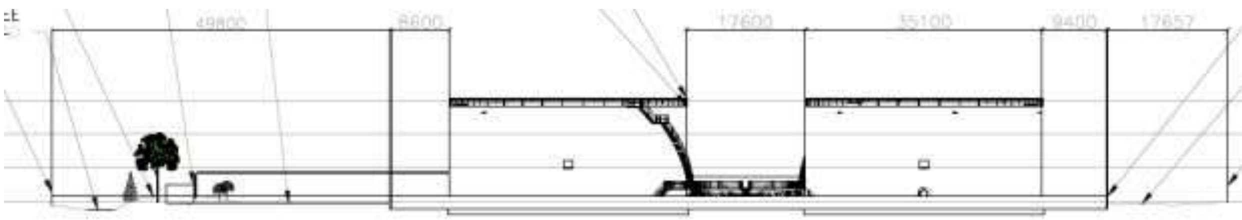


Figure 3: Storage area end elevation. (Looking South)

2.3 FACILITY OPERATION

The sole purpose of the Fuel Receiving Facility is to receive Jet A1 fuel from the adjacent Marine Terminal on the Fraser River, store the fuel in storage tanks and transfer the fuel to the Vancouver International Airport by pipeline. This is intended to be achieved through the following operational procedures:

1) Once vessel arrival, vetting, and containment procedures are completed, fuel quality testing will occur prior to acceptance of the fuel consignment.
2) The Fuel Receiving Facility operator will determine the sequence of tanks to be filled from the vessel based on a volume calculation and the ullage in the anticipated tanks.
3) The operator will, using the Programmable Logic Controller (PLC), open line valves and tank valves to provide the flow path for the fuel.
4) The vessel operator and marine terminal operator will complete a final check of connections, safety systems, and instrumentation prior to the vessel operator engaging the on-board pumps.
5) Fuel will flow from the vessel into the appropriate tanks at the Fuel Receiving Facility. As tanks are filled to pre-determined maximum fill heights, tank valves will automatically close and additional tank valves will open to allow continuous flow of fuel.
6) After all fuel has been received, line valves and tank valves will be closed in sequence.
7) Additional fuel quality testing and settlement time will ensure the fuel in the Fuel Receiving Facility meets minimum fuel quality standards prior to releasing batches of fuel to the airport.
8) Similar to steps 2 through 6, fuel will be transferred from the Fuel Receiving Facility to the airport fuel storage facility as space becomes available.

2.4 JET A1 CHARACTERISTICS

Jet A1 is a standardized fuel, similar to kerosene, commonly used to power jet aircraft. The key properties of Jet A1 fuel are summarized in **Table 1.**

Table 1: Jet A1 Fuel Properties.

Property	**Value**
Density	775 to 840 kg/m^3
Flash Point (pilot)	> 38 °C
Autoignition Temperature	210 °C
Boiling Point	140 - 300 °C
Lower Explosive Limit	0.7%
Upper Explosive Limit	5 %
Vapour Pressure	5.25 mmHg (20 °C)

Compared to other lighter fuels, Jet A1 is relatively stable, difficult to ignite in ambient conditions and does not easily form explosive vapour.

3.0 REGULATORY FRAMEWORK

The regulatory framework identifies the applicable regulatory requirements for the design and operation of the Fuel Receiving Facility. The intent of the regulatory framework is to identify the basis upon which a qualitative risk analysis can be established.

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 Fuel Receiving 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 2010 National Fire Code of Canada (2010 NFCC) is the current model fire code.

The 2010 NFC 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 some of the 2010 NFC requirements applicable to the design and construction of the Fuel Receiving Facility and the objectives and intents of these requirements. This assessment is not intended to be a complete compliance assessment of the Fuel Receiving Facility, but a summary of key requirements related to development of credible fire scenarios, which will be discussed in more detail later in this report.

3.2 2010 NFC REQUIREMENTS

The 2010 NFC contains provisions related to the design, construction and operation of outdoor aboveground tanks for the storage of flammable and combustible liquids. These requirements are based on the type of liquid stored and address, in part, storage proximity, fire department access, fire protection systems, and containment. These requirements are summarized relative to the design, construction and operation of the Fuel Receiving Facility in the following sections of this report.

3.2.1 Jet A1 Hazard Classification

The 2010 NFC 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 2010 NFC 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 2010 NFC 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 2**.

Table 2: 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

As noted in **Section 2.0** of this report, Jet A1 has a flash point greater than 38 °C. Therefore, in accordance with Clause 4.1.2.1.(3)(a), Jet A1 is classified as a Class II Combustible Liquid. For purposes of comparison, gasoline is a Class IB Flammable Liquid.

3.2.2 Separation from Buildings and Property Line

Requirement

Flammable/combustible liquid storage tanks are required to be spatially separated from property lines and buildings on the same property to reduce the risk of fire spreading from a tank to a building or other property, or from a building to a tank. This is addressed by Sentence 4.3.2.1.(2) of the 2010 NFC, which requires every aboveground storage tank containing stable liquids and having a working pressure of not more than 17 kPa (gauge) to be separated from a property line or building on the same property by distances as a function of tank capacity as outlined in Table 4.3.2.1. of the 2010 NFC.

As outlined in **Section 2.0** of this report, each Jet A1 storage tank has a maximum shell capacity of 14.1 million litres. In accordance with Table 4.3.2.1. of the 2010 NFC, where the maximum tank capacity is greater than 5 million litres, it is required to be at least 15 m from the closest property line or building on the same property.

Acceptable Risk

The intent of Sentence 4.3.2.1.(2) is to limit the probability that a fire in or associated with tanks and their liquids will:

- spread to adjacent buildings or facilities, which could lead to damage to adjacent buildings or facilities, or
- lead to harm to persons in outdoor areas or adjacent buildings.

Therefore, locating the Jet A1 fuel storage tanks 15 m or more from the property line or building on the same property is intended to limit the risk of damage to adjacent buildings/facilities and harm to persons to a level deemed to be acceptable by the 2010 NFC.

3.2.3 Separation of Storage Tanks

Requirement

Flammable/combustible liquid storage tanks are required to be spatially separated to reduce the risk of fire spread from one tank to another if fire occurs in a tank. This is addressed by Sentence 4.3.2.2.(1) of the 2010 NFC, which requires a minimum distance of 0.25 times the sum of the diameters between every combination of 2 aboveground storage tanks. This distance is not permitted to be less than 1 m.

As outlined in **Section 2.0** of this report, each Jet A1 storage tank has a diameter of 35.05 m. Therefore, the required separation distance between tanks is:

$$D = 0.25 \cdot (35.05\, m + 35.05\, m)$$
$$D = 17.53\, m$$

Acceptable Risk

The intent of Sentence 4.3.2.1.(2) is to limit the probability of:

- the spread of fire from one tank to another, which could lead to damage to the facility.
- delays or inefficiencies in conducting firefighting operations, which could lead to the spread of fire from one tank to another, which could lead to damage to the facility.

Therefore, separating the Jet A1 fuel storage tanks by 17.53 m or more is intended to limit the fire and life safety risk of fire spread from one tank to another, damage to the facility and inefficiencies in conducting firefighting operations to a level deemed to be acceptable by the 2010 NFC.

3.2.4 Secondary Containment

Requirement

Flammable/combustible liquid storage tanks are required to have secondary containment to contain any liquid that may spill from transfer operations or failure of a tank or tanks. This is addressed by Sentence 4.3.7.3.(2) of the 2010 NFC, which requires a minimum volumetric capacity of not less than the sum of the capacity of the largest storage tank in the containment space plus the greater of 10% of the:

a) capacity of the largest storage tank in the containment space, or
b) the aggregate capacity of all other storage tanks located in the containment space.

As outlined in **Section 2.0** of this report, the facility is intended to have 6 fuel storage tanks all located within the same containment space. Each tank has a shell capacity of 14.1 million litres. Therefore, the secondary containment is required to have a volumetric capacity of 21.15 million litres.

Acceptable Risk

The intent of Sentence 4.3.7.3.(2) is to limit the probability of overtopping [overflowing] of the spill containment area, which could lead to the escape and spread of liquid outside of the secondary containment, which could lead to the ignition of vapour from a nearby ignition source, which could lead to:

- harm to persons, or
- damage to the building or facility.

Sentence 4.3.7.3.(2) is also intended to limit the probability of overtopping [overflowing] of the spill containment area, which could lead to the escape and spread of liquid outside of the secondary containment, which could lead to harm to the public.

Therefore, providing secondary containment with a volumetric capacity of 21.15 million litres is intended to limit the fire and life safety risk of harm to persons and damage to the facility to a level deemed to be acceptable by the 2010 NFC.

3.2.5 Fixed Protection Systems

Requirement

A fixed fire protection system is required for tanks exceeding a certain size which may complicate firefighting operations. This is addressed by Sentence 4.3.2.5.(2) of the 2010 NFC, which requires that where the diameter of a storage tank exceeds 45 m, the storage tank is required to be provided with fixed protection systems designed in conformance with good engineering practice such as that described in:

a) NFPA 11, “Low-,Medium-, and High-Expansion Foam,”
b) NFPA 15, “Water Spray Fixed Systems for Fire Protection,” and
c) NFPA 69, “Explosion Prevention Systems.”

As outlined in **Section 2.0** of this report, each Jet A1 storage tank has a diameter of 35.05 m. Therefore, the 2010 NFC does not require a fixed fire protection system for the Fuel Receiving Facility Jet A1 fuel storage tanks.

Acceptable Risk

The intent of Sentence 4.3.2.5.(2) is to limit the probability that a fire in or associated with the tank will:

- spread to adjacent tanks on the same property, which could lead to damage to the facility, or
- lead to harm to persons in adjacent buildings or on adjacent properties.

Sentence 4.3.2.5.(2) is also intended to limit the probability of the spread of fire from adjacent buildings, tanks or property to the tank, which could lead to damage to the facility.

3.3 NFPA 30, “Flammable and Combustible Liquids Code”

While not applicable to the design, construction and operation of flammable and combustible storage tanks in British Columbia, NFPA 30, “Flammable and Combustible Liquids Code” is an industry document considered to be good engineering practice. This document includes requirements specific to outside aboveground storage tanks that are included in this report for purposes of comparison with the requirements in the 2010 NFC.

3.3.1 Separation from Buildings and Property Line

As outlined in **Section 2.0** of this report, it is our understanding that the Jet A1 fuel storage tanks will be designed with a floating roof, and will be provided with protection for exposures. Protection for exposures is defined in Section 3.3.46 of NFPA 30 as:

> *Fire protection for structures on property adjacent to liquid storage that is provided by (1) a public fire department or (2) a private fire brigade maintained on the property adjacent to the liquid storage, either of which is capable of providing cooling water streams to protect the property adjacent to the liquid storage.*

In accordance with Table 22.4.1.1(a) of NFPA 30, the minimum distance of the storage tank from the property line is ½ the diameter of the tank. As outlined in **Section 2.0** of this report, each Jet A1 storage tank has a diameter of 35.05 m. Therefore, the minimum required distance from a property line is:

$$D = \frac{1}{2} \cdot (35.05\,m)$$

$$D = 17.53\,m$$

The minimum distance calculated in accordance with NFPA 30 is 2.53 m greater than required by the 2010 NFC, as outlined in **Section 3.2.2** of this report.

In addition, in accordance with Table 22.4.1.1(a) of NFPA 30, the minimum distance of the storage tank from the nearest side of any public way or from the nearest important building on the same property is:

$$D = \frac{1}{6} \cdot (35.05\,m)$$

$$D = 5.84\,m$$

The minimum distance from a building on the same property, calculated in accordance with NFPA 30, is 9.16 m less than required by the 2010 NFC, as outlined in **Section 3.2.2** of this report.

3.3.2 Separation of Storage Tanks

In accordance with Table 22.4.2.1 of NFPA 30, for tanks storing Class II liquids, the separation distance from shell-to-shell to other tanks is:

$$D = \frac{1}{6} \cdot (35.05\,m + \ 35.05\,m)$$

$$D = 11.68\,m$$

The minimum shell-to-shell distance calculated in accordance with NFPA 30 is 5.85 m less than required by the 2010 NFC, as outlined in **Section 3.2.3** of this report.

3.3.3 Secondary Containment

In accordance with Section 22.11.2.2, the volumetric capacity of the diked area is required to be not less than the greatest amount of liquid that can be released from the largest tank within the diked area, assuming a full tank.

As outlined in **Section 2.0** of this report, the facility is intended to have 6 fuel storage tanks all located within the same containment space. Each tank has a maximum capacity of 14.1 million litres. Therefore, the secondary containment is required to have a volumetric capacity of 14.1 million litres. This is two thirds of the volumetric containment required by the 2010 NFC.

3.3.4 Fixed Protection Systems

In accordance with Section 22.8.2 of NFPA 30, floating-roof tanks storing any liquid does not require protection when installed in accordance with this Chapter 22 of NFPA 30.

3.4 Regulatory Summary

Table 3 provides a comparative summary of the 2010 NFC and 2012 NFPA 30 requirements for tank spacing, secondary containment and required fire protection system. These are compared to the proposed design.

Table 3: Summary of regulatory requirements.

Parameter	2010 NFC	2012 NFPA 30	Proposed Design
Minimum distance from property line (m)	15	17.5	19.5
Minimum distance from a building on the same property (m)	15	5.8	15
Minimum shell-to-shell distance between tanks (m)	17.5	11.7	17.5
Minimum secondary containment volume (L)	21,150,000	14,100,000	22,891,000
Fixed fire protection system	Not required	Not required	Foam system (NFPA 11)
Tank water spray cooling system	Not Required	Not Required	To be provided

3.5 COMPARATIVE RISK DISCUSSION

As outlined in **Table 3**, the proposed design will comply with and exceed the requirements for both the 2010 NFC and the 2012 NFPA 30 relative to tank spacing, secondary containment and the requirement for fixed fire suppression. The 2012 NFPA 30 does not identify objectives relative to its acceptable solutions. However, similar to the 2010 NFC, compliance with the acceptable solutions is considered to address the risk of fire spread and life safety to an "acceptable" level with respect to the operation of outside aboveground tanks storing Jet A1 fuel.

The purpose of the analysis outlined in this report is to examine the design of the Fuel Receiving Facility and protective features intended to limit the probability of fire occurring or the consequence should a fire occur. The intent is to examine the risk on a comparative basis with the acceptable risk implicit to the regulatory requirements outlined above.

Comparative risk is the process of comparing two or more risks with respect to a common scale, typically expressed as a ratio. The National Fire Code of Canada indirectly considers comparative risk relative to the alternative solution process:

> *an effort must be made to demonstrate that an alternative solution will perform as well as a design that would satisfy the applicable acceptable solutions in Division B—not "well enough" but "as well as." [2010 NFCC]*

In this case, comparative risk is considered relative to a quantified consequence and qualitative probability. Thus, the result will be more qualitative than quantitative, which is largely a consequence of the limitation in assessing probability quantitatively. These concepts are discussed in more detail in the following sections.

3.5.1 Base Risk

Acceptable risk is difficult to quantify, and Canada has little to no guidance on what is considered "acceptable" relative to fire and life safety for outside fuel storage facilities. However, facilities designed in accordance with the 2010 NFC are considered to have an "acceptable" level of fire risk. However, this level of acceptability is based on regulations developed and reviewed by persons involved in the NFC process, and may differ from what the general public considers "acceptable". Nonetheless, the 2010 NFC provides a reasonable basis for risk comparison.

The measure of comparative risk is the combination of consequence and probability for each case under consideration. The base risk is the unmitigated risk. That is, the relative risk before any potential mitigation strategies are implemented. This is the level of risk implicit to compliance with the applicable regulatory requirements (i.e., the 2010 NFC).

3.5.2 Risk Reduction

In general, risk is reduced by:

- Reducing the probability of a fire occurring, or
- Mitigating the consequences, if a fire were to occur.

The intent of the design of the Fuel Receiving Facility is to reduce the risk of fire below that intended by conformance with the applicable regulatory requirements by implementation of mitigation strategies. The purpose of the mitigation strategies is to provide a design and operation that are risk informed to maximize the risk reduction potential beyond the minimum.

The following section of this report outlines the hazard/risk analysis objectives, considering compliance with the regulatory requirements as a minimum level of acceptable risk for purposes of comparison with the results of a hazard/risk analysis and impact of proposed mitigation strategies.

4.0 HAZARD ANALYSIS AND RISK RANKING

The applicable regulatory requirements, outlined in the previous section of this report, have been developed with the intention of addressing the fire and life safety risks associated with operation of flammable/combustible liquid storage facilities in general. Conformance with these requirements is expected to address the majority of the fire and life safety risks that may be faced in the operation of such a facility. However, each fuel storage facility is uniquely designed relative to its intended operation, interfaces, environmental conditions and capability of the responding fire service. Therefore, supplemental analysis of the fire and life safety risks can help facilitate design of the Fuel Receiving Facility within the context of these unique factors.

4.1 HAZARD/RISK ASSESSMENT OBJECTIVES AND APPROACH TO ANALYSIS

The objective of the fire and life safety hazard/risk assessment is to analyze the:

- risk of injury to the public, site personnel and responding fire service as a result of exposure to heat from credible fires.
- risk of damage to the Fuel Receiving Facility as a result of exposure to heat from credible design fires.

Examination of the performance of the Fuel Receiving Facility relative to these objectives requires consideration of the following:

1. Historical incident data.
2. The propensity for ignition.
3. Identification of scenarios of concern.
4. Establishing credible fire scenarios from the scenarios of concern.
5. Identification of the criteria by which performance of the Fuel Receiving Facility design is analyzed.
6. Selection of appropriate methods for examination of the Fuel Receiving Facility design relative to the hazard/risk objectives and associated performance criteria.
7. Analysis using appropriate methods to demonstrate performance of the Fuel Receiving Facility design based on the performance criteria in order to achieve the hazard/risk objective.

The historical incident data, propensity for ignition, identification of possible scenarios of concern and selection of credible fires are discussed in the following sections of this report. Performance criteria and analysis methodologies are discussed later in this report.

4.2 HISTORICAL INCIDENT DATA

A 2014 study conducted by the NFPA [1] summarizes fire loss statistics for outside storage tanks in the United States between the years 2007 and 2011, and includes data relative to injuries and property damage between the years 1980 and 2011. One of the key findings of this report is that [1]:

> *Fires at outside storage tanks have decreased markedly over the past three decades. In 2011, there was an estimated 275 reported fires in these facilities, a 76% decrease from 1,142 estimated fires in 1980. Even since 2000, when there was an estimated 608 fires, fires have fallen by 55%. Civilian injuries have also fallen sharply since 1980. In the five years from 1980 to 1984, there were an estimated 28 injuries per year caused by fires at*

outside storage tanks, compared to an average of one injury per year between 2007 and 2011, compared to an average of 3.8 civilian fatalities per year between 1980 and 1984.

This report also notes that of 239 "outside and other fires at outdoor storage tanks", the heat source, item first ignited and factors contributing to ignition are summarized respectively in **Table 4** to **Table 6**.

Table 4: Summary of heat source of fires at outdoor storage tank facilities.

Heat Source	**Fires**	
	Number	**Percent**
Lightning	81	34
Outside rubbish fires	46	19
Spark, ember or flame from operating equipment	22	9
Flame or torch used for lighting	16	7
Other known heat source	16	7
Unclassified heat source	14	6
Molten or hot material	8	3
Unclassified heat from powered equipment	8	3
Unclassified hot or smoldering object	7	3
Radiated, conducted heat from operating equipment	7	3
Arcing	5	2
Heat or spark from friction	4	2
Hot ember or ash	4	2
Total	**239**	**100**

Table 5: Summary of item first ignited for fires at outdoor storage tank facilities.

Item First Ignited	**Fires**	
	Number	**Percent**
Flammable or combustible liquids or gases, piping or filter	152	64
Outside rubbish fire	46	19
Unspecified item first ignited	21	9
Light vegetation, including grass	19	8
Bulk storage	14	6
Rubbish, trash or waste	6	3
Unclassified organic materials	4	2
Total	**239**	**100**

Table 6: Summary of factor contributing to ignition for fires at outdoor storage tank facilities.

Factor Contributing	Fires	
	Number	**Percent**
Storm	80	33
Outside rubbish fire	46	19
Cutting or welding too close to combustible	29	12
Other known factor contributing to ignition	22	9
Mechanical failure or malfunction	17	7
Natural condition, other	14	6
Other factor contributed to ignition	9	4
Electrical failure or malfunction	9	4
Heat source too close to combustibles	6	3
Exposure fire	6	2
Unclassified operational deficiency	4	2
Flammable liquid or gas spilled	4	2
Rekindle	3	1
Total	**239**	**100**

A study of tank farm incidents in the United States from 1960 to 2003 note that most tank fire incidents occurred between 1980 and 1999 [3]. The study indicates that these years were the “most prosperous for a wide range of developments” and that “Safety issues caught the industries attention, and many worked to find better solutions for improving tank farm safety and preventing similar incidents”. These results are consistent with those summarized in the NFPA study above.

Specific fire and explosion events involving jet fuel storage facilities is outlined in **Table 7** below. These incidents and the loss data summarized in **Table 4** to **Table 6** above will be used to establish propensity for ignition and potential hazardous scenarios, which will be discussed in more detail in the next few sections of this report.

Table 7: Specific fire/explosion incidents involving jet fuel storage.

Incident	Year	Fatalities	Summary
Ajjacio, Corsica	1970	0	Two tanks containing one million litres of kerosene exploded causing US$300,000 damage.
Netherlands	1975	0	A metal storage tank of 5000 m^3 capacity encased in concrete and covered with earth, 1/3rd full of aviation fuel exploded when lightning struck a tree adjacent to the tank. The tank was allowed to burn out.
Harare, Zimbabwe	1978	0	22 of 28 tanks containing diesel, jet fuel and gasoline were destroyed during a 3 day fire. Ignition source tracer bullets and rockets. The 40 acre terminal was largely destroyed.

Incident	Year	Fatalities	Summary
Yokohama, Japan	1981	0	An explosion in an underground storage tank containing jet fuel. Nearby residents were evacuated and there were 2 injuries.
Baltimore Airport, US	1989	0	Jet fuel overflowed a storage tank due to a defective bleed valve.
Denver, Colorado	1990	0	A fire that burned for 55 hours at the fuel storage area for an airport destroyed or damaged 7 tanks and consumed more than 1.66 million gallons of jet fuel, causing $30 million damage. No reported injuries.
Avonmouth, UK	1994	1	A port worker was killed in a fire at a fuel pipeline at dock. Fire spread to kerosene in tanks at the storage depot and burned for 18 hours.
Dronka, Egypt	1994	420	Blazing liquid fuel flowed into the village of Dronka, Egypt. The fuel came from a depot of eight tanks, each holding 5000te of aviation or diesel fuel. The release occurred during a rainstorm and was said to have been caused by lightning. 420 fatalities reported.
Dikson, Russia	1995	0	Pipeline ruptured at storage tank under weight of snow at airport. 1800 tonnes of jet fuel poured over snow and ice and then to sea.
Trainer, US	1998	0	A 55-foot tank containing 16,000 bbl jet fuel exploded and burned at a refinery. Approximately 700,000 gallons of fuel burned for more than four hours before being brought under control. No death or serious injury.
Anchorage, Alaska, US	2000	0	A fire occurred on a tank during tank cleaning. The tank contained 2000 gallons of jet fuel. No injuries.
UK	2000	0	Jet fuel was seen to be shooting from a stationery tank in a continuous stream. The incident occurred due to valves on the tank being opened by vandals. Approx. 150,000 litres was released into the environment. Bund drain valve was left open and allowed oil to escape. Company fined.
Miami, USA	2011	0	Failure of a fuel filter in the process area resulted in spilled jet fuel and a subsequent fire. The fire was suppressed by the responding fire service and did not involve the storage tanks.

4.3 Propensity for Ignition

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.

4.3.1 Ignition Source

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

As outlined in **Section 4.2** of this report, the majority of tank fire incidents occurred as a result of ignition by lightning, or outside rubbish fires. Environment Canada notes that 1889 lightning strikes have been recorded within 25 km of the centre of the city of Richmond between 1999 and 2013 (14 years). In addition, the average annual number of days which one would expect to detect lightning within 25 km of the centre of the city of Richmond has been estimated to be 8.6. This is a relatively low frequency of lightning occurrences relative to other locations in which lightning ignitions of fuel storage facilities have occurred. **Figure 4** shows the global distribution of lightning strikes based on satellite monitoring and the value corresponding with the Lower mainland of British Columbia is on the low end of the scale. Therefore, the probability of a fire occurring as a result of lightning ignition at the Fuel Receiving Facility is considered lower than for the most tank locations (i.e., those represented by the loss statistics).

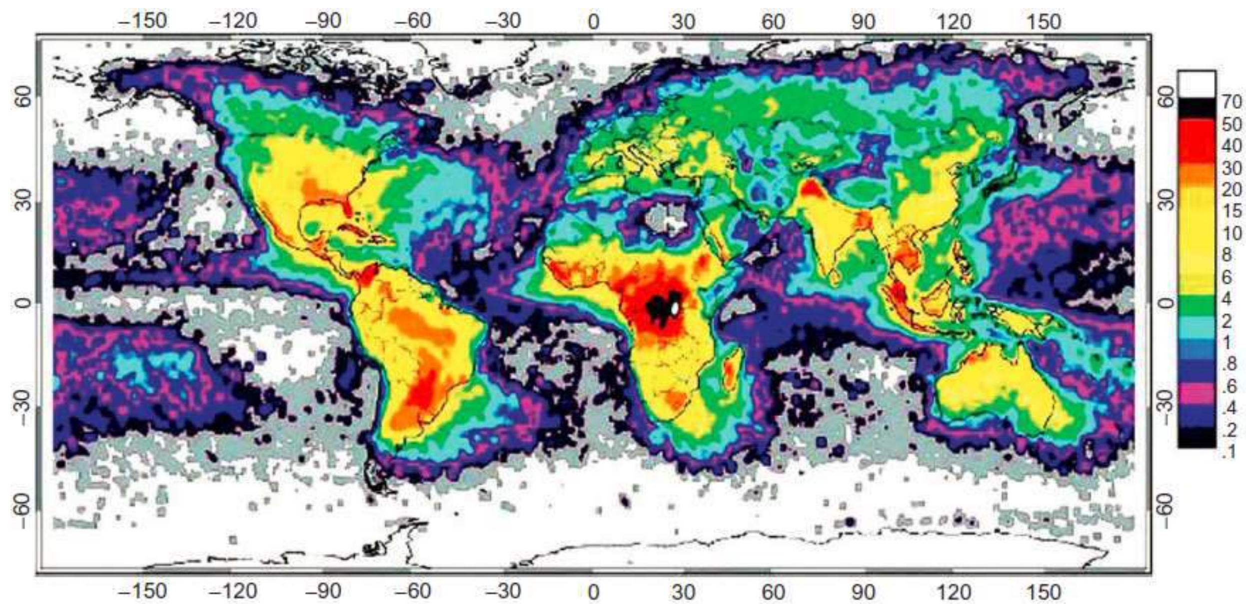


Figure 4: global distribution of lightning strikes based on satellite monitoring [3].

The Fuel Receiving Facility will be fenced, have on site staff, 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 explosion. 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. Therefore, the propensity for a fire to occur as a result of ignition of outside rubbish, intentional damage is low and not anticipated to be a significant for this Project.

In an industrial setting, there are a number of possible ignition sources including 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 as follows:

- **Static:** The Fuel Receiving Facility equipment will be designed to limit the potential for static discharge including grounding systems, static dissipating additives in the fuel, and use of non-sparking metals and materials in system components. Operational procedures also protect the facility from risk of static discharge by use of air elimination equipment, relaxation time between filtration and tanks, and minimizing of fuel free-flow which oxygenates the fuel.

- **Hot Work Operations:** The Fuel Receiving Facility will have detailed hot work operation procedures and training in compliance with the 2010 NFC and other applicable codes/standards. This will reduce the probability of ignition by hot work operations.
- **Smoking:** Smoking will not be permitted on the Fuel Receiving Facility property.
- **Mechanical Failure/Friction:** The Fuel Receiving Facility will have minimal mechanical components other than pumps, which will be designed specific to hazards associated with the transfer Jet A1 fuel. The pumps will be provided with bearing temperature sensors that are continuously monitored through the PLC and alarmed in the event of a high temperature.

The proposed design and intended operation of the Fuel Receiving Facility, as noted above, will limit the probability of ignition.

4.3.2 Material First Ignited (Fuel)

Ambient temperatures in Richmond, BC are shown in **Figure 5**. The average high temperatures range between 5 °C and 23 °C. The maximum temperature recorded for Richmond, BC was 34 °C on July in 2009.

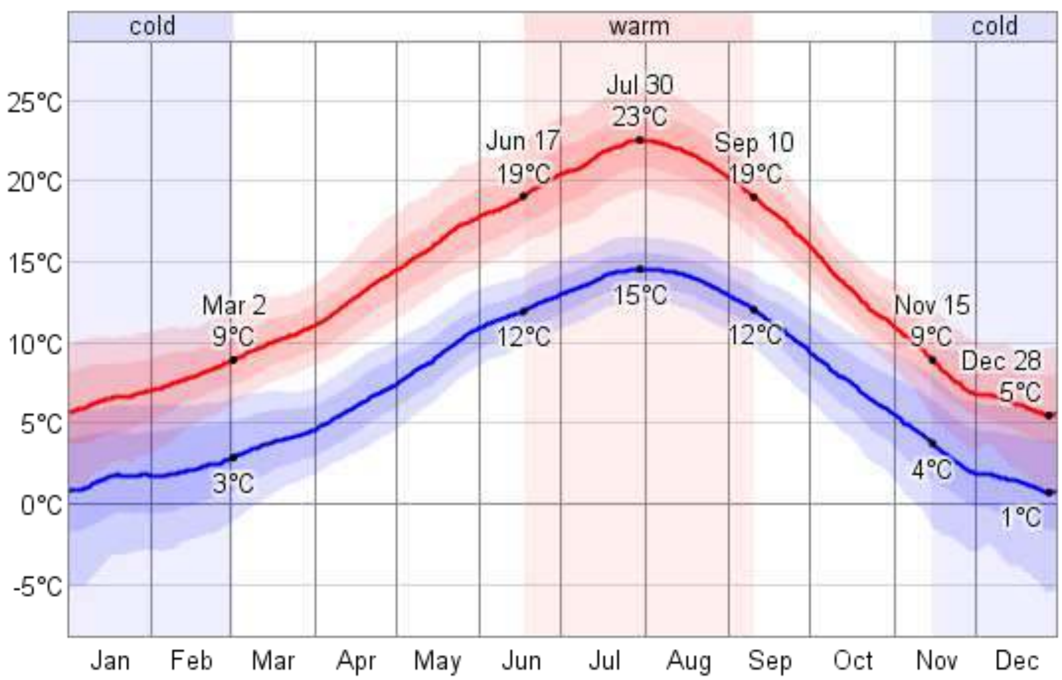


Figure 5: Average temperatures in Richmond, BC [4].

The peak of the average daily high temperatures (23 °C) is significantly lower than the flash point of Jet A1 fuel (greater than 38 °C), which is also higher than the maximum temperature recorded in Richmond (34 °C). Therefore, given the ambient temperature data for Richmond, BC, the propensity for Jet A1 fuel to ignite without external heat is negligible.

4.4 IDENTIFICATION OF FIRE SCENARIOS OF CONCERN (POSSIBLE)

In establishing appropriate design fires [5], a distinction should be made between possible fire scenarios and credible design fire scenarios. Possible fire scenarios include the spectrum of all fire scenarios that may occur, whereas design fire scenarios are a subset of the possible fires considered credible.

Identification of fire scenarios of concern is primarily based on experience, records of past fires, statistical data and similar methods based on the materials and activities that may exist in the facility being considered.

The Fuel Receiving Facility is intended for the sole purpose of storage and transfer of Jet A1 fuel by a single operator. Therefore, the identification of fire scenarios of concern relate to the ignition and combustion properties of this product and is based on a review of historical fire losses relative to the following components:

- fuel tanks
- pumps and transportation lines (this risk assessment does not address the pipeline from the storage tanks to the airport).

The barges used to transport the Jet A1 fuel to the Fuel Receiving Facility and the pipeline intended to transfer the Jet A1 fuel to the Vancouver International Airport are not within the scope of the analysis outlined in this report.

The following fire hazards have been developed based on historical data outlined in **Section 4.2** of this report:

1. Tank overfilling and fire,
2. Tank head fire,
3. Multiple tank head fires,
4. Single tank release and bund fire,
    a) Full tank,
    b) Partially full tank,
5. Multiple tank release and bund fire,
    a) Contained to bund,
    b) Bund overtopping
6. Explosion in empty tank,
7. Boilover,
8. Process area fire.

The credibility of these scenarios will be examined in the following section of this report, based on risk indexing.

4.5 RISK RANKING AND CREDIBLE SCENARIOS

Credible fire scenarios are defined by considering the combination of all factors (such as operational procedures, environmental factors, geometric constraints, fuel location, potential exposure, risk of ignition, frequency of events, etc.) and the corresponding likelihood of that scenario. Scenarios with a low severity are considered acceptable; more frequent scenarios with a higher severity are defined as credible; scenarios that require the combination of worst case events that are remote with a high severity are considered improbable and unrealistic for the purpose of design. Specifically in establishing credible design fires, the following is noted:

> *The selected fire scenarios should ensure that, if the design results in acceptable outcomes for those scenarios, it may be considered safe for the applicable scenarios, except for those specifically excluded as too unrealistically severe, too unlikely to be fair tests of the design, or considered to be outside the bounds of how the building or space is intended to be used. Detailed discussions need to be undertaken with the stakeholders in defining the above so stakeholders are in agreement as to which design fires are and are not credible.*

Possible fire scenarios have been identified in **Section 4.4** of this report relative to the activities and operations of the facility. These scenarios are examined qualitatively using risk scoring, which allows identification of credible scenarios relative to the risk and design objectives. Using a qualitative assessment of likelihood and the potential severity (i.e. occupant exposure relative to egress), the fire scenarios are assigned a risk score. The risk scoring assessment relative to the design fires is based upon the concepts and guidelines outlined in NFPA 551 – Guide for the Evaluation of Fire Risk Assessments[1]; the criteria are outlined in **Table 10** and **Table 11**, with descriptors for the frequency and consequence levels included in **Table 8** and **Table 9**.

Table 8: Frequency levels.

Category	Frequency of Occurrence	Quantification	Frequency
Frequent	Continually occurs during operational life cycle	6 incidents per year	6+
Probable	May occur a few times during operational life cycle	1.25 incidents per year	1.25 to 6
Occasional	May occur several times during operational life of facility	one incident every 0.8 to 4 years	0.25 to 1.25
Remote	May occur at some time in the facility life cycle	one incident every 4 to 20 years	0.05 to 0.25
Improbable	Unlikely to occur during facility life	one incident every 20 to 100 years	0.01 to 0.05
Eliminated	Extremely unlikely to occur	one incident every 100 to 500 years	0.002 to 0.01

Table 9: Consequence levels.

Severity Level	Consequence to Persons	Consequence to Facility
Catastrophic	Fatalities and/or multiple severe injuries	Total system facility
Critical	Single fatality and/or severe injury	Loss of a major facility component
Marginal	Minor injury	Severe facility damage
Negligible	Possible minor injury	Minor facility damage

[1] NFPA 551: Guide for the Evaluation of Fire Risk Assessments, 2013 Edition, National Fire Protection Association.

Table 10: Risk Scoring Matrix.

Likelihood	**5 - Frequent**	Undesirable	Intolerable	Intolerable	Intolerable
	4 - Probable	Tolerable	Undesirable	Intolerable	Intolerable
	3 - Occasional	Tolerable	Undesirable	Undesirable	Intolerable
	2 - Remote	Negligible	Tolerable	Undesirable	Undesirable
	1 - Improbable	Negligible	Negligible	Tolerable	Tolerable
	0 - Eliminated	Negligible	Negligible	Negligible	Negligible
Consequence		**1 - Negligible**	**2 - Marginal**	**3 - Critical**	**4 - Catastrophic**

Table 11: Risk Score Descriptions and Acceptance Criteria.

Risk Score	Description
Intolerable	Unacceptable: Poses immediate threat to personal safety. Correct, control, avoid, or mitigate immediately.
Undesirable	Acceptable short-term: May pose a threat to personal safety. Formulate corrective action plans and implement on a priority basis.
Tolerable	Acceptable with management review: Deemed acceptable or unavoidable risk after review by key stakeholders. Formal documentation of acceptance necessary.
Negligible	Acceptable: Deemed to be an acceptable risk. Documentation of this acceptance is necessary.

Therefore, a risk result of “Undesirable” or “Intolerable” is considered to be a credible design fire for purposes of examining the Project objectives.

The frequency of a tank fire event in a fixed roof tank containing volatile hydrocarbons is once in 833 tank years [3], or a probability of 0.0012 occurrences per year. This includes all types of volatile hydrocarbons including those that are more prone to ignition than Jet A1, and also includes all types of failures and modes of ignition. Jet A1 is much less volatile than many other types of hydrocarbons, will be stored in internal floating roof tanks intended to be protected with a foam suppression system, and will include other risk mitigation design measures; therefore, the probability of a fire event is anticipated to be much lower for the Fuel Receiving Facility. Further, as noted earlier, the most probable source of ignition is lightning (34%), which has a low frequency of occurrence in Richmond.

The Fuel Receiving Facility will be designed with 6 storage tanks. Using the conservative probability of occurrence of fire noted above, and assuming fire events as mutually exclusive, the estimated probability of a tank fire for six tanks is 0.0072 occurrences per year, which translates to the potential for one fire event in 138.9 years.

Based on the frequency levels outlined in **Table 8**, the frequency of occurrence of a tank fire event based on a probability per tank/year of 0.0072 is considered “eliminated”. Based on the “Risk Scoring Matrix” detailed in **Table 10**, this indicates that the consequence would be considered “Negligible” for all consequence categories and that the design would be considered “Acceptable” in terms of the “Risk Scoring Acceptance Criteria” outlined in **Table 11**. This assumes that the facility is designed in conformance with the applicable regulations (i.e., the 2010 NFC). Conformance with the 2010 NFC is considered by the 2010 NFC to result in a design that has an "acceptable" level of risk, which is consistent with the "Risk Scoring Acceptance Criteria" result noted above.

However, as outlined in **Section 3.5.2** of this report, the intent of the design of the Fuel Receiving Facility is to reduce the risk of fire below that intended by conformance with the applicable regulatory requirements through implementation of risk mitigation strategies. Therefore, while the probability of the occurrence of fire in fuel storage tanks is incredibly low, the purpose of the following sections of this report is to review a breadth of possible fire scenarios with the intent of selecting a range of scenarios sufficient to examine the impact of the mitigation strategies.

4.5.1 Tank Overfilling and Fires

Tank overfilling was the cause of the Buncefield, UK gasoline tank explosion and fire that occurred in 2005. The Buncefield event occurred as a result of the release of gasoline, development and ignition of a vapour cloud, resulting in a major explosion. The explosion and resulting fire engulfed approximately 23 large atmospheric storage tanks, causing subsequent tank ignitions and releases. The fire burned for several days and resulted in 43 people injured.

Overfilling can occur when the tank reaches its maximum capacity and the pump continues to supply fuel from the barge to the tank. This typically occurs as a result of failure of the fuel level instrumentation and controls. In the case of the Buncefield incident, the servo gauge failed and alarms and other controllers did not operate. This resulted in the release of 300 metric tons of unleaded gasoline. Since then, many changes have occurred in the industry to reduce the probability of equipment failure relative to overfilling. The tanks at the Fuel Receiving Facility will be designed to limit the potential for overfilling based on the following:

- Batch receipts programmed based on available tank space.
- High resolution digital tank gauging with automated shut-off set points.
- Independent high and high-high level switches with automated valve closure.
- PLC communication with marine terminal to shut down off-loading operations.

Therefore, the probability of overfilling is remote. However, should it occur and Jet A1 fuel be released, the probability of ignition (similar to the Buncefield event) is also remote. This is due to the difference in flash point of the gasoline involved in the Buncefield incident relative to Jet A1. The cumulative impact of these remote events is considered "eliminated", as noted previously.

Gasoline has a flash point of approximately −43 °C, and is classified as a flammable liquid. Gasoline can form an explosive mixture with air at normal working temperatures, as well as temperatures much lower than normal working temperatures. Jet A1 has a much higher flash point (approx. 81 °C higher) and is not prone to forming an explosive mixture with air under normal working temperatures. Therefore, a release of Jet A1 due to overfilling is anticipated to have an "eliminated" likelihood of ignition and explosion than gasoline, limiting the probability of a Buncefield type event.

Based on the information summarized above, a fire occurring as a result of tank overfilling is considered "eliminated". Should overfilling occur, given the safety measures to mitigate the extent of overfilling and limited probability of ignition, the potential consequence is anticipated to be no injury to potential minor injury with minor to severe facility damage. This correlates with a consequence level of "Negligible" to "Marginal".

Therefore, overfilling and potential fire from a tank is not considered a representative design fire for purposes of examining the risk of fire for the Fuel Receiving Facility.

4.5.2 Tank Head Fire

A tank head fire can occur, and is one of the more frequent types of fire in storage tanks, where the roof of the tank fails and the fuel surface is ignited. Two conditions are required for ignition of fuel at the tank head to occur:

1. The presence of sufficient Jet A1 vapour at the head or head space of the tank, and
2. The presence of an ignition source with adequate energy to cause sustained combustion of the Jet A1 fuel.

The tanks at the Fuel Receiving Facility will be designed with an internal floating roof. A floating roof in an atmospheric pressure storage tank eliminates the vapour space in the tank head space, limiting the potential for Jet A1 vapour to develop. Further, as noted earlier in this report, Jet A1 is a combustible liquid that does not generally develop a flammable vapour sufficient for ignition under normal working temperatures (i.e., less than 38 °C). Floating roof tanks can be open or closed. The Fuel Receiving Facility will use closed-type floating roof tanks, which have a good fire record such that foam suppression systems are generally not required [3]. However, rim fires are the most common type of fire for floating roof tanks, but primarily in open type floating roof tanks [3].

Assuming ignition occurs and the foam suppression system is not activated or is ineffective, a tank head fire could occur and range from a rim fire to full tank head involvement. Full tank involvement is anticipated to damage the directly exposed portion of the tank rim and potentially cause minor spillage into the bund area. However, the liquid below the burning surface is expected to provide cooling to the tank shell below, limiting the potential for shell failure.

Full tank head involvement is a significant event that has the potential to result in a single fatality/severe injury and potential for loss of a major facility component (i.e., a tank). Therefore, a full tank head fire is considered a representative design fires for purposes of examining the risk of fire for the Fuel Receiving Facility.

4.5.3 Multiple Tank Head Fires

A tank head fire can impact adjacent tanks, which may result in additional tank fires. This can occur sequentially from tank to tank, potentially resulting in ignition of all proximal tanks within a facility.

A tank head fire will transmit heat to adjacent tanks primarily through radiant exposure, which can vary as a function of fire size, flame shape (i.e., wind tilting) and exposure duration. Regulatory separation distances are intended to mitigate the spread of fire to adjacent tanks for a period of time sufficient to allow evacuation of the facility and initiation of suppression activities to protect adjacent tanks.

In addition to tank separation distance, the Fuel Receiving Facility will be equipped with a fixed water cooling system for each storage tank which will require manual activation followed by automatic nozzle array selection. The system will provide cooling to the tanks adjacent to the tank involved in fire, and will be designed to protect the adjacent tanks for the duration of the fire. Water cooling systems are effective in limiting heat transfer between tanks and significantly reducing the probability of ignition of adjacent tanks.

Therefore, the following sequence of events is anticipated for a multiple tank head fire to occur:

1. Ignition of tank contents
2. Failure of the foam system to operate or suppress a tank fire
3. Growth of the tank fire to significantly impact adjacent tanks
4. Failure of the water cooling system to operate or cool adjacent tanks

5. Fire severity limits fire service application of water to adjacent tanks or water supply for fire service application limited

As noted earlier, the probability of a tank fire incident is considered "eliminated". Considering the lower probability of occurrence associated with Jet A1 fuel storage and the additional mitigation measures being provided for the Fuel Receiving Facility that further reduce the probability of fire spread (i.e., foam suppression system and tank cooling), the potential for a more than one tank head fire is almost insignificant. Further, the time associated with the occurrence of multiple tank head fires is likely sufficient to allow for evacuation of the area surrounding the facility, limiting the potential for injuries and fatalities beyond that associated with a single tank head fire.

In addition, assuming a full tank, the Fuel Receiving Facility has the ability to draw down tank contents within approximately 12 to 18 hours, limiting the total fuel on site and potential for fire spread. For a less than full tank, the draw down time would be reduced.

Therefore, the potential for a fire involving multiple tank heads is not considered sufficiently probable to be considered a representative design fire for purposes of examining the risk of fire for the Fuel Receiving Facility.

4.5.4 Tank Release and Bund Fire

A tank release can occur as a result of a failure of the tank structure potentially from a head fire, explosion, corrosion, physical damage, or earthquake. The release of the liquid from the tank can range from small and gradual to large and instantaneous. A small, gradual release can occur where a small hole forms in the tank wall. A large instantaneous release can occur where the tank wall fails.

The probability of tank failure can be reduced by regular tank inspection and maintenance. The Fuel Receiving Facility will have periodic inspection and maintenance scheduled to address potential tank issues than could result in failure, with specific 3rd party inspections on the storage tanks to API Standard 653 - Tank Inspection, Repair, Alteration, and Reconstruction. In addition, the fuel storage tanks will be constructed in conformance with API 650, which limits the probability of potential modes of failure by requiring specific design features. As discussed in **Section 4.5.2** of this report, tank failure as a result of a tank head fire is limited by the cooling of the tank shell by the liquid contained within the tank. The probability of tank failure as a result of explosion will be significantly limited by provision of a floating roof and limited ignition propensity of Jet A1. Therefore, given the tank design standard, and periodic inspection and maintenance, catastrophic tank failure as a result of head fire, explosion, corrosion or physical damage is considered insignificant.

Given the history of seismic activity in Richmond and potential magnitude of such an event, tank failure as a result of an earthquake is possible. However, API 650 Annex E contains design provisions to limit the impact of seismic activity on tank performance and a study of the "Seismic Design Loads for Storage Tanks" notes the following [6]:

> *There appears to be adequate evidence that even unanchored tanks on grade can sustain certain modes of inelastic behaviour, such as base uplift and elephants foot buckling of steel tanks, without losing their contents.*

An analysis of the probability of tank failure relative to earthquake activity has not been conducted for the Fuel Receiving Facility. However, the design criteria for the facility includes a Seismic User Group III (SUG III) rating and 1:2475 year seismic event capability. In order to meet these stringent operational requirements, the geotechnical design calls for extensive soil replacement and ground densification, as well as concrete tank foundations and anchoring system. For the purposes of establishing representative design fires in this report it is assumed that multiple tank failure has a reasonably low probability of occurrence during an earthquake, but that failure of a single tank is possible. This assumption is predicated on the corresponding assumption of ignition of the spilled contents, and a resulting bund fire.

The bund is designed to contain the full volume of any one of the Fuel Receiving Facility tanks plus 62% of another tank. As noted in **Section 3.4** of this report, this is more containment than required by the 2010 NFC (1 tank plus 10% of the remaining tanks) and NFPA 30 (1 tank).

Full tank release and bund fire is a significant event that has the potential to result in fatalities/severe injuries and potential for loss of the entire facility.

As noted earlier in this report, the probability of a fire event in a tank storing volatile hydrocarbons is sufficiently low to be considered "eliminated", and is even lower for the Fuel Receiving Facility considering the reduced propensity for ignition of Jet A1 relative to other volatile hydrocarbons and the additional risk mitigation design measures being added to the facility. A further reduction in probability is warranted considering the likelihood of occurrence of an earthquake of sufficient magnitude to result in failure of a tank and subsequent fire (i.e., a 1:2475 year seismic event capability). Given these considerations, the probability of such an event is estimated to be extremely low to not be considered a credible fire scenario. However, given the potential severity of such an event, a single tank release and bund fire is considered a challenge design fire for purposes of examining the upper bound risk of fire for the Fuel Receiving Facility. A challenge fire scenario is evaluated for information purposes as an extreme upper bound, but is not intended to govern the design of the Fuel Receiving Facility.

4.5.5 Explosion in an Empty Tank

Work inside a tank will be limited to tanks that have been emptied. While complete removal of all residual Jet A1 fuel from a tank is not possible, it is anticipated that very little fuel will remain in a tank when work is conducted. As outlined in **Section 2.4** of this report, Jet A1 has a flash point above normal working temperatures and is not anticipated to develop a flammable vapour below this temperature. Therefore, even with residual fuel present, it is not anticipated to result in an explosion.

However, given the limited amount of fuel remaining in a tank, any resulting explosion is not anticipated to cause injury or damage beyond the boundary of the individual tank, and is not expected to result in fatalities or severe damage to the tank. This correlates with a consequence level of "Negligible" to "Marginal". Therefore, an explosion in an empty tank is not considered a representative design fire for purposes of examining the risk of fire for the Fuel Receiving Facility.

4.5.6 Boilover, Slopover and Frothover

Boilover, slopover and frothover are events that can occur following fires in tanks where the top becomes damaged and exposes the fuel to the open. Boilover is a significant event that can result in the sudden ejection of burning liquid from an open top tank. It is caused by water at the tank bottom that reaches its boiling point, forms a quickly expanding steam-oil froth that expulses oil from the tank. The NFPA Handbook notes that the following three conditions are required for boilover to occur [2]:

1. *The tank must contain free water or water-oil emulsion at the tank bottom. This situation will normally prevail in tanks storing crude oil.*
2. *The oil must contain components having a wide range of boiling points, such that when the lighter components have been distilled off and burned at the surface, the residue, with a temperature of 300°F (149°C) or over, is more dense than the oil immediately below. This residue sinks below the surface and forms a layer of gradually increasing depth which advances downward at a rate substantially faster than the*

rate of regression of the burning surface. This sets up the so-called heat wave, which is the result of localized settling of a part of the hot surface oil until it reaches the colder oil below. There is no heat conduction from the burning surface downward.

3. *Sufficient content of heavier oils are present in the oil to produce a residue that can form a tough persistent froth of oil and steam.*

Jet A1 fuel is not crude oil, does not have components with a wide range of boiling points, and does not have sufficient heavy oils. Therefore, the probability of boilover is considered near impossible for Jet A1 fuel. Moreover, typical water content of refined products, especially Jet A1 fuel, is extremely low and is immediately removed upon receipt into tank from marine vessels.

Slopover involves the interaction of water/steam with the surface layer of a burning oil; therefore, the extent of expulsion of liquid is mild relative to a boilover. Slopover is more likely to occur in a crude oil liquid, having components with a wide range of boiling points, and not a refined liquid [3] like Jet A1. Therefore, the probability of slopover is considered near impossible for Jet A1.

Frothover is not associated with fire, but occurs as a result of water mixing with a heated oil, resulting in steam generation and frothing of the oil. Since this event is not fire related, it is not considered a design fire event for purposes of this report.

Therefore, boilover and slopover are not considered representative design fires for purposes of examining the risk of fire for the Fuel Receiving Facility.

4.5.7 Process Area Fire

Failure of the process equipment in the tank storage area could result in a spill, ignition and subsequent fire. This scenario is considered similar to a tank overfilling and fire scenario, but with a different source of fuel release at the process equipment. The likely result is a fire in the containment area and in proximity to a tank.

Similar to an overfilling condition, a fire occurring as a result of failure of the process equipment is considered “eliminated”. Should equipment failure occur, given the safety measures to mitigate the extent of fuel release and limited probability of ignition, the potential consequence is anticipated to be no injury to potential minor injury with minor to severe facility damage. This correlates with a consequence level of “Negligible” to “Marginal”.

One of the more recent fire incidents at a fuel storage facility at the Miami Airport in 2011, summarized in **Table 7**, had a failure of the process equipment and subsequent fire. Though this fire is considered “eliminated” in terms of likelihood and “Negligible” to “Marginal” in terms of consequences, it is a reasonable lower bound assessment of the Fuel Receiving Facility.

4.6 Summary of Scenarios and Credibility Assessment

A summary of the possible scenarios with credibility assessment is included in **Table 12**.

Table 12: Fire Scenario and Representative Design Fire Assessment.

Scenario Description		Likelihood	Potential Severity	Representative Design Fire
1	Tank Overfilling and Fire	Eliminated	Negligible to Marginal	No
2	Tank Head Fire	Eliminated	Critical	Yes
3	Multiple Tank Head Fires	Eliminated	Critical to Catastrophic	No

Scenario Description		Likelihood	Potential Severity	Representative Design Fire
4	Tank Release and Bund Fire	Eliminated	Critical to Catastrophic	Yes[A]
5	Explosion in an Empty Tank	Eliminated	Negligible to Marginal	No
6	Boilover, Slopover and Frothover	Eliminated	N/A	No
7	Process Area Fire	Eliminated	Negligible to Marginal	Yes[B]

A This fire is considered a challenge fire evaluated for information purposes, but is not intended to govern the design of the Fuel Receiving Facility.

B This fire is considered a lower bound fire for purposes of evaluating a range of potential fire incidents.

Three representative fire scenarios, identified in **Table 12**, provide a broad range of fire sizes considered sufficient to examine the impact of the design strategies intended to mitigate the risk of fire beyond that corresponding with application of the regulatory requirements. The locations of the representative design fires are summarized in the following section of this report.

4.7 DESIGN FIRE LOCATIONS

The locations of design fire nos. 2 and 7 are shown are shown in **Figure 6** below.

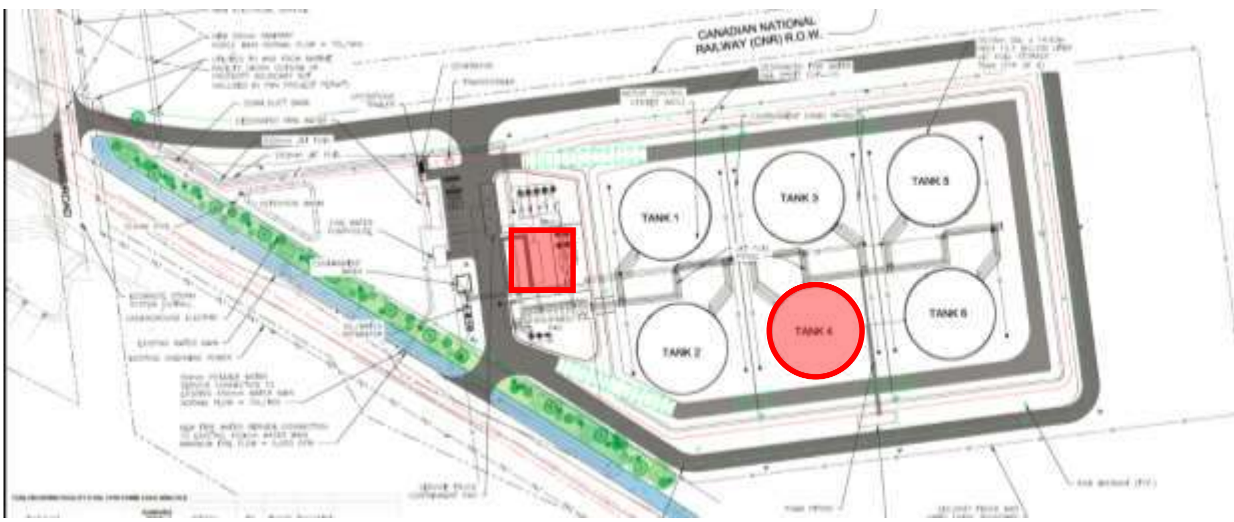


Figure 6: Locations of design fire nos. 2 and 7.

The locations of design fire no. 4 is shown are shown in **Figure 6** below.

command centers or locations of primary fire system controls where responders can establish operations.

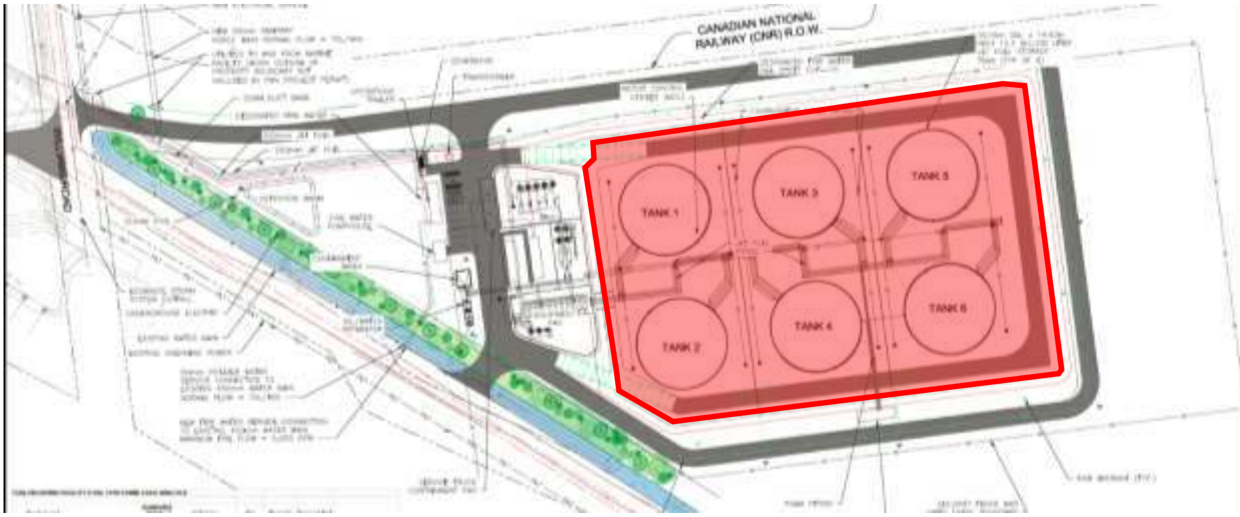


Figure 7: Location of design fire no. 4.

The methodology to assess these representative fires is detailed in the following section of this report.

5.0 ANALYSIS METHODOLOGY

As outlined in **Section 4.2** of this report, fires that have occurred at fuel storage facilities 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 in terms of phenomena of interest, characterization of the exposing source, radiant heat transfer model and target criteria. This criteria relates to limiting the probability of:

- harm to persons in outdoor areas or adjacent buildings,
- fire spread to adjacent buildings, facilities or tanks.

With respect to the objectives related to “harm to persons”, the regulatory requirements do not differentiate between facility employees, the fire service, and the general public. Therefore, the criteria presented in this report is intended to address each of these groups.

5.1 PHENOMENA OF INTEREST

The principal means by which fuel fires can impact persons and spread from a storage tank to a spatially separated building or another tank is by radiative heat transfer [7]. Therefore, the analysis and associated discussion in this document is limited to the phenomena of radiant heat transfer.

5.2 QUANTIFICATION OF RADIATIVE HEAT TRANSFER

As noted above, the phenomena of interest in this analysis is radiant heat transfer, which can be expressed as a function of the source emissive energy, attenuating factors, and the geometrical relationship between the source and target(s).

Quantification of radiative heat from hydrocarbon 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. The magnitude of thermal radiation and separation distances has been quantified for large pool fires by McGrattan, et al [8] in a report based on a literature review and theory of heat transfer. The methodology contained in this report is used as the basis for quantifying radiant heat for the identified credible fires for this Project. The methodology is described in more detail in the following sections of this report.

5.2.1 Large Pool Fire Concept

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 in **Figure 8(a)** showing a relatively small pool fire versus **Figure 8(b)** showing a larger hydrocarbon pool fire.

(a) **(b)**

Figure 8: (a) relatively small pool fire, **(b)** larger hydrocarbon pool fire.

The methodology used to define the radiant heat transfer for larger hydrocarbon pool fires with respect to smoke obscuration are provided in the following sections of this report.

5.2.2 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 [12]:

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

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 the equation as they would be nearly unity for larger pool fires.

5.2.3 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 5.2.1** of this report. This requires determination of fire diameter and luminous zone height. A correlation to establish mean visible flame height in absence of wind is provided as follows [12]:

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

Where: H = Mean visible 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 (9.8 m/s^2)

In the presence of wind, the mean visible flame height is as follows [12]:

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

Where u* is the nondimensional wind velocity given by the following [12]:

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

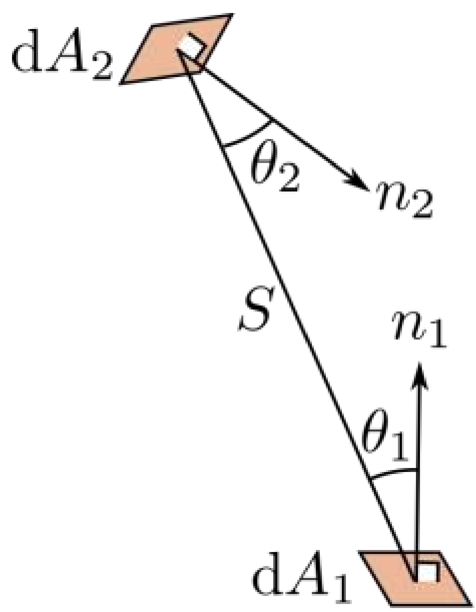
Where: u_w = Wind speed (m/s)
ρ_v = Fuel vapour density (kg/m^3)

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

$$\cos\theta = \begin{cases} 1 & for\ u^* \le 1 \\ \frac{1}{\sqrt{u^*}} & for\ u^* \ge 1 \end{cases}$$

5.2.4 View Factor

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:



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, where the diameter is determined based on the extent of liquid surface spread. For tanks, the containment is typically circular. Therefore, the flame shape for the luminous portion of the flame can be considered cylindrical, as shown in **Figure 9(a)**. For a containment area, the shape depends on the shape of the containment walls, which for this Project is rectangular. Therefore, the flame shape for the luminous portion of the flame can be considered planar, as shown in **Figure 9(b)**.

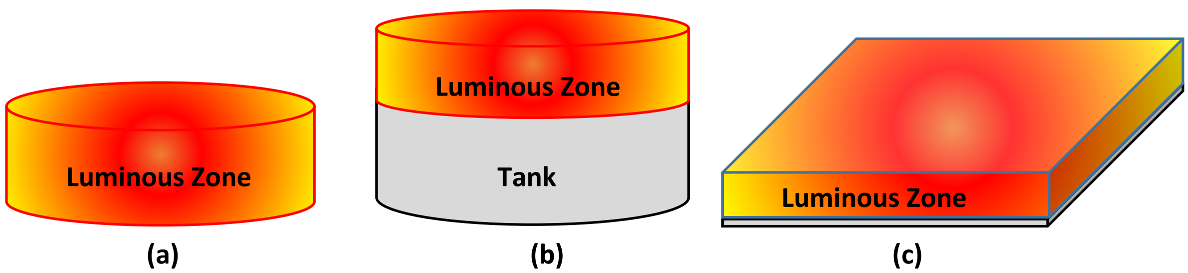


Figure 9: (a) cylindrical source - pool, **(b)** cylindrical source – tank, **(c)** planar source.

Wind can have an impact on the shape of the flame, and can be represented by a tilted cylinder or tilted plane. The prevailing wind direction and speed will be established from Environment Canada weather data relative to quantifying the extent of impact on flame geometry. 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 the conservative view factors is conservative target values.

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

5.2.5 Emissive Power

The emissive power for luminous spots for gasoline and kerosene fires has been measured at 100 kW/m^2 to 140 kW/m^2 [8], and smoke at 20 kW/m^2. Jet A-1 and kerosene are very similar; therefore, this value is reasonable for the purposes of analysis in this report.

The fire height includes both luminous and smoke covered areas. A correlation by Mudan [7] 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 5.2.1** 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. Therefore, the result are less characteristic of actual emissive power when a target is close to the fire perimeter, and more directly impacted by radiant heat from flamelets that appear within the smoke shield. Thus, results for large diameter fires suggest that the heat flux received in proximity to the fire perimeter is 20 kW/m^2, when in actual fact it can be much higher. However, the results become more representative as a target's distance increases from the fire perimeter.

5.3 TARGET CHARACTERISTICS

The target characteristics significant to the analysis contained in this document are:

- target configuration, and
- target response.

Target configuration defines the angle of incidence 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.

5.3.1 Configuration of Target

As outlined in **Section 5.2** of this document, the magnitude of the incident radiant heat flux relates to the configuration of the target (i.e., how much of the exposing plane can be seen from the target). A target that is angled away from an exposing cylinder/plane will receive less incident heat flux than a target directly parallel to the centre of an exposing cylinder/plane.

For purposes of simplification, targets in the proposed analysis are considered to be parallel to the closest exposing cylinder/plane at all locations. The impact of this assumption is that the model will accurately predict "peak" incident heat fluxes directly opposite from the centre of the exposing cylinder/plane, and "near peak" incident heat fluxes away from the centre of the exposing cylinder/plane. The difference between the "peak" and "near peak" heat fluxes will be negligible.

5.3.2 Material Ignition

Material ignition is the process by which self-sustaining combustion of a material is initiated [14], and can occur with an external energy source (piloted ignition) or through high heat (autoignition). Ignition is typically expressed as a temperature, but can also be expressed as a heat flux.

Development of the spatial separation tables in the National Building Code of Canada considered the ignition properties of wood to provide reasonable threshold values for combustible material. The piloted ignition and autoignition values for wood were noted to be 12.5 kW/m^2 and 33.5 kW/m^2 respectively [15]. In choosing these values, it was assumed that most combustible materials, with some exceptions, would not ignite at lower heat flux levels.

Ignition requires heating of a material's surface to a depth sufficient to initiate self-sustaining combustion, which is a function of the material's thermal inertia and time. The following expression can be used to calculate time to ignition for materials exposed to an external (incident) heat flux.

$$t_{ig} = \frac{\pi}{4} \frac{TRP^2}{\left(\dot{q}_e'' - CHF\right)^2}$$

Where: t_{ig} = Time to ignition (s)
TRP = Thermal response parameter (kW·s^{½}/m^2)
$\dot{q}_e''$ = External heat flux (kW/m^2)
CHF = Critical heat flux (kW/m^2)

The critical heat flux and thermal response parameter for wood are 10 kW/m^2 and 138 kW·s^{½}/m^2 respectively. Thus, at a heat flux of 33.5 kW/m^2 (autoignition flux of wood), the calculated time to ignition is 27 seconds. Therefore, this value is used in this analysis relative to predicting ignition of building materials on and off the Project site.

5.3.3 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 [16]:

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

Reference Source	Heat Flux W/cm^2	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			

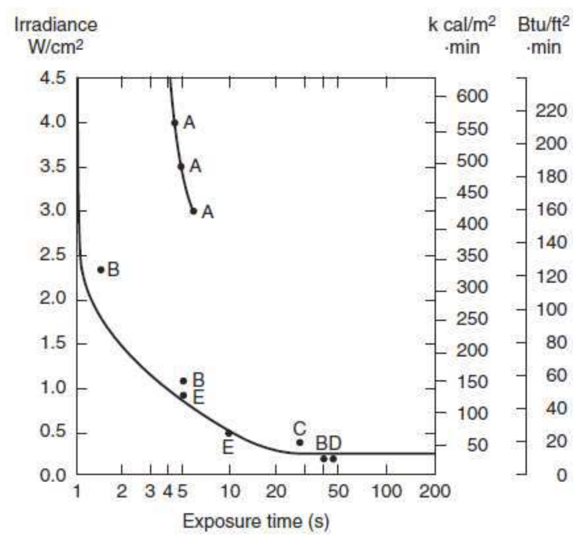


Figure 2-6.28. ***Time to severe skin pain from radiant heat. Adapted from Berenson and Robertson.[111] See text and Table 2-6.18 for discussion of data points A to E.[56,112,115,118,124,125]***

The variation of results complicates practical application for design purposes. A paper by Wieczorek and Dembsey [17] 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:

No Pain Threshold

1.7 kW/m^2 is the critical heat flux below which no pain is experienced no matter how long the duration of exposure [17]. Note that the heat flux on a sunny summer day is approximately 1 kW/m^2.

Pain Threshold

The time to experience pain from incident radiant heat fluxes between 1.7 kW/m^2 and 20 kW/m^2 can be expressed as follows [17]:

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

Where: t_p = Time to pain (s)
q = Heat flux (kW/m^2)

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/ m^2.

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 [17]:

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

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.

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 13: Abbott. [18]

	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 14: Foster and Roberts. [19]

	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 15: Department of Fire & Emergency Services – Australia. [20]

	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 [19] and it has been shown that at that heat flux, pain is experienced after approximately 5 minutes [21]. This is the criteria used in this analysis.

Summary of Target Criteria

A summary of the heat flux target criteria, based on the previous sections, are summarized in **Table 16** and **Table 17** below.

Table 16: Target 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

Table 17: Target Criteria: Fire Spread.

Criteria	Target Value (kW/m^2)
Pilot Ignition of Wood	12.5
Autoignition of Wood (30 seconds)	33.5

5.4 LOCATION OF PERSONS AND STRUCTURES

The objective of the applicable regulatory requirements is to limit the probability of harm to persons and fire spread to adjacent buildings, facilities and tanks. The purpose of the analysis outlined in this report is to assess the impact of fire on persons, buildings, facilities and tanks, which requires an understanding of the locations relative to fires.

Understanding the impact of fire on persons requires an understanding of the potential locations of persons during a credible fire, which further requires consideration of who may be in proximity to the Facility at the time of a fire. The following summarizes the assumptions relative to potential locations of persons during a fire:

- **Public:** The Fuel Receiving Facility will be fenced with no public access to the facility. Therefore, it is assumed that public may be in proximity to the Fuel Receiving Facility property at the time of a fire, but not within the property boundary.
- **Staff:** The Fuel Receiving Facility will be occupied by 1 to 3 staff members with potential for a maximum of 10 staff on site at any one time. The staff will access different parts of the facility to conduct maintenance and repair operations, but will primarily be located in the Operations Trailer, located at the south end of the site as shown in **Section 2.1** of this report. This location provides a direct route of egress from the site.
- **Fire Service:** As outlined in **Section 2.1** of this report, the Fuel Receiving Facility has 2 primary and 1 secondary entrances/exits, a perimeter access road, primary and secondary fire department response points. 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. Depending on the location and size of a fire, this location may vary, but most likely be in locations A and B identified in **Figure 1** of **Section 2.1** of this report.

Understanding the impact of fire on adjacent buildings, facilities or tanks requires an understanding of the locations of buildings, tanks and facilities. The locations of the on-site buildings and tanks are shown in **Section 2.1** of this report.

An understanding of the locations of persons, buildings, facilities and tanks provides a means to establish the boundaries to which the performance criteria applies, which is discussed in more detail in the following sections of this report.

5.4.1 Time of Tenability

The following is assumed relative to the time of tenability for this Project:

1. The time for the fire to initiate and be noticed and reported. In this case, this time will be associated with observation of fire or smoke detection. A general alarm is assumed to initiate upon smoke detector or in-tank heat detector at which time it is expected that the fire service will be notified to respond.
2. The time for persons to respond to a fire alarm. The staff are expected to be trained to respond to a fire alarm system within a short period of time; therefore, this time is anticipated to be approximately 30 seconds.
3. The time required for persons to evacuate to a point of safety.
4. Fire service response considerations.
5. The time for emergency personnel to locate and suppress the fire. If the fire is too large to suppress, the time required to provide exposure protection.

Therefore, based on the time considerations outlined above, the credible design fire scenarios and associated performance criteria are evaluated for:

- the occupants for the period of time required for egress from the facility, and
- property protection for the period of time required for emergency personnel to suppress the fire or provide exposure protection.

5.4.2 Zone of Tenability

The zone of tenability is the area in which the tenability criteria are applied as a function of the time of tenability criterion. This zone encompasses routes of egress for the period of time required to evacuate those routes, as well as locations by which the responding fire service can approach and provide suppression/protection operations.

Maintaining tenability within the zone immediately surrounding the fire is impractical and tenability should apply to a boundary surrounding the fire that may be as much as 30 m or more depending on the heat release rate of the fire and the degree of radiant heat.

Based on the time-of-tenability criteria outlined in the previous section of this report, the zone of tenability encompasses the routes of egress out of the facility and fire service access routes into the facility.

5.4.3 Environmental Conditions

Environmental conditions can impact the consequence associated with a combustible liquid. The most significant environmental factor relative to the phenomena of interest (radiant heat transfer) is wind, which can have an impact on the size and shape of a fire, as outlined in **Appendix A** of this report.

The wind speeds and directions for Richmond, BC are shown in **Figure 10** and **Figure 11** respectively. **Figure 10** shows a daily average maximum of 7 m/s which is reasonable for design purposes considering that the potential for the absolute maximum wind speed occurring at the same time as a storage tank facility fire is likely less than improbable. Therefore, a wind speed of 7 m/s will be used in the analysis.

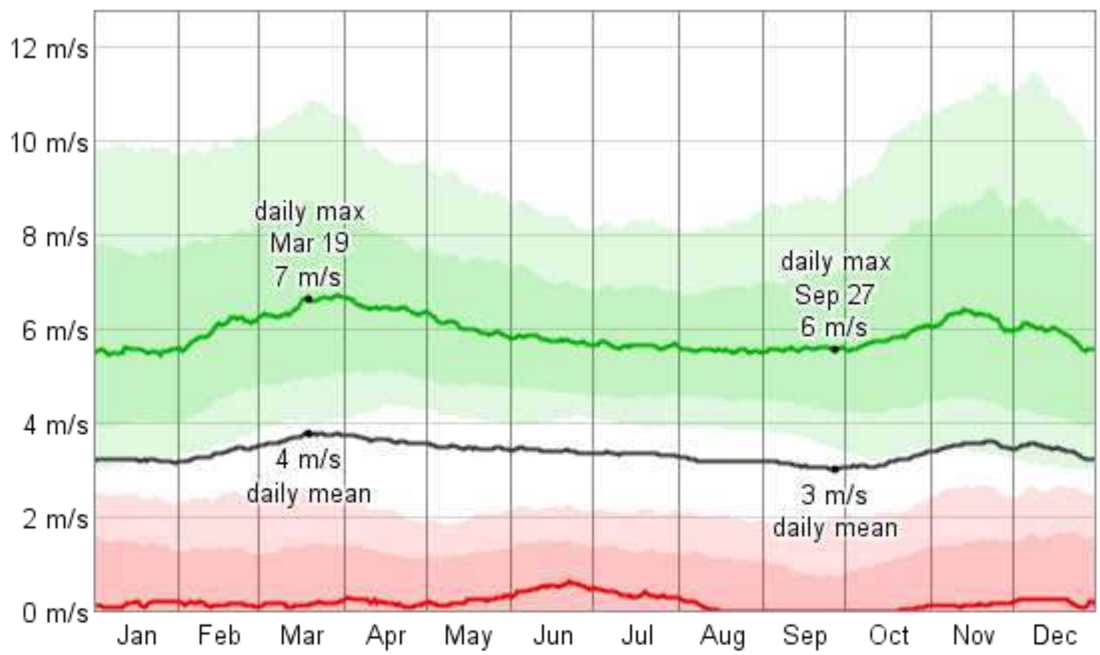


Figure 10: Wind speeds in Richmond, BC: daily minimum (red), maximum (green), average (black) [4].

As shown in **Figure 11**, the wind direction is primarily from the east, southeast and west. However, wind directions from the east, west, north and south will be considered in the analysis.

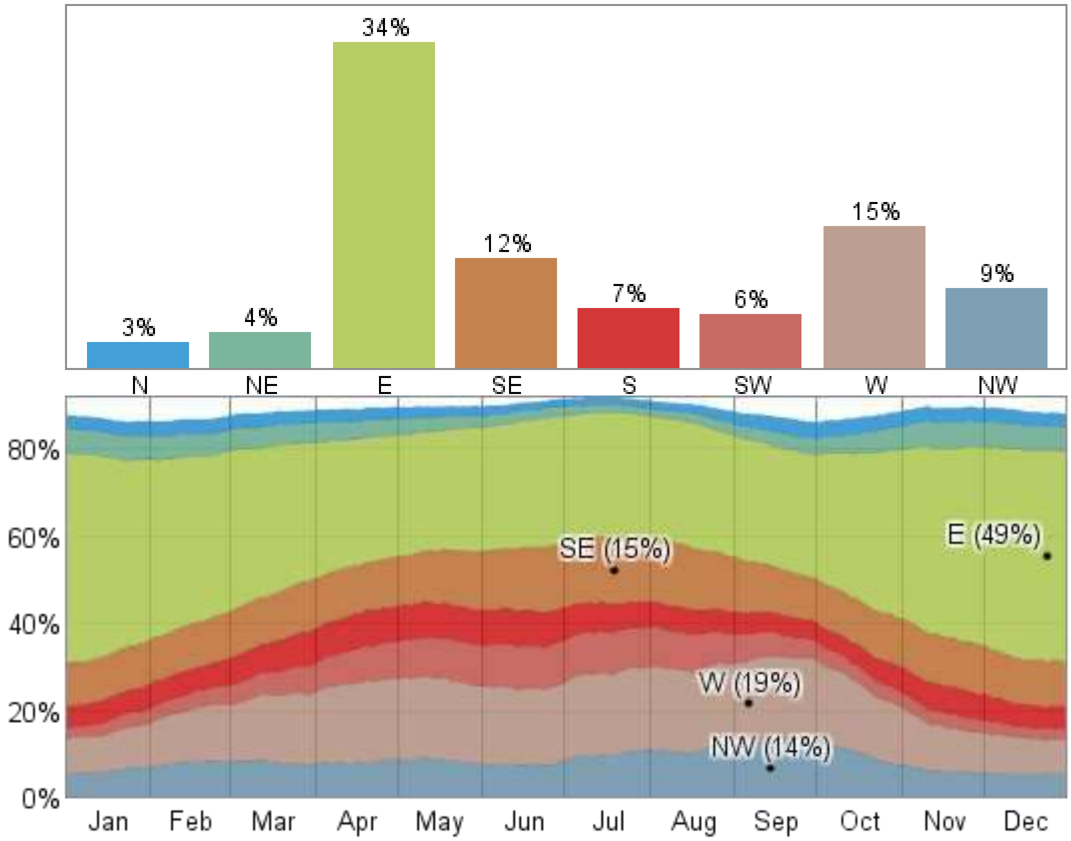


Figure 11: The fraction of wind direction on a daily basis. in Richmond, BC [4].

5.5 METHOD OF COMPARATIVE ANALYSIS

As outlined in **Section 3.1** and **Section 3.5** of this report, the hazard/risk analysis outlined in this report is intended to provide a means to quantify the performance of the Fuel Receiving Facility relative to the objectives of the applicable regulatory requirements. The means of quantification is by comparative risk assessment, which is the process of comparing two or more risks with respect to a common scale (Base Risk).

The base risk is established by examining the performance of a facility design that directly complies with the Division B requirements of the 2010 National Fire Code, compared to the performance of the proposed Fuel Receiving Facility design. Performance will be quantified based on the design fires detailed in **Section 4.6**, using the analysis methodologies in **Section 5.2**, and criteria outlined in **Section 5.3** of this report.

The result of the analysis is intended to facilitate interface and approvals with the various jurisdictions in quantifying the approach, addressing concerns, and facilitating the necessary fire and life safety approvals in order to allow the Project to proceed.

6.0 ANALYSIS AND DISCUSSION

As noted previously in this report, the proposed design is intended to meet the requirements of the National Fire Code of Canada, and be provided with additional design measures to further mitigate the risk of fire beyond the level considered acceptable by the applicable regulatory requirements. Therefore, the following sections of this report detail:

- the scenarios to be compared, which include a design compliant with the National Fire Code of Canada and the proposed design.
- the results of the analysis of the representative design fires summarized in **Section 4.6** of this report, based on the methodology outlined in **Section 5.0** of this report, and relative to the performance criteria outlined in **Section 5.3** of this report.

6.1 COMPARATIVE SCENARIOS

As outlined in **Section 5.5** of this report, the method of analysis is comparative risk assessment, which is the process of comparing two or more risks with respect to a common scale (Base Risk). In this case, the base risk is established based on the performance of a facility design that directly complies with the Division B requirements of the 2010 National Fire Code. This risk will be compared to the performance of the proposed Fuel Receiving Facility design.

6.1.1 National Fire Code Compliant Design (Reference Design)

For purposes of comparative analysis, it is recommended that the reference (base) design be in accordance with the applicable fire safety regulations and equivalent to the proposed facility design with the exception of the added mitigation measures [22].

A design that is compliant with the 2010 National Fire Code of Canada and equivalent to the proposed design (the “Reference Design”) is summarized as follows.

Tank Features

The 2010 NFC does not require a combustible liquid storage tank be equipped with a floating roof. Therefore, the Reference Design will include tanks with fixed roofs with a vapour head space.

Tank Diameter

Tank diameter is not regulated by the 2010 NFC. However, fixed fire protection is required in accordance with good engineering practice where the diameter of a storage tank exceeds 45 m. Therefore, the Reference Design storage tanks will have a diameter equal to 45 m.

Tank Height

The 2010 NFC does not regulate storage tank height. Therefore, the Reference Design will have a tank height equivalent to the Proposed Design, which is a shell height of 14.63 m.

Tank Volume

The 2010 NFC does not limit tank volume. Therefore, the Reference Design will have a tank volume proportional to the Proposed Design, but based on the Reference Design diameter of 45 m. With a 45 m tank diameter and height of 14.63 m, the tank shell volume is increased by 65%. Therefore, the Reference Design storage tank volume is assumed to be 23.2 million litres.

Separation from Buildings and Property Line

As noted in **Section 3.2.2** of this report, where the maximum tank capacity is greater than 5 million litres, it is required to be at least 15 m from the closest property line or building on the same property. Therefore, the Reference Design storage tanks will be located within 15 m of the closest building and property line.

Distance from Adjacent Storage Tanks

As noted in **Section 3.2.3** of this report, a minimum distance of 0.25 times the sum of the diameters between every combination of 2 aboveground storage tanks is required. As outlined earlier in this section, each of the Reference Design storage tanks will have a diameter of 45 m. Therefore, the required separation distance between tanks is:

$$D = 0.25 \cdot (45\,m + 45\,m)$$
$$D = 22.5\,m$$

Secondary Containment

As noted in **Section 3.2.4** of this report, a minimum volumetric capacity of not less than the sum of the capacity of the largest storage tank in the containment space plus the greater of 10% of the:

a) capacity of the largest storage tank in the containment space, or
b) the aggregate capacity of all other storage tanks located in the containment space.

The Reference Design is intended to have 6 fuel storage tanks all located within the same containment space. Each Reference Design storage tank has a shell capacity of 23.2 million litres. Therefore, the secondary containment is required to have a volumetric capacity of 34.8 million litres. For purposes of the analysis in this report, it is assumed that the area of the secondary containment for the Reference Design is proportional to the Proposed Facility Design secondary containment area as a function of volume, assuming the same containment depth. As noted in **Section 2.2** of this report, the containment area of the Proposed Facility Design is approximately 166 m long by 106 m wide, which is 17,596 m^2 in area. Therefore, the Reference Design containment area is approx. 28,592 m^2 with proportional dimensions of approx. 212.93 m long by 135.97 m wide.

Fixed Protection Systems

Based on the Reference Design storage tank diameter, a fixed fire protection system is not required by the 2010 NFC. Therefore, a fixed fire protection system is not included in the Reference Design.

6.1.2 Proposed Facility Design

The proposed facility design has been detailed in **Section 2.0** of this report, and has been compared to the applicable regulatory requirements (2010 NFC) in **Section 3.0** of this report.

6.1.3 Design Scenario Summary

Table 18 provides a summary of the design scenarios.

Table 18: Summary of design scenarios.

Parameter	Reference Design	Proposed Facility Design
Tank Features	No Additional	Internal Floating
Tank Diameter (m)	45	35.05

Parameter	Reference Design	Proposed Facility Design
Tank Height (m)	14.63	14.63
Tank Volume (L)	23.2 million	14.1 million
Separation from Buildings (m)	15	15
Separation from Property Line (m)	15	28
Separation from Adjacent Storage Tanks (m)	22.5	17.5
Secondary Containment (L) (% of Total Storage)	34.8 (25%)	22.9 (27%)
Foam Suppression	None	In-tank and process area
Tank Cooling System	None	Automatic
Fixed Fire Protection Systems	None	• Foam system • Tank water spray cooling system

The following sections of this report quantify the representative design fire scenarios for purposes of modelling using the methodology and performance criteria outlined in **Section 5.0** of this report.

6.2 Process Area Fire

The Process Area fire is located as shown in **Figure 12**, and is based on the design fire assessment summarized in **Section 4.5.7**.

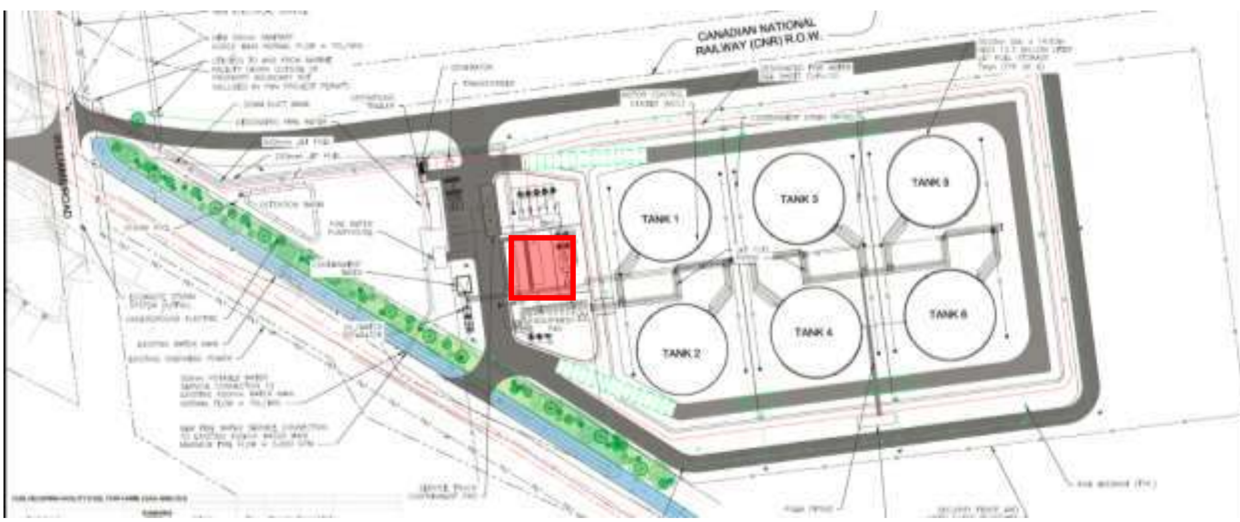


Figure 12: Locations of the Process Area Design Fire.

This fire is anticipated to occur as a result of a release of Jet A1 from process equipment and spill within a containment areas located below the equipment. The process area is separated into three parts:

- Fuel receipt from the ships (max. transfer rate of 38,000 Lpm).
- Tank to tank transfer system that will consist of two parallel 2,500 Lpm pumps.
- Pipeline transfer – 5 pumps at 4,150 Lpm each pump (max. of three in operation at one time).

The containment cells will be approximately 27.5 m by 27.5 m, with a depth of approximately 0.5 m. This results in a containment area of 756.25 m^2 and a volume of 378.13 m^3.

The size of the spill depends on the rate of release, containment area/volume, and drainage rate. The Fuel receiving Facility will be occupied at all times by staff and be equipped with mechanisms to limit release of Jet A1 from process equipment upon discovery or detection of a release by shutting down transfer equipment. The time associated with shut down is approximately 5 to 10 minutes from release.

The process area will be provided with a general containment area, divided into three cells coinciding with the processes for receipt from ships, tank to tank transfer, and pipeline transfer. The process containment cells are free draining to an oil water separator which is provided with a 400 gpm pump (1514 Lpm).

Assuming a worse-case spill during fuel receipt from a ship of 38,000 Lpm, a drainage rate of 1,514 Lpm, for 10 minutes results in a volume of 364.86 m^3. This is less than the volume of the containment cells. Therefore, a resulting process area fire is anticipated to be 27.5 by 27.5 m at approximately grade level.

6.2.1 Basic Calculations

The process area for the Reference Design and Proposed Facility Design will be equivalent. Therefore, the following analysis is applicable to both designs.

As outlined in **Section 6.1.1** of this report, the containment cell area of the Reference Design has dimensions of 27.5 m long by 27.5 m wide (756.25 m^2). The resulting equivalent pool diameter using the area of the Reference Design containment area is 31 m. Using the equation in **Section 5.2.5** of this report, the emissive power is 22.9 kW/m^2. Using the equations summarized in **Section 5.2.3** of this report, and a mass burning rate of 0.039 kg/m^2·s, the luminous flame height is 27.8 m.

For a 7 m/s wind condition and a fuel vapour density of 5.51 kg/m^3 [23], the nondimensional wind speed is calculated to be 5.42, which results in a luminous flame height is 17.5 m and flame tilt angle of 64.6° from vertical.

6.2.2 No Wind Radiant Heat Calculations

For a no-wind condition, the flame will have no tilt and based on the flame height of 27.8 m, the distances at which the heat flux at ground level surrounding the containment area will reach the critical heat fluxes outlined in **Section 5.3** of this report are summarized in **Table 19** below.

Table 19: No Wind, Process Area Fire.

Criteria	Heat Flux Values (kW/m^2)	Critical Distance
No Pain (Unlimited Time)	1.7	52.50
Pain (30 seconds)	2.1	46.20
Second Degree Burn (30 seconds)	4	29.90
Firefighter Pain (5 minutes)	5	25.05
Pilot Ignition of Wood	12.5	6.82
Autoignition of Wood (30 seconds)	33.5	N/A

6.2.3 Wind Radiant Heat Calculations

For a 7 m/s wind condition the flame will have a 24.6° tilt from vertical, and based on the flame height of 17.5 m, the distances at which the heat flux at ground level surrounding the containment area will reach the critical heat fluxes outlined in **Section 5.3** of this report are summarized in **Table 20** below.

Table 20: Wind*, Process Area Fire.

Criteria	Heat Flux Values (kW/m^2)	Critical Distance
No Pain (Unlimited Time)	1.7	73.50
Pain (30 seconds)	2.1	67.10
Second Degree Burn (30 seconds)	4	51.40
Firefighter Pain (5 minutes)	5	47.00
Pilot Ignition of Wood	12.5	32.94
Autoignition of Wood (30 seconds)	33.5**	N/A

* See **Section 5.2.4** of this report

** See **Section 5.2.5** of this report.

6.3 TANK HEAD FIRE

The Tank Head Fire is located as shown in **Figure 13**, and is based on the design fire assessment summarized in **Section 4.5.2**.

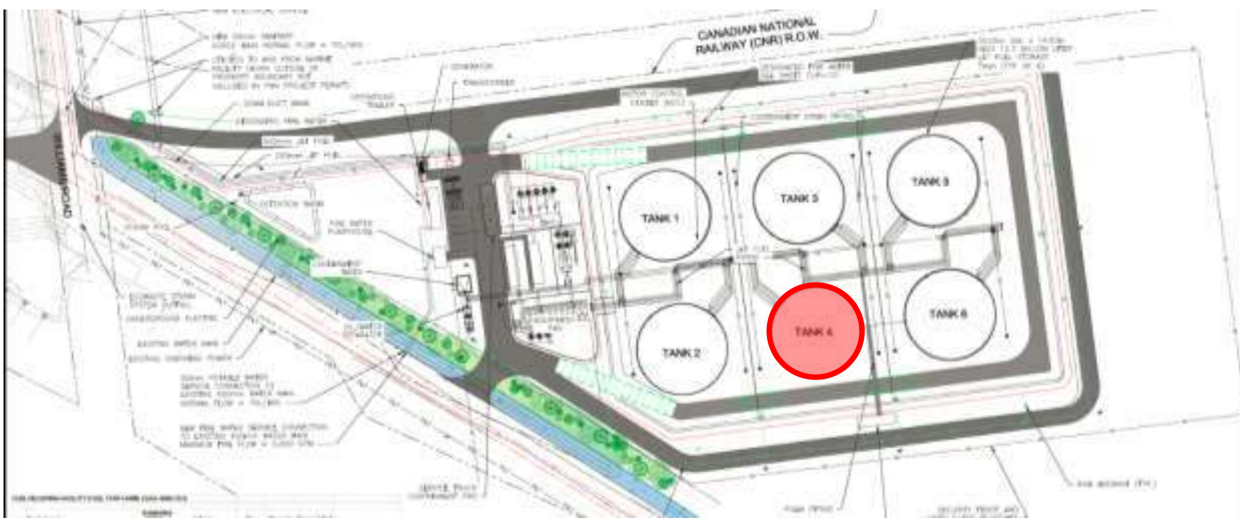


Figure 13: Locations of the Tank Head Fire.

The Tank Head Fire will have the same diameter as the tank, as shown in **Figure 13**, and have a fire base at the top of the tank (approx. 14.63 m). The fire is anticipated to burn as long as fuel is available, or suppression occurs.

6.3.1 Basic Calculations

Reference Design Calculations

As outlined in **Section 6.1.1** of this report, the Reference Design storage tanks have a diameter of 45 m. Based on this diameter the flame height is 36.0 m. Using the equation in **Section 5.2.5** of this report, the emissive power is 20.5 kW/m^2. For a 7 m/s wind speed, the nondimensional wind speed is calculated to be 4.79, which results in a luminous flame height is 23.0 m and flame tilt angle of 62.8°.

Proposed Facility Design Calculations

As outlined in **Section 6.1.1** of this report, the Proposed Facility Design storage tanks have a diameter of 35.05 m. Based on this diameter the luminous flame is 30.3 m. Using the equation in **Section 5.2.5** of this report, the emissive power is 21.8 kW/m^2. For a 7 m/s wind speed, the nondimensional wind speed is calculated to be 5.20, which results in a luminous flame height is 19.1 m and flame tilt angle of 64.0°.

Comparison

A comparison of luminous flame heights and tilt angles for the Reference Design and Proposed Facility Design are included in **Table 21** below.

Table 21: Comparison of Basic Calculations – Tank Head Fire.

Value	Reference Design	Proposed Facility Design
Luminous Flame Height – No Wind (m)	36.0	30.3
Luminous Flame Height – Wind (m)	23.0	19.1
Flame Tilt Angle – Wind (Degrees)	62.8	64.0

6.3.2 No Wind Radiant Heat Calculations

For a no-wind condition, the flame will have no tilt and based on the flame height of 36.0 m for the Reference Design and 30.3 for the Proposed Facility Design, the distances at which the heat flux at ground level surrounding the containment area will reach the critical heat fluxes outlined in **Section 5.3** of this report are summarized in **Table 22** below.

Table 22: No Wind, Tank Head Fire.

Criteria	Heat Flux Values (kW/m^2)	Critical Distance	
		Reference Design (m)	Proposed Facility Design (m)
No Pain (Unlimited Time)	1.7	83.50	69.00
Pain (30 seconds)	2.1	74.90	61.80
Second Degree Burn (30 seconds)	4	52.70	43.35
Firefighter Pain (5 minutes)	5	46.10	37.85
Pilot Ignition of Wood	12.5	23.95	19.43
Autoignition of Wood (30 seconds)	33.5*	N/A	N/A

* See **Section 5.2.5** of this report.

6.3.3 Wind Radiant Heat Calculations

For a 7 m/s wind condition the flame will have a 62.8° tilt from vertical for the Reference Design and 64.0° tilt from vertical for the Proposed Facility Design. This corresponds with a luminous flame height of 23.0 m for the Reference Design and 19.1 m for the Proposed Facility Design. Based on these parameters, the distances at which the heat flux at ground level surrounding the containment area will reach the critical heat fluxes outlined in **Section 5.3** of this report are summarized in **Table 23** below.

Table 23: Wind*, Tank Head Fire.

Criteria	Heat Flux Values (kW/m^2)	Critical Distance	
		Reference Design (m)	Proposed Facility Design (m)
No Pain (Unlimited Time)	1.7	70.80	57.60
Pain (30 seconds)	2.1	66.80	54.35
Second Degree Burn (30 seconds)	4	56.65	46.10
Firefighter Pain (5 minutes)	5	53.75	43.75
Pilot Ignition of Wood	12.5	42.05	34.65
Autoignition of Wood (30 seconds)	33.5**	N/A	N/A

* See **Section 5.2.4** of this report

** See **Section 5.2.5** of this report.

6.4 Tank Release and Bund Fire

The Bund Fire is located as shown in **Figure 14**, and is based on the design fire assessment summarized in **Section 4.5.4**.

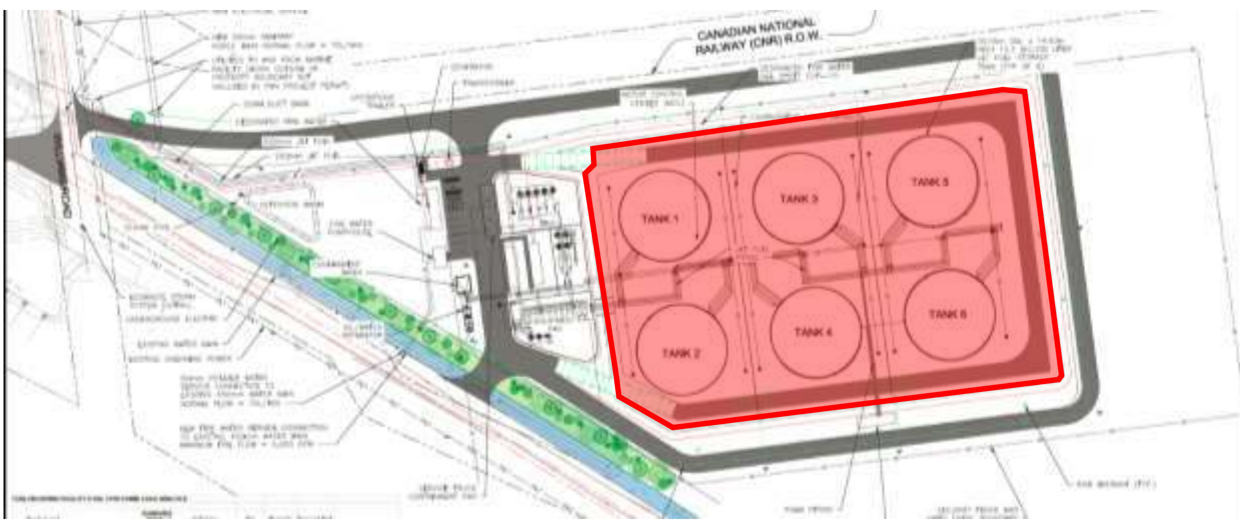


Figure 14: Location of the Bund Fire.

The Tank Release and Bund Fire will have the same base area as the containment area, as shown in **Figure 14**, and have a base that is approximately at grade. The fire is anticipated to burn as long as fuel is available, or suppression occurs.

6.4.1 Basic Calculations

Reference Design Calculations

As outlined in **Section 6.1.1** of this report, the containment area of the Reference Design has dimensions of 212.93 m long by 135.97 m wide (28,952 m^2). The resulting equivalent pool diameter using the area of the Reference Design containment area is 192 m. Based on this diameter the luminous flame height is

98.7 m. Using the equation in **Section 5.2.5** of this report, the emissive power is 20.0 kW/m^2. For a 7 m/s wind condition and a fuel vapour density of 5.51 kg/m^3 [23], the nondimensional wind speed is calculated to be 2.95, which results in a luminous flame height is 66.8 m and flame tilt angle of 54.4°.

Proposed Facility Design Calculations

As outlined in **Section 6.1.1** of this report, the containment area of the Reference Design has dimensions of 166 m long by 106 m wide (17,596 m^2). The resulting equivalent pool diameter using the area of the Reference Design containment area is 149.7 m. Based on this diameter the luminous flame height is 83.05 m. Using the equation in **Section 5.2.5** of this report, the emissive power is 20.0 kW/m^2. For a 7 m/s wind condition, the nondimensional wind speed is calculated to be 3.21, which results in a luminous flame height is 55.6 m and flame tilt angle of 56.0°.

Comparison

A comparison of luminous flame heights and tilt angles for the Reference Design and Proposed Facility Design are included in **Table 24** below.

Table 24: Comparison of Basic Calculations – Tank Release and Bund Fire.

Value	Reference Design	Proposed Facility Design
Luminous Flame Height – No Wind (m)	98.7	83.1
Luminous Flame Height – Wind (m)	66.8	55.6
Flame Tilt Angle – Wind (Degrees)	54.4	56.0

6.4.2 No Wind Radiant Heat Calculations

For a no-wind condition, the flame will have no tilt and based on the flame height of 98.7 m for the Reference Design and 83.1 for the Proposed Facility Design, the distances at which the heat flux at ground level surrounding the containment area will reach the critical heat fluxes outlined in **Section 5.3** of this report are summarized in **Table 25** and **Table 26** below.

Table 25: Long Side: No Wind, Reference Design, Tank Release and Bund Fire.

Criteria	Heat Flux Values (kW/m^2)	Critical Distance	
		Reference Design (m)	Proposed Facility Design (m)
No Pain (Unlimited Time)	1.7	257.00	208.50
Pain (30 seconds)	2.1	226.00	183.50
Second Degree Burn (30 seconds)	4	145.50	118.20
Firefighter Pain (5 minutes)	5	121.00	98.30
Pilot Ignition of Wood	12.5	19.35	15.90
Autoignition of Wood (30 seconds)	33.5*	N/A	N/A

* See **Section 5.2.5** of this report.

Table 26: Short Side: No Wind, Reference Design, Tank Release and Bund Fire.

Criteria		Critical Distance

	Heat Flux Values (kW/m^2)	Reference Design (m)	Proposed Facility Design (m)
No Pain (Unlimited Time)	1.7	205.00	166.00
Pain (30 seconds)	2.1	186.00	146.00
Second Degree Burn (30 seconds)	4	116.00	93.50
Firefighter Pain (5 minutes)	5	96.50	77.70
Pilot Ignition of Wood	12.5	16.00	12.90
Autoignition of Wood (30 seconds)	33.5*	N/A	N/A

* See **Section 5.2.5** of this report.

6.4.3 Wind Radiant Heat Calculations

For a 7 m/s wind condition the flame will have a 54.4° tilt from vertical for the Reference Design and 56.1° tilt from vertical for the Proposed Facility Design. This corresponds with a luminous flame height of 66.8 m for the Reference Design and 55.6 m for the Proposed Facility Design. Based on these parameters, the distances at which the heat flux at ground level surrounding the containment area will reach the critical heat fluxes outlined in **Section 5.3** of this report are summarized in **Table 27** and * **See Section 5.2.4** of this report

** See **Section 5.2.5** of this report.

Table 28 below.

Table 27: Long Side: Wind*, Reference Design, Tank Release and Bund Fire.

Criteria	Heat Flux Values (kW/m^2)	Critical Distance	
		Reference Design (m)	Proposed Facility Design (m)
No Pain (Unlimited Time)	1.7	198.00	159.00
Pain (30 seconds)	2.1	178.10	143.70
Second Degree Burn (30 seconds)	4	128.40	104.50
Firefighter Pain (5 minutes)	5	113.80	93.10
Pilot Ignition of Wood	12.5	61.60	51.80
Autoignition of Wood (30 seconds)	33.5**	N/A	N/A

* See **Section 5.2.4** of this report

** See **Section 5.2.5** of this report.

Table 28: Short Side: Wind*, Reference Design, Tank Release and Bund Fire.

Criteria	Heat Flux Values (kW/m^2)	Critical Distance	
		Reference Design (m)	Proposed Facility Design (m)
No Pain (Unlimited Time)	1.7	171.00	138.00
Pain (30 seconds)	2.1	155.70	125.90
Second Degree Burn (30 seconds)	4	116.40	94.80
Firefighter Pain (5 minutes)	5	104.60	85.60
Pilot Ignition of Wood	12.5	59.00	49.50
Autoignition of Wood (30 seconds)	33.5**	N/A	N/A

* See **Section 5.2.4** of this report

** See **Section 5.2.5** of this report.

6.5 LIFE SAFETY

The results of consequence analysis indicate that in the rare event of a fire, occupants in the Proposed Facility Design are likely to be exposed to a reduced exposure than the Reference Design, allowing greater time for escape to a point of safety. In addition, the reduced heat flux allows greater access to the fire for the responding fire service to suppress the fire or provide protection for adjacent properties. These results suggest the probability of a more tenable environment associated with the Proposed Facility Design than a Reference Design.

7.0 DISCUSSION AND CONCLUSION

This report has summarized a hazard/risk analysis to demonstrate the design of the Project will achieve and exceed the fire and life safety objectives attributed to the applicable regulatory requirements (2010 NFCC). This was achieved through comparative analysis whereby the Proposed Facility Design was compared with a Reference Design (2010 NFCC compliant) to establish the relative performance of these designs within the context of risk and consequence.

Through statistical analysis of fire loss history, fire occurring in fuel storage tanks has been demonstrated to be an extremely rare occurrence. The probability of occurrence is reduced even further considering:

- The relatively high flash point for Jet A1 relative to other fuels considered in the statistics.
- The staffed, secured and patrolled site, which reduces the probability of intentional ignition or ignition through rubbish fires – a statistically high source of ignition.
- The low occurrence of lightning strikes in Richmond, which is the most statistically significant ignition source for fuel storage tanks.
- The provision of floating roof in the tanks that is expected to significantly reduce the probability of the development of a flammable head space and potential for ignition from lightning.
- The provision of water cooling for neighbouring tanks in the event that a fire does occur, reducing the probability for fire to spread.
- The provision of foam suppression for the fuel storage tanks to reduce the probability of fire spread in or on the tanks, should ignition occur.

The provision of the design features outlined above are in addition to those required by the 2010 NFCC, resulting in a design that exceeds the performance and level of risk deemed “acceptable” by the 2010 NFCC. This has been demonstrated by the consequence analysis, which identified the critical distances at which the heat flux reached the performance levels outlined in **Section 5.3** of this report. The results show that in the rare event that a fire does occur, the critical distances for the Proposed Facility Design are at least as good as, and in most cases, exceed the values for the Reference Design (2010 NFCC compliant design).

Therefore, the design of the Fuel Receiving Facility will provide an environment that has a lower risk of fire occurrence and reduced consequence of fire than a design that is considered by the 2010 NFCC to have an “acceptable level” of risk.

8.0 SOURCES OF INFORMATION

The following sources of information have been used in the preparation of this report.

1. Campbell, R., "Fires at Outside Storage Tanks", National Fire Protection Association, Fire Analysis and Research Division, Quincy, MA, August 2014.
2. Cote, Arthur E., "Fire Protection Handbook", National Fire Protection Association, Nineteenth Edition, 2003.
3. Mannan, S., "Lees' Loss Prevention in the Process Industries", Elsevier, Fourth Edition, 2012.
4. Weatherspark Website, https://weatherspark.com/averages/28404/Vancouver-British-Columbia-Canada, accessed July 9, 2015.
5. Society of Fire Protection Engineers, "The Code Official's Guide to Performance-Based Design Review," 2004.
6. Whittaker, D., Jury, R.D., "Seismic Design Loads for Storage Tanks", New Zealand Society for Earthquake Engineering, 12WCEE Paper Number 2376, 2000.
7. Beyler, C.L., "Fire Hazard Calculations for Large Open Hydrogen Fires", Section 3, Chapter 1, SFPE Handbook of Fire Protection Engineering, 3rd Edition, P.J. DiNenno, Editor-in-Chief, National Fire Protection Association, Quincy, Massachusetts, 2002.
8. McGrattan K., Baum H., Hamins A., "Thermal Radiation from Large Pool Fires", NISTIR 6546, National Institute of Standards and Technology, November 2000.
9. E. Ufuah, C.G. Bailey, Flame Radiation Characteristics of Open Hydrocarbon Pool Fires, Proceedings of the World Congress on Engineering, 2011, Vol. III, July 2011.
10. NUREG1805 spreadsheet, Chapter 5 – Estimating Radiant Heat Flux from Fire to a Target Fuel at Ground Level under Wind-free Conditions, U.S. Nuclear Regulatory Commission, http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1805/.
11. "ALOHA (Areal Locations of Hazardous Atmospheres) User's Manual", US Environmental Protection Agency, National Oceanic and Atmospheric Administration, dated February 2007.
12. Beyler, C.L., "Fire Hazard Calculations for Large, Open Hydrocarbon Fires", SFPE Handbook of Fire Protection Engineering, Third Edition, 2002.
13. DiNenno, P.J., et al, "Configuration Factors", SFPE Handbook of Fire Protection Engineering, Appendix D, pp. A-46.
14. Drysdale, D.D., "Chemistry and Physics of Fire", Section 2, Chapter 3, Fire Protection Handbook, National Fire Protection Association, Nineteenth Edition, 2003, pp. 2-55.
15. McGuire, J.H., "Spatial Separation of Buildings", National Research Council of Canada, Division of Building Research, Ottawa, ON, November 1959.
16. Purser, D.A., "Toxicity Assessment of Combustion Products", SFPE Handbook of Fire Protection Engineering, Section 2, Chapter 6, pp. 2-127.
17. Wieczorek, C.J., Dembsey, N.A., "Human Variability Correction Factors for Use with Simplified Engineering Tools for Predicting Pain and Second Degree Skin Burns", Journal of Fire Protection Engineering, Vol. 2, May 2001, pp. 96.
18. Abbott, N.J., Schulman, S., "Protection from Fire: Nonflammable Fabrics and Coatings", J. Coated Fabrics, Vol. 6, 1976, pp. 50.
19. Vettori, R.L., Twilley, W.H., Stroup, D.W., "Measurement Techniques for Low Heat Flux Exposures to Fire Fighters Protective Clothing", NISTIR 6750, National Institute of Standards and Technology, June 2001, pp. 2.
20. Department of Fire & Emergency Services, "Fire Safety Engineered Alternative Solutions", DFES BEB Guideline No. GL-15, Built Environment Branch, Issued January 2013, pp. 9.

21. Persson, H., "Basutrustning för skumsläckning - Försöksresultat och rekommendationer som underlag för dimensionering och utförande", SP Swedish National Testing and Research Institute, SP RAPPORT 1990:36, Borås, Sweden (in Swedish), 1990.
22. Standard Norge, “Fire Safety Engineering, Comparative method to verify fire safety design in buildings”, SN-INSTA/TS 950:2014, April 2014.
23. Petro Canada, “Material Safety Data Sheet – Jet A/A-1 Aviation Turbine Fuel”, August 2001.

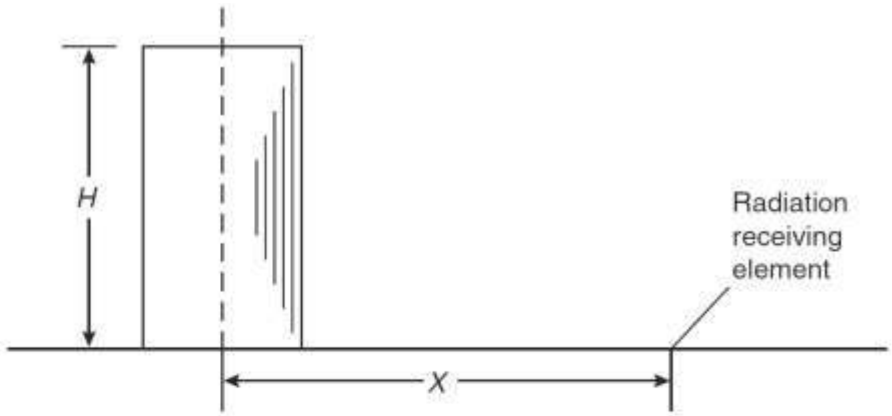
Appendix A

SERECA

View Factor Calculations

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:

$$\phi_{1-2,V} = \frac{1}{\pi S}\tan^{-1}\left(\frac{h}{\sqrt{S^2-1}}\right) - \frac{L}{\pi S}\tan^{-1}\sqrt{\frac{(S-1)}{(S+1)}} + \frac{Ah}{\pi S\sqrt{A^2-1}}\tan^{-1}\sqrt{\frac{(A+1)(S-1)}{(A-1)(S+1)}}$$

Horizontal receiving element:

$$\phi_{1-2,H} = \frac{\left(B-\frac{1}{S}\right)}{\pi\sqrt{B^2-1}}\tan^{-1}\sqrt{\frac{(B+1)(S-1)}{(B-1)(S+1)}} - \frac{\left(A-\frac{1}{S}\right)}{\pi\sqrt{A^2-1}}\tan^{-1}\sqrt{\frac{(A+1)(S-1)}{(A-1)(S+1)}}$$

Where:

$$S = \frac{2L}{D}$$

$$h = \frac{2H}{D}$$

$$A = \frac{h^2+S^2+1}{2S}$$

$$B = \frac{1+S^2}{2S}$$

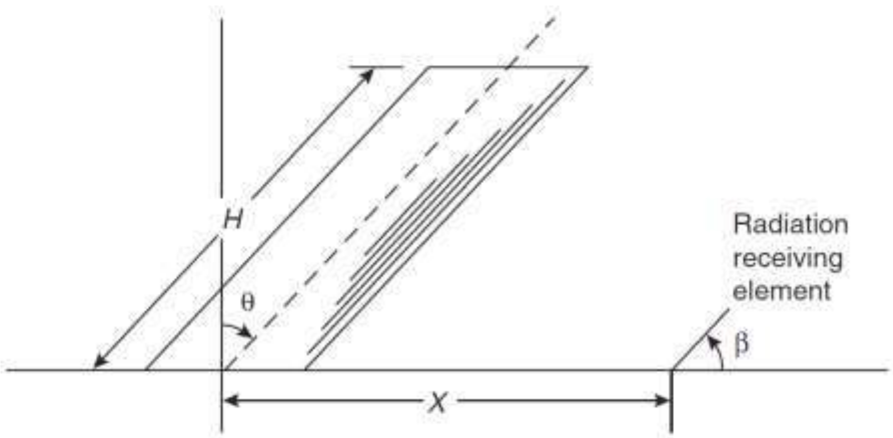
L = Distance between the centre of the pool fire and the target (m)
H = Height of the pool fire (m)
D = Pool fire diameter (m)

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.

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

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

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



Vertical receiving element:

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

Horizontal receiving element:

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

Where:

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

$b = \dfrac{L}{R}$

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

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

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

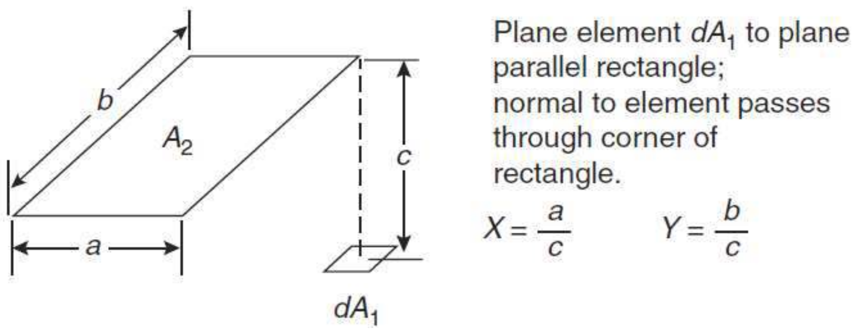
Similar to the equations for the view factor for a vertical cylinder, the maximum configuration factor at a given point is a function of the vertical and horizontal receiving elements as follows:

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

Planar Source

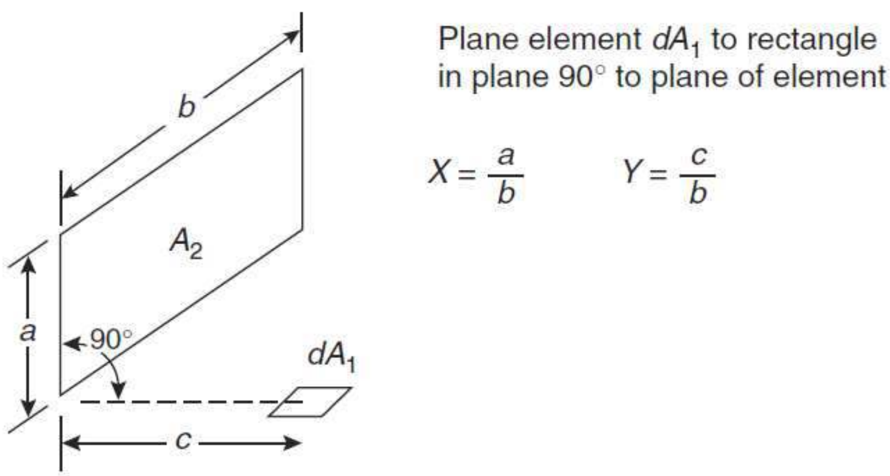
For planar sources, the finite configuration factor is determined by integrating over the area of the exposing plane. A simplified version of the result for parallel planes is as follows [13]:

Vertical receiving element:



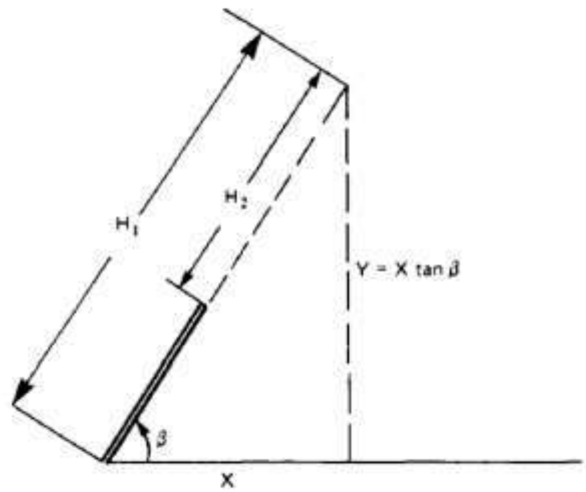
$$\phi_{1-2,V} = \frac{1}{2\pi}\left(\frac{X}{\sqrt{1+X^2}}\tan^{-1}\frac{Y}{\sqrt{1+X^2}} + \frac{X}{\sqrt{1+Y^2}}\tan^{-1}\frac{X}{\sqrt{1+Y^2}}\right)$$

Horizontal receiving element:



$$\phi_{1-2,H} = \frac{1}{2\pi}\left(\tan^{-1}\frac{1}{Y} - \frac{Y}{\sqrt{X^2+Y^2}}\tan^{-1}\frac{1}{\sqrt{X^2+Y^2}}\right)$$

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



Vertical receiving element:

$$\phi_{1-2,V} = \frac{1}{2\pi}\left\{\cos\theta \tan^{-1}\left(\frac{W}{X}\right) - \frac{X\cos\theta}{A}\left[\tan^{-1}\left(\frac{L\sin\theta}{A}\right) + \tan^{-1}\left(\frac{W - L\sin\theta}{A}\right)\right]\right\}$$

Horizontal receiving element:

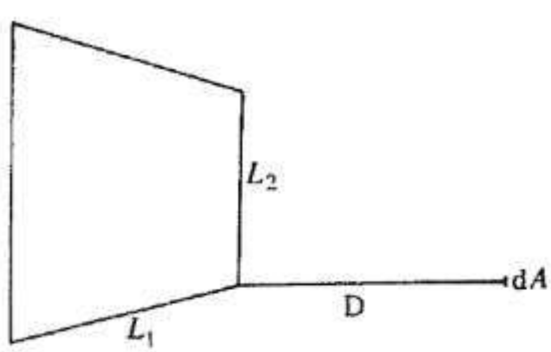
$$\phi_{1-2,H} = \frac{1}{2\pi}\left\{\frac{L\cos\theta}{A}\left[\tan^{-1}\left(\frac{W - L\sin\theta}{A}\right) + \tan^{-1}\left(\frac{L\sin\theta}{A}\right)\right] + \frac{W\cos\theta}{B}\left[\tan^{-1}\left(\frac{W\sin\theta}{B}\right) + \tan^{-1}\left(\frac{L - W\sin\theta}{B}\right)\right]\right\}$$

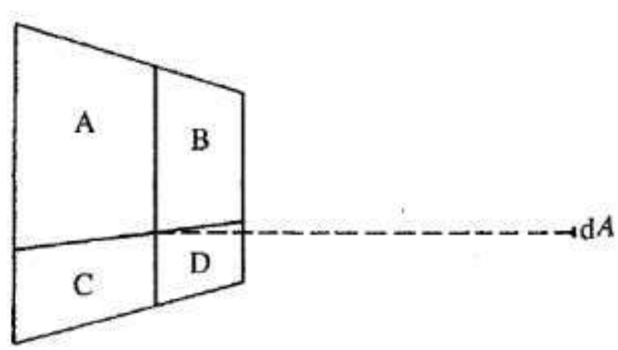
Where:

$A = \sqrt{L^2\cos^2\theta + X^2}$

$B = \sqrt{W^2\cos^2\theta + X^2}$

The planar equations can be applied to separate planes as shown below to establish the view factor from a single plane [13]:





The configuration factors are then added to produce the final configuration factor as follows [13]:

$$\phi_{total} = \phi_A + \phi_B + \phi_C + \phi_D$$