HAZARD AND RISK ASSESSMENT

Oil & Gas Pipelines near proposed Melrose Park High School

For NSW Department of Education

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Arriscar
Risk Engineering Solutions

Arriscar Pty Limited
ACN 162 867 763
www.arriscar.com.au

Sydney
Level 26
44 Market Street
Sydney NSW 2000
T: +61 2 9089 8804

Melbourne
Level 2 Riverside Quay
1 Southbank Boulevard
Southbank VIC 3006
T: +61 3 9982 4535

Distribution List

Name	Organisation	From	To
Joanna Hole	NSW Department of Education	-	Rev A
Tamara Podgorsek	NBRS Architects Pty Ltd	-	Rev A
Joshua DeAngelis	Colliers International Holdings (Australia) Limited		Rev A

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Summary

Arriscar Pty Ltd (Arriscar) was engaged by the NSW Department of Education (School Infrastructure) to undertake a hazard analysis for the high-pressure oil and gas pipelines in the vicinity of the proposed Melrose Park High School (MPHS) in the Melrose Park Precinct. This precinct is in the Parramatta Council Local Government Area (LGA) in NSW.

The scope of the study included undertaking a hazard analysis for the high-pressure pipelines in the Melrose Park Precinct, in accordance with HIPAP No. 6 [1]. It included an assessment of the risks against the risk criteria for land use safety planning in HIPAP No. 10 [2], for the proposed high school:

The underground pipelines in the vicinity of the precinct include:

(a) The Gore Bay Pipeline - a high-pressure dangerous goods pipeline operated by Viva Energy Australia (Viva).

(b) Secondary Natural Gas Mains operated by Jemena.

The findings of the study are as follows:

- The Gore Bay to Clyde fuel pipe's Measurement Length (i.e. thermal radiation to 4.7 kW/m^2 for full bore rupture and ignition) is 132m. The distance to the nearest boundary of the proposed school is 123m, which is just inside the measurement length distance.
- Since the Activity falls within the Measurement Length, in accordance with AS 2885.6-2018 [3], the pipeline operator Viva Energy Australia needs to be notified and a Safety Management Study (SMS) should be conducted with the stakeholders prior to construction, once the construction plan is developed.
- The maximum individual fatality risk is 0.5 x 10^{-6} p.a. and this only occurs at two locations where the Gore Bay Pipeline changes direction (Refer to Figure 9). This risk criterion level only applies to sensitive land uses (schools, hospitals, etc.), which are not currently proposed at these locations. Therefore, the proposed development satisfies the individual fatality risk criteria in HIPAP No.10 [2].
- The maximum individual fatality risk is approximately 0.3 x 10^{-6} p.a. at the boundary of the existing school in the South Precinct (Waratah Street) and approximately 0.04 x 10^{-6} p.a. at the boundary of the proposed new school in the North Precinct (Hope Street). Therefore, these uses are compliant with the 0.5 x 10^{-6} p.a. individual fatality risk criterion in HIPAP No.10 [2].
- All other individual risk levels comply with the corresponding quantitative risk criteria in HIPAP No.10 [2] (Refer to Sections 9.2 to 9.6).
- The from oil and gas pipelines comply with the individual and societal risk criteria in HIPAP No.10 [2].
- the majority of the risk contribution for societal risk from the oil and gas pipelines is from adjoining high density population buildings in the Melrose park Urban Development.

- Irrespective of the numerical value of any risk criteria level for risk assessment purposes, it is essential that certain qualitative principles be adopted concerning the land use safety acceptability of a new development or existing activity (Refer to Section 9.7). This is particularly relevant where for a planning proposal where rezoning and population intensification may occur. Whilst the risk to the Melrose Park High School meets the quantitative individual and societal risk criteria, risk reduction measures are included in Section 11.2, consistent with the qualitative principles in HIPAP No.10 [2].
- The entirety of the F-N curve is in the 'Negligible' or 'ALARP' regions and complies with the DPHI's indicative societal risk criteria (Refer to Section 9.9).
- The thermal radiation level at the nearest building of the MPHS at a frequency of $1x10^{-6}$ p.a. was calculated to be 1 kW/m2 (adopted design accident load for fire from pipelines). The buildings designed to the Building Code requirements can implicitly resist this radiation level.
- There is no explosion overpressure at the nearest school building of the MPHS at a frequency of $1x10^{-6}$ p.a.
- The maximum explosion overpressure on the buildings is 10 kPa at a frequency of 1.75E-09 p.a. This risk is negligible.
- There is no DAL defined for the buildings. The structures designed to the National Construction Code requirements are considered adequate.
- There are no recommendations from the study relating to the buildings design at the MPHS.
- The school emergency plan must include pipeline rupture as a scenario and develop an appropriate shelter in place policy to prevent the potential for injuries from people exposed to radiated heat flux in open.

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Notation

Abbreviation	Description
ALARP	As Low As Reasonably Practicable
Arriscar	Arriscar Pty Ltd
AS	Australian Standard
BoM	Bureau of Meteorology
BYDA	Before You Dig Australia (formerly DBYA – Dial Before You Dig)
CH4	Methane
CP	Cathodic Protection
DAL	Design Accidental Load
DoT	Department of Transport (USA)
DPHI	NSW Department of Planning, Industry and Environment
EGIG	European Gas Pipeline Incident Data Group
EIS	Environmental Impact Statement
FBR	Full Bore Rupture
F-N	Cumulative Frequency vs. Number of Fatalities
HAZID	Hazard Identification
HDD	Horizontal Directional Drilling
HDPE	High Density Polyethylene
HIPAP	Hazardous Industry Planning Advisory Paper
kg/m3	Kilograms per cubic metre
kg/s	Kilograms per second
km	Kilometres
KP	Kilometre Point (pipeline distance measurement)
kPa	Kilo Pascals
kPag	Kilopascals gauge
kW/m^2	Kilo Watts per square metre
LFL	Lower Flammability Limit
LGA	Local Government Authority
LSIR	Location-Specific Individual Risk
m	Metres
m/s	Metres per second
MAE	Major Accident Event

Abbreviation	Description
MAOP	Maximum Allowable Operating Pressure
mg/m^3	milligrams per cubic metres
MIE	Minimum Ignition Energy
mJ	milli Joules
ML	Megalitres
mm	millimetres
NG	Natural Gas
OBRA	Occupied Buildings Risk Assessment
OGP	Offshore Oil & Gas producers Association
OSHA	Occupational Safety and Health Agency (USA)
p.a.	per annum
PHA	Preliminary Hazard Analysis
PHMSA	Pipeline and Hazardous Materials Safety Administration (USA)
ppm	Parts per million
QRA	Quantitative Risk Assessment
RA	Risk Analysis
SEPP	State Environmental Planning Policy
SINSW	School Infrastructure NSW
TNT	Tri-nitro Toluene
TPA	Third Party Activity
UFL	Upper Flammability Limit
UG	Underground
UK HSE	United Kingdom Health & Safety Executive
UKOOA	United Kingdom Offshore Operators Association
UKOPA	United Kingdom Onshore Pipeline Operators' Association
v/v	volume/volume
VCE	Vapour Cloud Explosion

1 INTRODUCTION

1.1 Background

NSW Department of Education (DoE), through the School Infrastructure NSW (SINSW) is planning to build a new high school at 37 Hope Street, Melrose Park, NSW (the Activity)

The proposed Activity is being assessed under Part 5 of the *Environmental Planning and Assessment Act 1979*. Subject to legislative amendment the Activity is expected to be permitted without consent under *State Environmental Planning Policy (Transport and Infrastructure) 2021*.

A high pressure pipeline carrying refined petroleum products from the Viva Energy Australia (Viva) receiving terminal at Gore Bay to the distribution terminal at Clyde, runs close to the proposed school sites.

A Preliminary Hazard Analysis (PHA) of the oil and gas pipelines in the vicinity of the proposed Activity is required by the Planning Circular PS 2024-005 [4] to determine the risk impact on people and school buildings from potential incidents of loss of containment from the pipelines.

This PHA has been prepared by Arriscar on behalf of the Department of Education (DoE) to assess the potential environmental impacts that could arise from the Activity.. This report supports the assessment of the proposed Activity under Part 5 of the *Environmental Planning and Assessment Act 1979*. The Activity is proposed by the DoE to meet the growth in educational demand in the Melrose Park precinct.

The proposed Melrose Park High School site is in the Parramatta Council Local Government Area (LGA) and is proposed to be redeveloped in two stages.

This PHA report assesses the potential gas and oil release scenarios from the pipelines and the risk impact on proposed site, and evaluates compliance with the risk criteria in Hazardous Industry Planning Advisory Paper (HIPAP) No.10 [2]. This PHA will form part of the supporting documents with the Development Application.

1.2 The Proponent

The Department of Education (DoE) is the proponent and determining authority pursuant to Section 5.1 of the *Environmental Planning and Assessment Act 1979* (the Act).

1.3 Landowner

The NSW Minister for Education and Early Learning is the landowner of the site.

1.4 Objectives

The principal objective of the study was to conduct a PHA of the Viva Energy oil pipeline and Jemena gas pipelines in the vicinity of the proposed Melrose Park High School and assess the risk against the criteria in HIPAP 10 [2].

- Identification of release events from the multi product fuel pipeline and natural gas secondary mains in the vicinity of the proposed Melrose Park High School site;
- Development of appropriate and relevant representative oil and gas release scenarios that may impact on the school;
- Quantification of the consequences of harmful effects for each representative scenario (fires, explosions), including the potential for impact on the school buildings and people;

- Quantification of the likelihood of occurrence of each representative scenario;
- Development and justification of assumptions for the risk assessment that are appropriate, with a focus on minimising uncertainty and obtaining a 'cautious best estimate' of risk to the proposed development;
- Generation of Location-Specific Individual Risk (LSIR) contours for comparison with the DPHI's risk criteria for land use safety planning , viz. as per HIPAP No.4 [5] and HIPAP No.10 [2]; and
- Estimation of societal risk for comparison with the Department of Planning, Housing and Infrastructure (DPHI) indicative risk criteria for land use safety planning, viz. as per HIPAP No. 4 [5] and HIPAP No.10 [2].
- Prepare a PHA report in accordance with HIPAP No.6 [1].

1.5 Planning Circular 24-005

The Viva Energy oil pipeline in the vicinity of MPHS is listed under section 2.77 of the (T&I SEPP). Therefore the planning requirements outlined in the Planning Circular 24-005 [4] for high pressure pipelines applies to the Activity.

2 Study Area

2.1 School Location

The proposed Melrose Park High School site is located in the City of Parramatta LGA, bordering on the boundary of the City of Ryde LGA. The precinct is currently an industrial area with plans for redevelopment.

A locational map is shown in Figure 1.

Figure 1: Melrose Park High School Location Map

Ref: Google Earth Pro

2.2 Surrounding Land Uses

The Melrose Park Precinct is divided into northern and southern parts, with Hope Street dividing the two. The northern part is bound by Victoria Road to the north, Wharf Road to the east, Hope Street to the south and Hughes Avenue to the west.

The Proposed site abuts Wharf Road and Hope Street on two sides, and located in the North Precinct of Melrose Park. The following land uses surround the site:

To the North: High density residential including new Town Centre.

To the East: Across Wharf Road – existing low density residential (RE2)

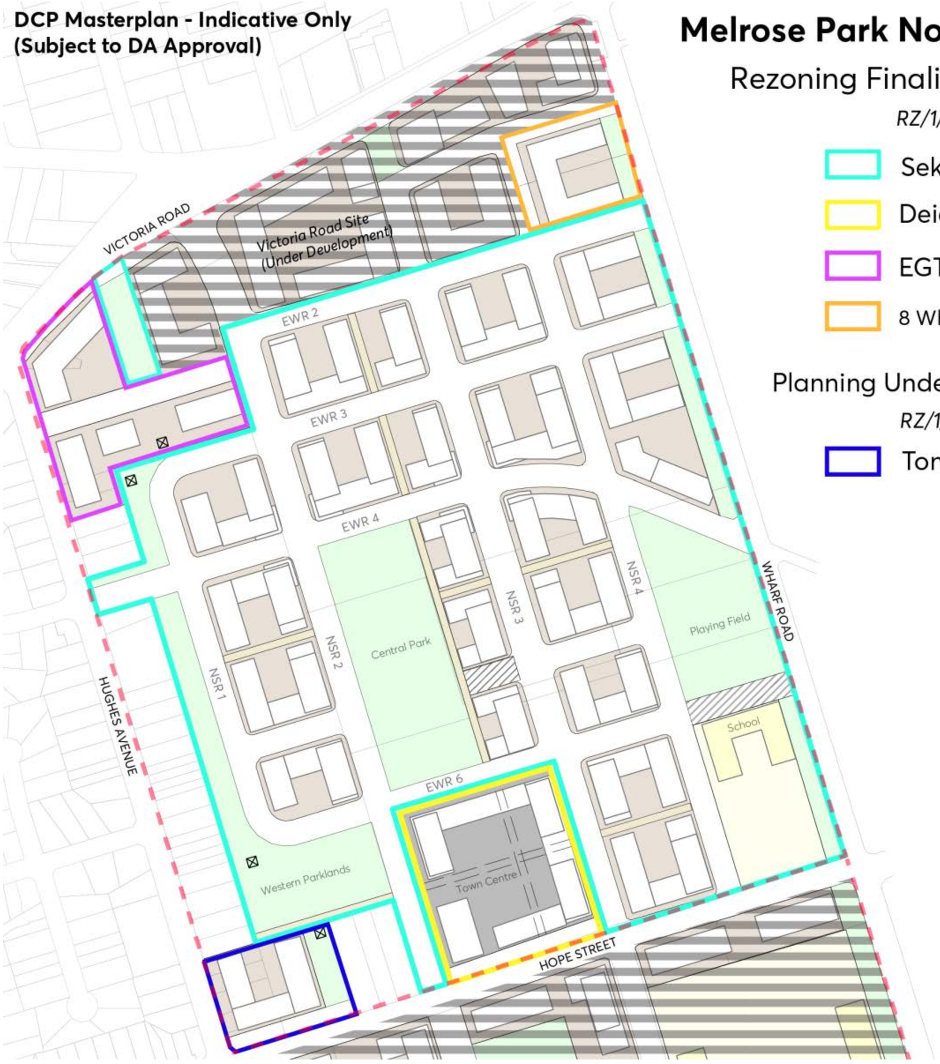
To the South: Across Hope Street –High density residential (South Precinct).

To the West: High density residential

2.2.1 Land Use Zoning

Structural planning maps have been drawn up for the Melrose Park precincts. The north precinct is shown in Figure 2 [6].

Figure 2: Melrose Park North Precinct Structural Plan



The assumed population data for the various existing land uses is given in Appendix A.2 (Assumption No. 6 and Assumption No. 7). The proposed school population and the proposed 19 Hope Street development are included in the societal risk assessment.

2.3 Pipeline Locations

The following pipelines have been identified in the vicinity of the Melrose Park School site.

1. The Gore Bay to Clyde liquid fuel pipeline operated by Viva Energy Australia (Viva). This is a licensed pipeline.
2. Two Jemena Secondary Natural Gas Mains. These are not licensed pipelines, but covered by the NSW Work Health and Safety Regulation [7].

Details are provided in Section 4.

The location of the pipelines was determined through a review of 'Before You Dig Australia' (BYDA) information. The pipeline locations used in the risk model are shown in Figure 3.

Figure 3: Locations of Gore Bay Pipeline and Secondary Natural Gas Mains

The Gore Bay to Clyde oil pipeline operated by Viva passes along Waratah Street, and then towards west along Hope Street. The proposed high school site south eastern corner is 123m away from the Viva pipeline.

The Jemena secondary gas mains run along Hope Street and then deviate to run along the length of Wharf Road, to the east of the subject site.

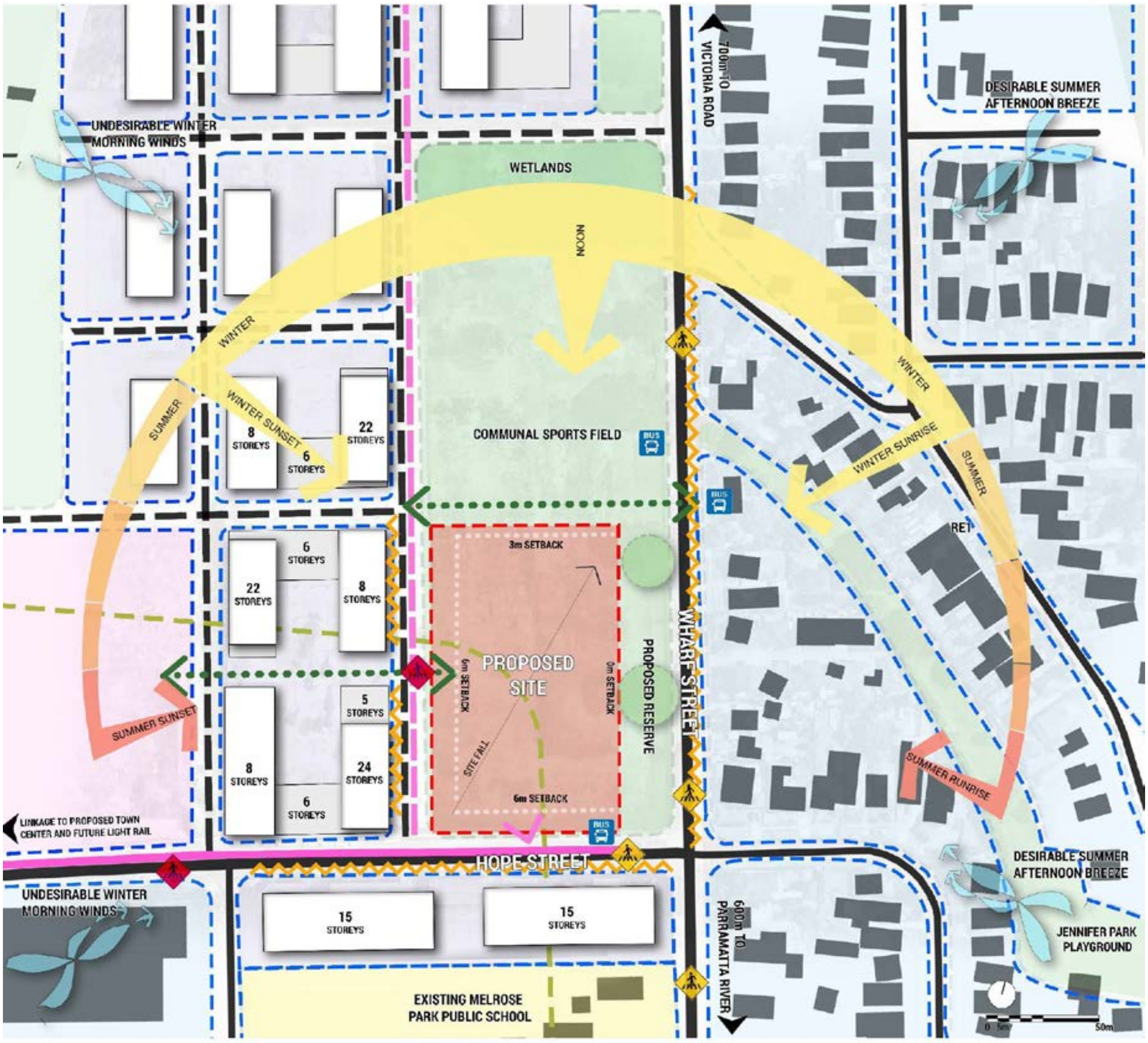
3 OUTLINE OF MELROSE PARK HIGH SCHOOL PROJECT

3.1 Site Description

The site is located at 37 Hope Street, Melrose Park within the Parramatta LGA. The school covers an approximate area of 9,500m^2 and is generally rectangular in shape. The site is currently cleared and vacant. The site is located approximately 8km east of the Parramatta CBD.

A map of site and surrounds is shown in Figure 4.

Figure 4: Melrose Park High School Site and Surrounds



3.2 Proposed Activity

The proposed activity involves the construction and use of a new high school in two stages for approximately 1,000 students. The project will be constructed in two stages [8].

Stage 1 of the proposed activity includes the following:

- Site preparation works.

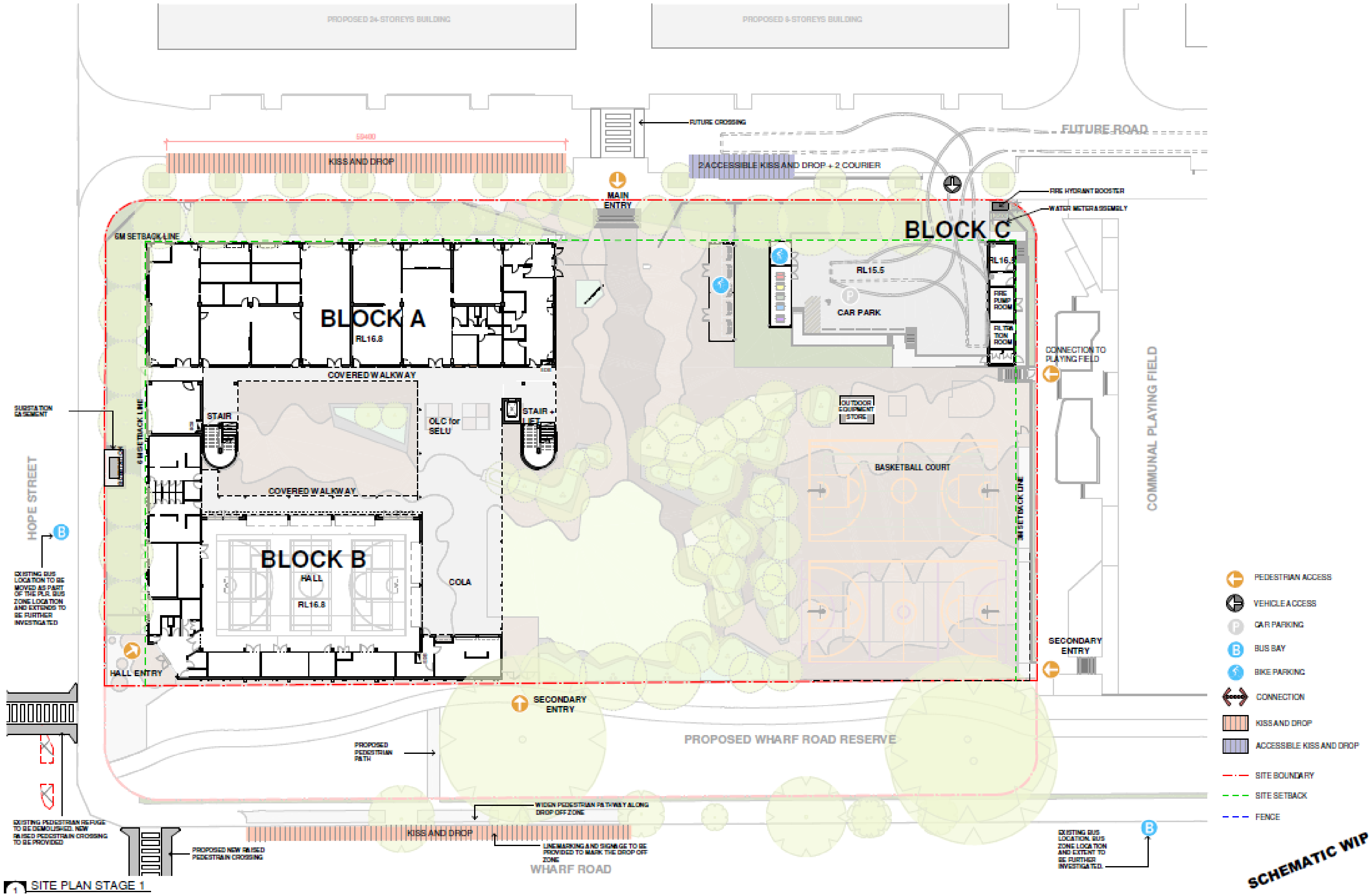
- Construction of Block A – a six-storey (with additional roof/plant level) school building in the south-western portion of the site containing staff rooms and General Learning Spaces (GLS).
- Construction of Block B – a one storey (double height) hall, gymnasium, canteen and covered outdoor learning area (COLA) building in the south-eastern portion of the site.
- Construction of Block C – a single storey plant and storage building at the north-eastern portion of the site.
- Associated landscaping.
- Construction of on-site car parking.
- Provision and augmentation of services infrastructure.
- Associated public domain infrastructure works to support the school, including (but not limited to):
  - Provision of kiss and drop facilities along Wharf Road, and widening of the Wharf Road footpath.
  - Raised pedestrian crossings on Wharf Road and Hope Street.

Stage 2 of the proposed activity includes the following:

- Construction of Block D – a five-storey (with additional roof/plant level) school building in the north-western portion of the site containing staff rooms and GLS:
- Additional open play spaces within the terrace areas of Building D.
- Minor layout amendments to Block A.

A site layout for Stage 1 is shown in Figure 5.

Figure 5: Stage 1 Site Plan



4 OVERVIEW OF PIPELINES IN THE STUDY AREA

4.1 Introduction

One high-pressure dangerous goods pipeline passes through the Melrose Park Precinct. This pipeline is operated by Viva Energy Australia (Viva).

Secondary natural gas mains and medium pressure natural gas mains also pass through, or adjacent to, the Melrose Park Precinct. These are part of Jemena's natural gas distribution network and similar mains are common throughout suburban streets. Although not licenced pipelines, three of the larger secondary mains may operate at pressures up to 1050 kPag and two of these mains are also located in Hope Street together with the Gore Bay Pipeline (Note: Only to west of Waratah Street).

The DPHI Circular PS 24-005 [4] applies only to licensed hazardous materials pipelines. However, the larger secondary mains were also included in the QRA.

4.2 Pipeline Data Gathering

In relation to a previous risk assessment study for the Melrose Park Urban Renewal Project [9], Arriscar initiated a BYDA enquiry in September 2020 ([10], [11]) and an initial response was received from Viva and Jemena. This response (including maps showing approximate locations of the pipelines in the study area) was used to determine the scope of the follow-up consultation.

Operational data (MAOP, transfer rates, etc.) for the Gore Bay Pipeline was sought directly from Viva. Viva declined to provide this information; therefore, the operational data required for the QRA was sourced from publicly available information (Refer to Section 4.3).

The secondary natural gas mains are not licenced pipelines and the information supplied by Jemena in the BYDA response [10] and in the Safety Case (SAOP) of Jemena Gas Assets (NSW) [12] was sufficient for the QRA. Additional consultation with Jemena was not undertaken.

The data collected and reported in Ref. [9] was used in this study.

4.3 Gore Bay Pipeline

The Gore Bay Pipeline is located on the southern side of Hope Street and traverses the precinct boundary between Atkins Street and Waratah Street. At the intersection of Hope Street and Waratah Street, the pipeline follows the western side of the Waratah Street towards the Parramatta River and then towards the east of the Melrose Park Southern Precinct (Refer to Figure 3).

The Gore Bay Pipeline is approximately 19 km long and is used to transfer gasoline, diesel and jet fuel from ships at Gore Bay directly to the fuel terminal at Clyde [13].

It is reported in the Exhibited Draft Melrose Park Southern Structure Plan [14] that Viva has advised that the measurement length for the Gore Bay Pipeline is 132 m. This is the distance to a heat radiation level of 4.7 kW/m^2 for a full bore rupture of the pipeline (as per AS/NZS 2885.1:2018 [15]).

The distance from Viva pipeline to the boundary of the proposed school is 123m. The school is with the Measurement Length distance.

The information tabulated below was primarily sourced from publicly available information.

Table 1: Gore Bay Pipeline

Pipeline Owner	**Viva Energy Australia**
Pipeline Name	Gore Bay Pipeline
Material/s Transferred	Gasoline, Diesel Fuel and Jet Fuel [16]
Licence No.	Not Applicable – The Gore Bay Pipeline is not a licensed pipeline under the Pipelines Act 1967. It is covered under the Work Health and Safety Regulations 2017, which is regulated by SafeWork NSW [4]
Original Year of Construction	The Gore Bay Pipeline has been in service since 1962 [16]
MAOP	6,500 kPag [16]
Normal Operating Pressure	*Information not provided*
Operating Temperature	*Information not provided*
Flowrate	19 ML/day capacity [17]
Pipeline Material	*Information not provided*
Pipeline Diameter	300 mm [16]
Wall Thickness	*Information not provided*
Depth of Cover	*Information not provided* These range from 500 mm to 1000 mm. It is understood that the pipelines were surveyed as part of a proposed light rail project
Cathodic Protection	*Information not provided* (Note: CP test points were observed during the site inspection at the western end of Hope Street and at the corner of Wharf Road and Waratah Street)
External / Internal Coating/s	*Information not provided* (Note: It is reported in the minutes of the Gore Bay Terminal GCA Engagement Forum (Nov 2017) that a section of the pipeline near Shell Park was 're-coated' following an inspection by intelligent pigging [18])
Leak Detection	A software-based leak detection system (pressure and mass balance) is installed and the pipeline shuts down if communications shut down [18]
Locations of Nearest Isolation Valves	*Information not provided*
Inspections and Maintenance	Viva pipelines are maintained in accordance with Australian Standard AS2885 [19] [18] and a Pipeline Integrity Management Plan [19]
Control Measures for Third Party Activity (TPA)	Consultation guideline for developers and Councils [20] Pipeline danger signs [21] Excavation works near pipelines are covered under Clauses 304, 305 and 306 of the WHS Regulation 2017 and require a BYDA [18]
Pigging	'Intelligent' pigging is used to identify areas of focus and a verification dig or excavation is performed in the field to verify the information and correlate this with the 'intelligent' pigging results [18]

4.4 Secondary Natural Gas Mains

The information tabulated below for the two secondary natural gas mains included in the QRA is primarily based on information supplied by Jemena in the DBYD response [10] and information in the Safety Case (SAOP) of Jemena Gas Assets (NSW) [12]. Data for other similar secondary mains is also included where relevant.

The Secondary Mains are operated and maintained in accordance with a Safety Management Manual and the requirements of AS/NZS 4645 [12].

Table 2: Secondary Natural Gas Mains

Pipeline Owner	**Jemena**	**Jemena**	**Jemena**
Pipeline Name	350 ST 1050 kPa [10]	150 ST 1050 kPa [10]	100 ST 1050 kPa [10]
Material/s Transferred	Natural Gas		
Licence No.	Not Applicable (Secondary mains are not licensed pipelines)		
Original Year of Construction	*Information not provided*		
MAOP	1050 kPag [10]		
Normal Operating Pressure	Secondary mains typically operate at > 545 kPag to 1050 kPag [12]		
Operating Temperature	*Information not provided* (15 °C typical)		
Flowrate	*Information not provided*		
Pipeline Material	Steel (Typically Carbon Steel, API 5L Grade B or Grade X42 [22])		
Pipeline Diameter	350 mm	150 mm	100 mm
Wall Thickness	*Information not provided* (4.78 mm typical)		
Depth of Cover	*Information not provided* Depth range from 550 mm to 1100 mm. It is understood that the pipelines were surveyed as part of a proposed light rail project		
Cathodic Protection	*Information not provided* (Secondary mains are typically provided with CP, which is periodically monitored [12]. CP test points were observed during the site inspection)		
External / Internal Coating/s	*Information not provided* (Typically coated with High-Density Polyethylene (HDPE) or Tri-laminate product and internally lined to reduce frictional loses and provide some internal corrosion protection [12])		
Leak Detection	*Information not provided*		
Locations of Nearest Isolation Valves	*Information not provided*	Isolation valves at Hope St / Wharf Rd and Hope St	Isolation valve at Hope St / Wharf Rd
Inspections and Maintenance	*Information not provided* (Integrity is assessed through integrity and performance assessments [12])		
Control Measures for Third Party Activity (TPA)	*Information not provided* (Typically includes BYDA, pipeline patrols and surveillance [12])		
Pigging	NA - Secondary mains are not piggable [12]		

4.5 Measurement Length

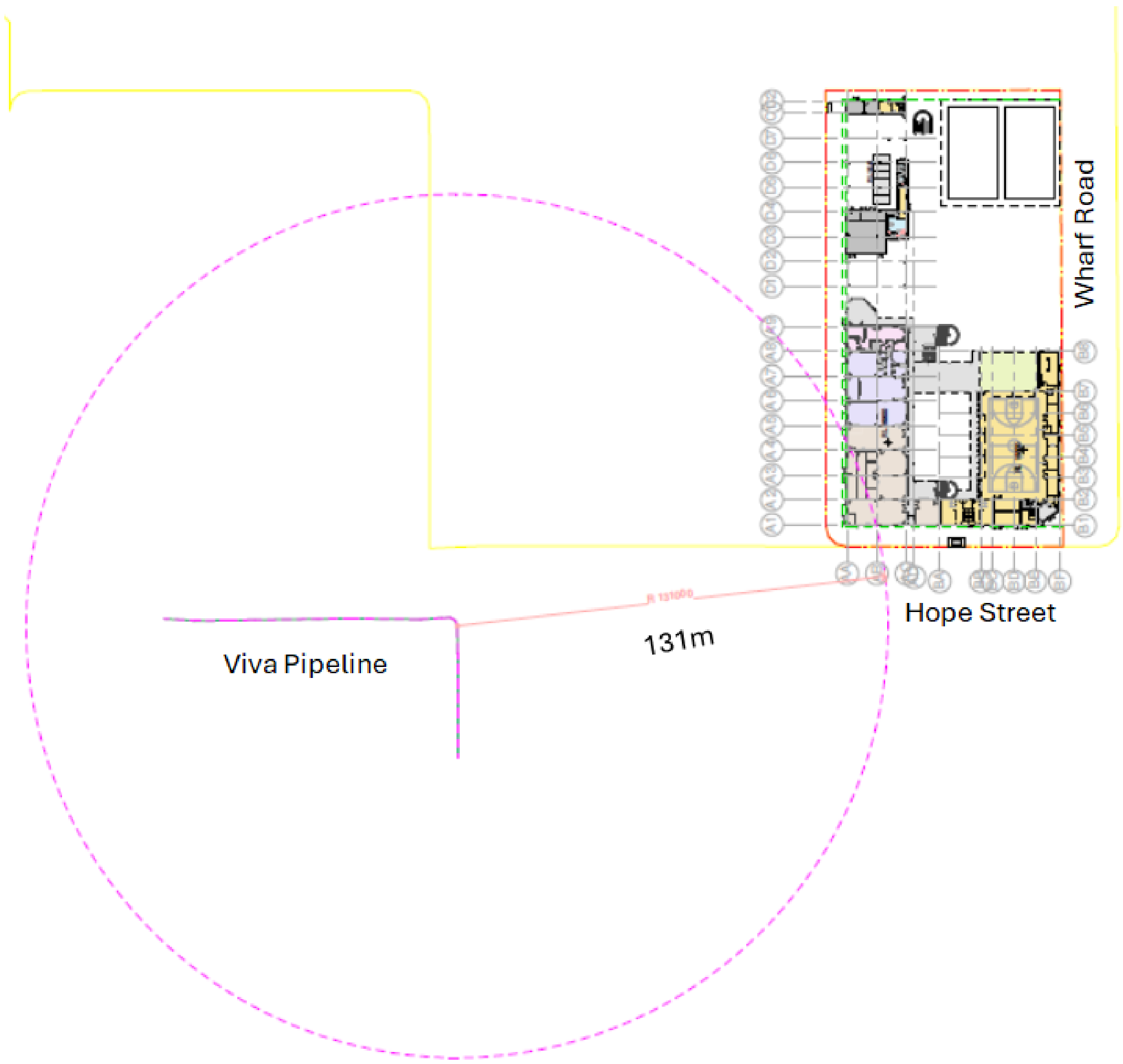
The “Measurement Length” is a technical term referred to in Australian Standard AS 2885.6-2018 [3], that determines the extent to which a Land Use Change Safety Management Study (SMS) is applicable.

“The Measurement Length is defined as the distance from the centre of pipeline to a distance to 4.7 kW/m^2 thermal radiation intensity, from a full-bore rupture of the pipeline and ignition.”

The section of the Viva Energy pipeline within one Measurement Length of the proposed MPHS is shown in Figure 6. The reported measurement length is 132m. This reaches the MPHS school site.

The Viva pipeline is 123m from the to the southwest corner of the property, as shown in Figure 6.

Figure 6: Proximity of Viva Oil Pipeline to Proposed Melrose park High School



The proposed activity is within the measurement length and hence AS 2885.6-2018 [3] SMS is required. This requirement is discussed further in the report.

5 RISK ASSESSMENT METHODOLOGY

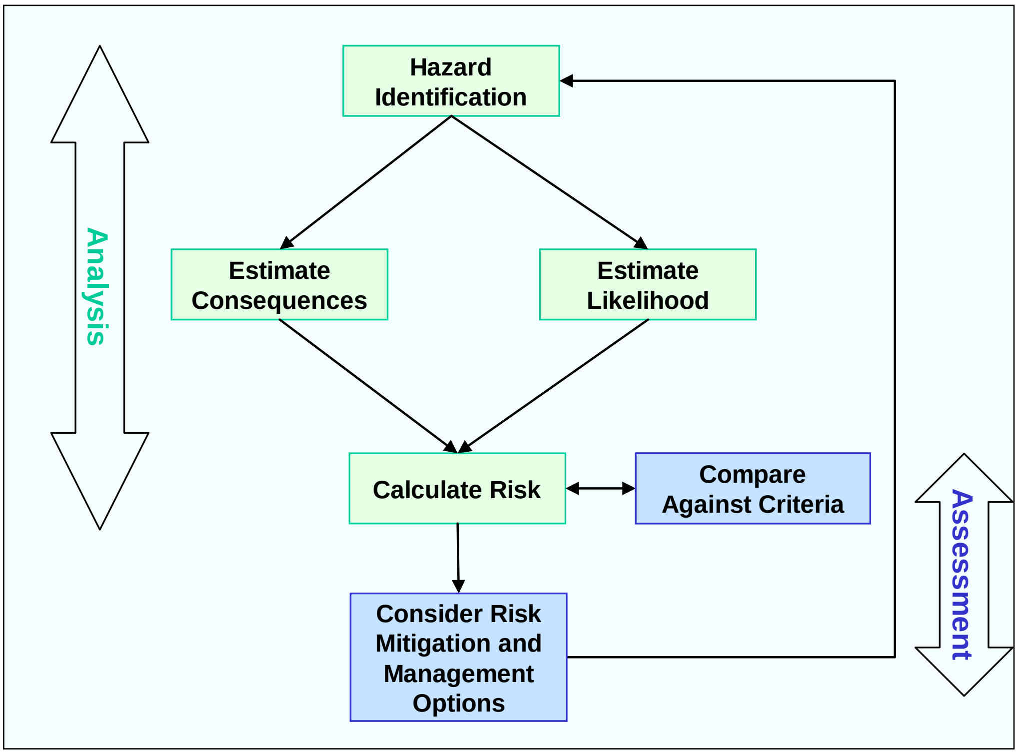
5.1 Introduction

This analysis involves the quantitative estimation of the consequences and likelihood of accidents (viz. a Quantitative Risk Assessment or QRA). For consequences to people, the most common risk measure is 'individual fatality risk' (viz. The likelihood of fatality per year).

In developing the estimates for use in a QRA, it is important to ensure that any estimates fall on the side of conservatism, particularly where there is uncertainty in the underlying data and assumptions. This precautionary approach uses 'cautious best estimate' values, which, whilst conservative, are still realistic. This approach is consistent with the DPHI's guidelines for undertaking this type of assessment [1].

Diagrammatically, the QRA process is as follows:

Figure 7: Overview of QRA Process [1]



5.2 Methodology Overview

5.2.1 Hazard Identification and Register of Major Accident Events

A hazard is something with the potential to cause harm (e.g. thermal radiation from a fire, physical impact from a moving vehicle or dropped object, exposure to stored energy, etc.). As well as identifying the hazards that exist, it is also important to identify how these hazards could be realised.

For example, the Hazard identification (or HAZID) step for a QRA of a potentially hazardous pipeline would identify representative events that could result in a release of the material from the pipeline with the potential to cause harm (e.g. due to a subsequent ignition and fire/explosion). The representative potentially hazard events are commonly described as 'Major Accident Events' (or MAEs). In the context of the QRA, an MAE is an event with the potential to cause: off-site fatality or injury; off-site property damage; or, long-term damage to the biophysical environment (i.e. any outcome for which DPHI has defined an acceptable risk criterion – Refer to Section 0).

There is no single definitive method for hazard identification (HAZID); however, it should be comprehensive and systematic to ensure critical hazards are not excluded from further analysis.

When identifying hazards for modelling in a QRA, it is necessary to capture the following information, either during the hazard identification process, or as part of the preparation for hazard consequence modelling:

- Hazardous materials and material properties;
- Inventory of hazardous materials that could contribute to the accident;
- How the material is released (e.g. hole in a pipeline or pipeline rupture);
- The condition of the material prior to release (e.g. compressed gas at a specific temperature and pressure);
- The area/s into which the material is released (e.g. inside an enclosed area, etc.);
- Ambient conditions in the area where the material is released (e.g. air temperature, wind speed and direction, atmospheric stability);
- Locations of ignition sources around the release point; and
- Duration of release before it is isolated.

The above information was used to develop a detailed list of Major Incidents (MAEs) for risk assessment. This QRA includes an estimate of the consequences and likelihood of each of these scenarios and aggregates the results to estimate the total risk.

5.2.2 Hazard Consequence Analysis

The physical consequences of a release of potentially hazardous material (e.g. flammable gas, flammable liquid, etc.) are generally dependent on:

- the quantity released;
- the rate of release; and,
- for fire and explosion events if ignition occurs.

The quantity of release depends on the inventory, size of release (viz. assumed equivalent hole diameter) and duration of release (how soon can the release be detected and isolated).

Meteorological conditions, such as wind speed, wind direction and weather stability class have an impact on the extent of the downwind and crosswind dispersion. Location-specific meteorological data is therefore required to undertake a QRA study. The representative wind directions, wind speeds and wind stability classes are normally determined from annual average of weather data available from the Bureau of Meteorology, for the local weather station.

In addition to wind speed, the Pasquil stability class has a significant impact on the vertical and crosswind dispersion of a released gas. Six wind stability classes (A to F) are normally used. Class A refers to more turbulent unstable conditions and Class F refers to more stable (inversion) conditions. Although the probability distribution of Pasquil stability classes is site-specific, it is generally observed that Class F conditions are more likely to occur during the night-time while Class D (neutral) conditions occur during the daytime (sunny conditions).

The wind direction, wind speed and stability class distribution used for the QRA is presented in Appendix A (Assumption No. 3).

The SAFETI v.9.0 software package was used for all consequence modelling and the generation of the risk contours and societal risk curves.

5.2.3 Impairment Criteria

Impairment criteria have been developed for the effects of explosions and fires as outlined below. The impairment criteria adopted for the QRA are included in Appendix A.6.

Explosion

During a flash fire, acceleration of the flame front can occur due to the turbulence generated by obstacles within in the combusting vapour cloud. When this occurs, an overpressure ('shock') wave is generated which has the potential to damage equipment and/or injure personnel.

The impact of explosion overpressure on humans takes two forms:

- For a person in the open, there could be organ damage (e.g. ear drum rupture or lung rupture), that may be considered to constitute serious harm.
- The person could be hit a flying missile, caused by the explosion, and this can lead to serious injury or even fatality.

The effects of exposure to explosion overpressure are summarised in Table 3 [1].

Table 3: Effects of Explosion Overpressure

Overpressure [kPa]	Effect/s
0.3	Loud noise.
1.0	Threshold for breakage of glass.
4.0	Minimal effect in the open. Minor injury from window breakage in building.
7.0	Glass fragments fly with enough force to cause injury. Probability of injury is 10%. No fatality. Damage to internal partitions and joinery of conventional buildings, but can be repaired.
14.0	1% chance of ear drum rupture. House uninhabitable and badly cracked.
21.0	10% chance of ear drum rupture. 20% chance of fatality for a person within a conventional building. Reinforced structures distort. Storage tanks fail.
35.0	50% chance of fatality for a person within a conventional building and 15% chance of fatality for a person in the open. House uninhabitable. Heavy machinery damaged. Significant damage to plant.
70.0	100% chance of fatality for a person within a building or in the open. 100% loss of plant.

Fire

The potential for injury or property damage from a fire is determined by the intensity of the heat radiation emitted by the fire and the duration of exposure to this heat radiation.

The effects of exposure to thermal radiation are summarised in Table 4 [1]. The vulnerability criteria used in the risk analysis are included in Appendix A.6.

Table 4: Effects of Thermal Radiation

Heat Radiation [kW/m²]	Effect/s
1.2	Received from sun in summer at noon.
1.6	Minimum necessary to be felt as pain.
4.7	Pain in 15 to 20 seconds, 1st degree burns in 30 seconds. Injury (second degree burns) to person who cannot escape or seek shelter after 30s exposure.
12.6	High chance of injury. 30% chance of fatality for extended exposure. Melting of plastics (cable insulation). Causes the temperature of wood to rise to a point where it can be ignited by a naked flame after long exposure. Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure.
23.0	Fatality on continuous exposure. 10% chance of fatality on instantaneous exposure. Spontaneous ignition of wood after long exposure. Unprotected steel will reach thermal stress temperatures, which can cause failure. Pressure vessel needs to be relieved or failure would occur.
35.0	25% chance of fatality on instantaneous exposure.
60.0	Fatality on instantaneous exposure.

The dominant effect in a flash fire is direct engulfment by flame within the combusting cloud. To estimate the magnitude of the flammable gas cloud, the furthest distance from the release location with a concentration equal or above the lower flammability limit (LFL) is estimated using a dispersion model.

5.2.4 Frequency and Likelihood Analysis

Once the consequences of the various accident scenarios have been estimated, it is necessary to estimate the likelihood of each scenario. In a QRA, the likelihood must be estimated in quantitative terms (i.e. occurrences per year). Exponential notation (e.g. 5.0 x 10^{-6} per year or 5E-06 per year) is normally used because the likelihood of an incident is usually a low number (i.e. less than 1 chance in 1000 to 10000 per year).

The likelihood of each scenario is normally estimated from historical incident and failure data. This is only possible because data on such incidents and failures has been collected by various organisations over a number of years. Various databases and reference documents are now available that provide this data.

When using historical data to forecast the likelihood of a future event, it is important to ensure any specific conditions that existed at the time of the historical event are taken into account. For very low frequency events (i.e. where historical occurrences are very rare), it might not be possible to estimate the likelihood values directly from the historical data and other techniques such as fault tree analysis may be required.

The frequency analysis data and results are summarised in Section 8 and Appendix C.

5.2.5 Risk Analysis and Assessment

Risk analysis and assessment are separate tasks although they are often undertaken together. Risk analysis involves combining the consequence and likelihood estimates for each scenario and then summing the results across all the accident scenarios to generate a complete picture of the risk. The risk assessment step involves comparing the risk results against risk criteria.

Location-specific individual risk (LSIR) contours are usually used to represent off-site risk for a land-use safety QRA study. These iso-risk contours are superimposed on a plan view drawing of the site. Example risk levels that are typically shown as iso-risk contours include: 1×10^{-6} per year, 10×10^{-6} per year and 50×10^{-6} per year.

The iso-risk contours show the estimated frequency of an event causing a specified level of harm at a specified location, regardless of whether or not anyone is present at that location to suffer that harm. Thus, individual iso-risk contour maps are generated by calculating individual risk at every geographic location, assuming a person will be present and unprotected at the given location 100% of the time (i.e. peak individual risk with no allowance for escape or occupancy).

The assessment of risk results involves comparing the results against risk criteria. In some cases, this assessment may be a simple listing of each criterion together with a statement that the criterion is met. In other, more complex cases, the risk criteria may not be met, and additional risk mitigation controls may be required to reduce the risk.

The SAFETI 9.0 software package was used to generate the iso-risk contours and societal risk results (Refer to Section 9).

In the context of Melrose Park urban renewal project getting implemented in the near future, the projected population in Melrose Park North and South precincts has been used in the societal risk assessment.

5.3 Study Assumptions

It is necessary to make technical assumptions during a risk analysis. These assumptions typically relate to specific data inputs (e.g. material properties, equipment failure rates, etc.) and modelling assumptions (e.g. release orientations, impairment criteria, etc.).

To comply with the general principles outlined in Section 2.2 of HIPAP No. 6 [1], all steps taken in the risk analysis should be:

> "*traceable and the information gathered as part of the analysis should be well documented to permit an adequate technical review of the work to ensure reproducibility, understanding of the assumptions made and valid interpretation of the results*". Therefore, details of the key assumptions adopted for the risk analysis are provided in Appendix A.

5.4 Quantitative Risk Criteria

5.4.1 Individual Fatality Risk

The individual fatality risk imposed by a proposed (or existing) industrial activity should be low relative to the background risk. This forms the basis for the following individual fatality risk criteria adopted by the NSW DPHI [2] and [5].

Table 5: Individual Fatality Risk Criteria

Land Use	Risk Criterion [per million per year]
Hospitals, schools, childcare facilities and old age housing developments	0.5
Residential developments and places of continuous occupancy, such as hotels and tourist resorts	1
Commercial developments, including offices, retail centres, warehouses with showrooms, restaurants, and entertainment centres	5
Sporting complexes and active open space areas	10
Industrial sites	50 *

* HIPAP 4 allows flexibility in the interpretation of this criterion. For example, 'where an industrial site involves only the occasional presence of people, such as in the case of a tank farm, a higher level of risk may be acceptable'.

The DPHI has adopted a fatality risk criterion of 1 x 10^{-6} per year (or 1 chance of fatality per million per year) for residential area exposure because this risk is very low in relation to typical background risks for individuals in NSW. For sensitive land uses such as schools, the criterion is one-half that for a residential area, viz. 0.5 x 10^{-6} pe year.

5.4.2 Injury Risk

The DPHI has adopted risk criteria for levels of effects that may cause injury to people but will not necessarily cause fatality. Criteria are included in HIPAP No. 4 [5] for potential injury caused by exposure to heat radiation, explosion overpressure and toxic gas/ smoke/dust.

The DPHI's suggested injury risk criterion for heat radiation is as follows:

- *Incident heat flux radiation at residential and sensitive use areas should not exceed 4.7 kW/m^2 at a frequency of more than 50 chances in a million per year.*

The DPHI's suggested injury/damage risk criterion for explosion overpressure is as follows:

- *Incident explosion overpressure at residential and sensitive use areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year.*

The DPHI's suggested injury risk criteria for toxic gas/ smoke/dust exposure are as follows:

- *Toxic concentrations in residential and sensitive use areas should not exceed a level which would be seriously injurious to sensitive members of the community following a relatively short period of exposure at a maximum frequency of 10 in a million per year.*

- *Toxic concentrations in residential and sensitive use areas should not cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community over a maximum frequency of 50 in a million per year.*

5.4.3 Risk of Property Damage and Accident Propagation

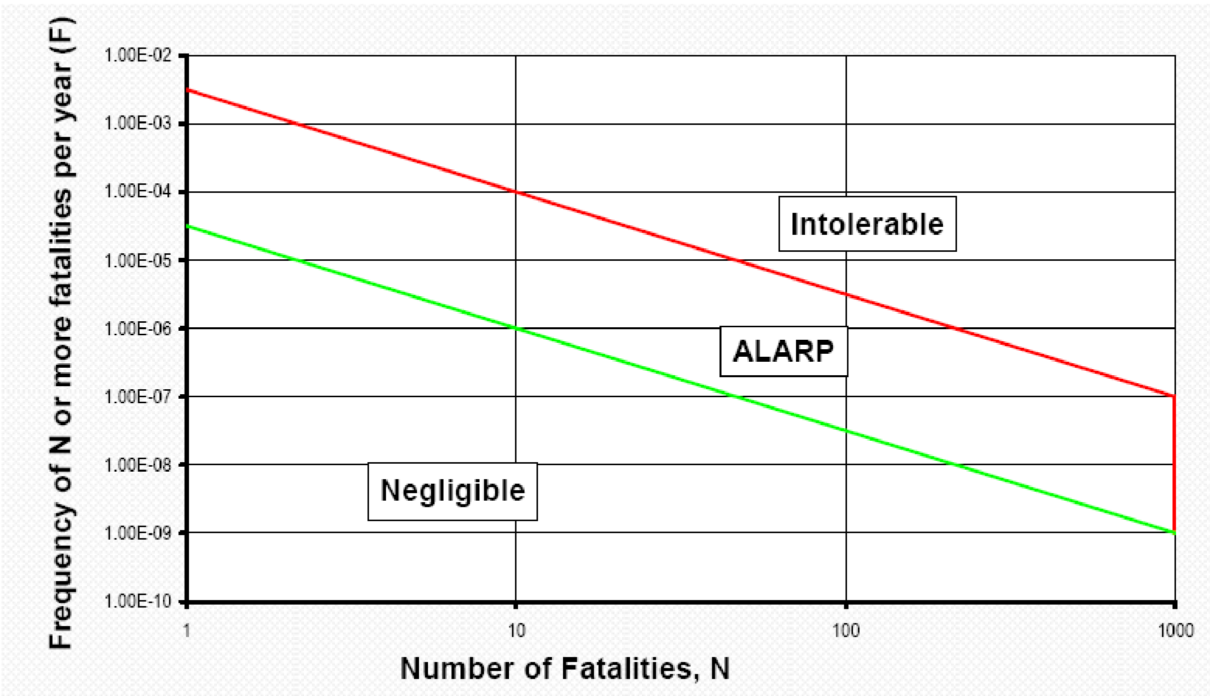
Heat radiation exceeding 23 kW/m^2 may cause unprotected steel to suffer thermal stress that may cause structural damage and an explosion overpressure of 14 kPa can cause damage to piping and low-pressure equipment. The DPHI's criteria for risk of damage to property and accident propagation are as follows [5]:

- *Incident heat flux radiation at neighbouring potentially hazardous installations or at land zoned to accommodate such installations should not exceed a risk of 50 in a million per year for the 23 kW/m^2 heat flux level.*
- *Incident explosion overpressure at neighbouring potentially hazardous installations, at land zoned to accommodate such installations or at nearest public buildings should not exceed a risk of 50 in a million per year for the 14 kPa explosion overpressure level.*

5.4.4 Societal Risk

The DPHI's suggested societal risk criteria (Refer to Figure 8), recognise that society is particularly intolerant of accidents, which though infrequent, have a potential to create multiple fatalities. Below the negligible line, provided other individual criteria are met, societal risk is not considered significant. Above the intolerable level, an activity is considered undesirable, even if individual risk criteria are met. Within the 'As Low As Reasonably Practicable' (ALARP) region, the emphasis is on reducing risks as far as possible towards the negligible line. Provided other quantitative and qualitative criteria of HIPAP 4 [5] are met, the risks from the activity would be considered tolerable in the ALARP region.

Figure 8: Indicative Societal Risk Criteria



The F-N criterion in NSW imposes an absolute upper limit of N=1000 (i.e. an incident that could cause more than 1000 fatalities is not tolerable), regardless of how low the frequency is.

It is reported in HIPAP No. 4 [5] that the criteria in Figure 8 are indicative criteria and provisional only and do not represent a firm requirement in NSW.

5.5 Qualitative Risk Criteria

Irrespective of the numerical value of any risk criteria for risk assessment purposes, it is essential that certain qualitative principles be adopted concerning the land use safety acceptability of a proposed development or existing activity. The qualitative risk criteria outlined in HIPAP No. 4 [5] encompass the following general principles:

- Avoidance of all 'avoidable' risks;
- Reduction, wherever practicable, of the risk from a major hazard, even where the likelihood of exposure is low;
- Containment, wherever possible, within the site boundary of the effects (consequences) of the more likely hazardous events; and,
- Recognition that if the risk from an existing installation is already high, further development should not be permitted if it significantly increases that existing risk.

6 HAZARD IDENTIFICATION

6.1 Introduction

The hazard identification was based on a review of the: information on the Gore Bay Pipeline and the Secondary Natural Gas Mains (Refer to Section 4); properties of Gasoline, Diesel, Jet Fuel and Natural Gas; and, potential failure modes and consequences if a leak were to occur from a pipeline. These findings are presented as follows:

Section 6.2 - Properties of Potentially Hazardous Materials.

Section 6.3 - Pipeline Failure Modes.

Section 6.4 - Consequences of Liquid or Gas Release.

Section 6.5 - Control Measures.

The representative MAEs carried forward to the consequence analysis are listed in Section 6.6.

6.2 Properties of Potentially Hazardous Materials

6.2.1 Gasoline

Gasoline (i.e. unleaded petrol) is typically a mixture of hydrocarbons (paraffins, cycloparaffins, aromatic and olefinic hydrocarbons, with carbon numbers predominantly in the C4 to C12 range) and is modelled as n-Heptane (C7) in the QRA.

Physical properties are listed in Table 6.

Table 6: Physical Properties of Gasoline and n-Heptane

	Gasoline	n-Heptane
Boiling Point	30 - 210 °C	98.4 °C
Flash Point	-40 °C	-4.2 °C
Autoignition Temperature	370 °C	204 °C
Relative Vapour Density (Air =1)	3.5	3.5
Liquid Density (kg/m^3) @25^{O}C	700-740	680
Lower Flammability Limit (vol. %)	1.4%	1%
Upper Flammability Limit (vol. %)	7.6%	7%

Gasoline is:

- Liquid at ambient conditions with vapour that is heavier than air;
- Flammable; and
- Non-toxic with a characteristic hydrocarbon odour.

6.2.2 Diesel

Diesel is typically a mixture of hydrocarbons (paraffins, cycloparaffins, aromatic and olefinic hydrocarbons with carbon numbers predominantly in the C9 to C25 range) and is typically modelled as n-Dodecane (C12) in a QRA.

Physical properties are listed in Table 7.

Table 7: Physical Properties of Diesel and Dodecane

	Diesel	Dodecane
Boiling Point	170 - 390 °C	216 °C
Flash Point	63 °C	73.85 °C
Autoignition Temperature	> 220 °C	205 °C
Relative Vapour Density (Air =1)	> 5	5.86
Liquid Density (kg/m3) @25^{o}C	850	755
Lower Flammability Limit (vol. %)	1%	0.6%
Upper Flammability Limit (vol. %)	6%	4.9%

Diesel is:

- Liquid at ambient conditions with vapour that is heavier than air;
- Flammable; and

Non-toxic with a characteristic hydrocarbon odour

6.2.3 Jet Fuel

Jet Fuel is typically a mixture of hydrocarbons (paraffins, cycloparaffins, aromatic and olefinic hydrocarbons with carbon numbers predominantly in the C9 to C16 range) and is typically modelled as n-Decane (C10) in a QRA.

Physical properties are listed in Table 8.

Table 8: Physical Properties of Jet Fuel and n-Decane

	Jet Fuel	n-Decane
Boiling Point	150 - 300 °C	174 °C
Flash Point	38 - 55 °C	46 °C
Autoignition Temperature	> 220 °C	201 °C
Relative Vapour Density (Air =1)	> 5	4.9
Liquid Density, kg/m^3 25^{o}C	780-830	726
Lower Flammability Limit (vol. %)	1%	0.7%
Upper Flammability Limit (vol. %)	6%	5.4%

Jet Fuel is:

- Liquid at ambient conditions with vapour that is heavier than air;
- Flammable; and
- Non-toxic with a characteristic hydrocarbon odour.

6.2.4 Natural Gas

Natural Gas is principally used as a fuel. It typically contains 95 to 97% methane (CH_4) and is modelled as methane in the risk analysis.

Physical properties are listed in Table 9.

Table 9: Physical Properties of Methane

Boiling Point	-162 °C
Flash Point	-218 °C
Autoignition Temperature	540 °C
Relative Density (Air =1)	0.55
Lower Flammability Limit in air (vol. %)	4.4%
Upper Flammability Limit in air (vol. %)	16.5%

Methane is:

- A gas at ambient conditions;
- A gas at typical operating conditions for Natural Gas pipelines;
- Flammable;
- Lighter than air at ambient temperatures; and
- Colourless, odourless and non-toxic (Note: Natural Gas is not odourless).

6.3 Pipeline Failure Modes

Pipelines may leak due to various causes. The four principal failure modes that may result in a leak from an underground pipeline include [23]:

- **Mechanical failures**, including material defects or design and construction faults;
- **Corrosion**, including both internal and external corrosion;
- **Ground movement and other failure modes**, including ground movement due to earthquakes, heavy rains/floods or operator error, and other natural hazards such as lightning, etc.; and
- **Third Party Activity (TPA)**, including damage from heavy plant and machinery, damage from drills/boring machines and hot tapping, etc.

The relative likelihood of each failure mode is shown in Appendix C.1 for underground pipelines.

6.3.1 Mechanical Failure

Leaks due to mechanical failures are usually caused by a construction fault, a material fault / defect or design of the pipeline.

This failure mode is credible for the Gore Bay Pipeline and the Secondary Natural Gas Mains; however, historical incident data for other pipelines (Refer to Appendix C) indicates this is generally a low likelihood failure mode, particularly for more recently manufactured pipelines (i.e. post 1980).

6.3.2 Corrosion

Leaks due to internal corrosion are generally a function of the material being transported, the wall thickness of the pipeline and the materials of construction.

Leaks due to external corrosion do not depend on the material being transported and are generally dependent on the soil type / conditions, pipeline coating and materials of construction, and the age of the pipeline.

This failure mode is credible for the Gore Bay Pipeline and the Secondary Natural Gas Mains; however, historical incident data for other pipelines (Refer to Appendix C) indicates this is a low likelihood failure mode, particularly for pipelines with a higher wall thickness (i.e. > 10 mm).

6.3.3 Ground Movement and Other Failure Modes

Pipeline leaks may occur due to ground movement (e.g. following a landslide or earthquake). The potential also exists for ground movement in the vicinity of water crossings (water erosion) or due to construction activities (new road infrastructure and buildings).

Other external events, such as lightning strikes, operational errors and erosion may also lead to a leak.

This failure mode is credible for the Gore Bay Pipeline and the Secondary Natural Gas Mains; however, the local topography is such that this is expected to be lower likelihood than would apply for areas with more potential for ground movement.

6.3.4 Third Party Activity

Most leaks due to Third Party Activity (TPA) are caused by construction vehicles and equipment (drills, etc.) or by farm machinery in rural areas. The leak typically occurs immediately upon contact; however, it may be delayed (i.e. if the TPA only weakens the pipeline such that it fails at a later time).

Leaks due to TPA include those caused by horizontal directional drilling (HDD), which is commonly used to install utilities and services (communication cables, etc.).

Leaks due to TPA are particularly relevant when considering development in the vicinity of existing pipelines due to the potential for significant construction activities (e.g. new road infrastructure and buildings).

This failure mode is credible for the Gore Bay Pipeline and the Secondary Natural Gas Mains.

6.4 Consequences of Liquid or Gas Release

6.4.1 Asphyxiation

Although non-toxic, Methane has the potential to cause asphyxiation at higher concentrations due to oxygen depletion, particularly if exposure occurs in a confined space.

Methane is a simple asphyxiant with low toxicity to humans. If a release does not ignite, then the potential exists for the gas concentration to be high enough to present an asphyxiation hazard to individuals nearby.

An atmosphere with marginally less than 21% oxygen can be breathed without noticeable effects. However, at 19.5% (which is OSHA's lower limit for confined space entry in 29 CFR 1915.12 [24]) there is a rapid onset of impairment of mental activity.

An oxygen concentration of about 15% will result in impaired coordination, perception and judgment. This may prevent a person from performing self-rescue from a confined space.

The potential for unconsciousness and fatality is only significant at less than 10% oxygen. However, to reduce the oxygen concentration to 10% requires a relatively high concentration (viz. approximately 52% v/v, which equates to 342,000 mg/m^3 for Methane).

Oxygen deficiency from exposure to Methane should not be a major issue because the fire hazards are usually the dominant effects in most locations (the LFL for methane is approximately one-tenth of the fatal asphyxiant concentration). Therefore, the potential for fatality from asphyxiation was not carried forward to the consequence, likelihood and risk estimation steps of the QRA.

6.4.2 Jet Fire

A pressurised release of Gasoline or Jet Fuel may also form a jet fire. In these cases, the liquid jet is surrounded by a diffusion flame supported by the evaporating liquid. Impingement of the liquid jet will result in a pool fire (Refer to Section 6.4.3).

The SAFETI 9.0 software uses a different correlation depending on the release conditions. For a liquid, or two-phase release, the Cook et. al. model is used.

The potential for fatality due to exposure to heat radiation from a jet fire (including direct exposure to the jet) was included in the QRA.

6.4.3 Pool Fire

Combustion of Gasoline, Diesel or Jet Fuel released from an orifice (e.g. hole in a pipeline) may create a pool fire.

The potential for fatality due to exposure to heat radiation from a pool fire (including direct exposure to the burning liquid) was included in the QRA.

6.4.4 Flash Fire

Ignition of an unconfined gas or vapour cloud will usually progress at low flame front velocities and will not generate a significant explosion overpressure. Unobstructed combustion of the gas cloud is referred to as a flash fire, which has the potential to cause injuries or fatalities for individuals within the ignited cloud.

A flash fire was included in the QRA as a potential outcome for all of the Natural Gas release events. A flash fire was also included in the QRA as a potential outcome for the larger Gasoline releases from the Gore Bay Pipeline, but only for the case where the liquid does not ‘rain out’ at the source (i.e. does not impinge on the ground and/or the machinery that caused the leak – Refer to Section 7.1.3).

The potential for fatality due to direct exposure to a flash fire was included in the QRA.

6.4.5 Vapour Cloud Explosion

A high degree of confinement and congestion is required to produce high flame speeds (i.e. > 100 m/s) in a flammable gas or vapour cloud, due to promotion of turbulence and accelerated combustion. This may occur inside buildings and around obstacles (e.g. buildings, vehicles, trees etc.).

An explosion was included in the QRA as a potential outcome for the larger Gasoline releases, but only for the case where the liquid does not ‘rain out’ at the source (i.e. does not impinge on the ground and/or the machinery that caused the leak – Refer to Section 7.1.3). Similarly, an explosion was included in the QRA as a potential outcome for a natural gas leak.

The potential for fatality due to exposure to the overpressure from an explosion was included in the QRA.

6.4.6 Gas Ingress into Buildings

A high momentum natural gas release will disperse downwind as the momentum effect drops. If the high momentum release is oriented towards a building, there is potential for the flammable natural gas to be drawn into a building through ventilation air intakes and open windows. If the gas reaches lower flammability limit, an ignition within the building would result in a confined explosion with serious harm to occupants and structural damage.

6.4.7 Toxic Smoke

Large quantities of smoke can be produced from hydrocarbon fires; however, this is rarely injurious for persons at ground level due to the buoyancy of the hot plume and its subsequent dispersion at heights well above ground level. Methane is a relatively clean burning fuel and the potential for injury due to smoke exposure was not carried forward to the consequence, likelihood and risk estimation steps of the QRA.

Large quantities of smoke can be produced from hydrocarbon fires, especially flammable / combustible liquids such as Gasoline, Diesel and Jet Fuel; however, this is rarely injurious for persons at ground level due to the buoyancy of the hot plume and its subsequent dispersion well above ground level.

If a fire were to occur on the Viva Gore Bay Pipeline, then smoke may ingress into the high school buildings. This was not specifically carried forward in the risk analysis as the heat radiation effects will dominate the risk in the near field and ingress of gas / vapour into these buildings has been separately assessed for flash fires and vapour cloud explosions (as above).

6.4.8 Explosion in a Confined Space

If a leak of flammable vapour enters a confined space, then a confined explosion may occur if it is ignited.

Liquid migration through the ground is credible; however, this was not included in risk analysis as underground areas of buildings are typically sealed to prevent water ingress.

A leak of flammable gas or liquid from an underground pipeline also has the potential to enter underground services (e.g. sewer pipes) if there is inadequate segregation. This was the cause of major explosions in Mexico and Taiwan; however, these incidents occurred due to very specific circumstances (e.g. For the incident in Taiwan, a gas pipeline had been routed through a sewer and subsequently leaked inside the sewer due to corrosion. For the incident in Mexico, a fuel pipeline was in direct contact with a water pipe and a leak occurred between the two due to corrosion). Due to the very situational and localised nature of these events, this type of confined explosion has not been included in the risk analysis.

6.4.9 Incident Escalation in Pipeline Easement

A major fire on one pipeline may result in the failure of an adjacent pipeline. Underground pipelines are typically protected by the surrounding soil but may be exposed if a large release creates a crater.

The likelihood and consequences of propagation and escalation were estimated based on a review of historical incidents (Primarily from Ref. [25]), pipeline operating conditions, estimated crater dimensions from SAFETI 9.0, and the separation distances between the Gore Bay Pipeline and Secondary Mains in the study area.

- **Historical Incidents** – In 2016, a review of buried pipeline rupture incidents identified only 2 propagation events from 17 pipeline rupture incidents due to an adjacent pipeline being exposed [25]. Both of these events involved the rupture of natural gas pipelines with larger diameters (viz. 1,067 mm and 406.4 mm) and higher pressures (viz. greater than 6,000 kPa) than the secondary mains in the study area.

- **Operating Conditions** – The Gore Bay Pipeline is used to transfer liquid hydrocarbons. When this pipeline is in use, the flowing liquid acts as a heat sink and reduces the likelihood of failure if exposed to an external fire. None of the escalation events reported in the 2016 review by Silva et. al. [25] involved escalation to a pipeline for refined petroleum liquids (See above).
- **Estimated Crater Dimensions** – The maximum crater radius and depth for full bore rupture of a 1050 kPa Secondary Natural Gas Main at a depth of 0.8 m in a clay soil was estimated to be c. 2.5m and c. 1.2 m, respectively (Note: It is not possible to estimate crater dimensions using SAFETI 9.0 for liquid pipelines). Based on this analysis and the separation distances (see below), even if a FBR of a secondary main were to occur, it is unlikely to expose a large section of the Gore Bay Pipeline.
- **Separation Distances** – There are only two sections of the Gore Bay Pipeline that are located in the same area as a 1050 kPa Secondary Natural Gas Main (Refer to Figure 3): Hope Street (West of intersection with Waratah Street), which includes a 150 mm and/or 350 mm Secondary Natural Gas Main; and Andrew Street (Between intersections with Wharf Road and Lancaster Avenue), which only includes a 150 mm Secondary Natural Gas Main.

  Where the Gore Bay Pipeline and a Secondary Natural Gas Main are both present, these are separated both horizontally and vertically.
- **Escalation Potential** – Propagation from a Secondary Natural Gas Main to the Gore Bay Pipeline does not appear to be a credible event based on the observations above.

  Even if it is postulated that propagation from the Gore Bay Pipeline to a Secondary Natural Gas Main is credible, escalation is still unlikely as the consequences of each pool / jet fire event are comparable and may not occur simultaneously.

Based on this review, propagation and escalation was not considered a credible event for inclusion in the risk assessment.

6.5 Control Measures

Part 7.1 (Hazardous Chemicals) of the WHS Regulation [7] applies to pipelines used to convey hazardous chemicals that are not regulated under the NSW Pipelines Act 1967 or the Gas Supply Act 1996. Division 9 under Part 7.1 of the WHS Regulation covers the: requirements for management of risk by the pipeline operator (Clause 389); duties of pipeline builders (390); and management of risks to health and safety by the pipeline operator (Clause 391).

The Gore Bay Pipeline pre-dates the NSW Pipelines Act 1967; therefore, this pipeline is regulated by SafeWork NSW under the NSW Work, Health and Safety (WHS) Regulation [4], [18]. The Gore Bay Pipeline is operated and maintained in accordance with AS/NZS 2885 [19] [18] [20].

Due to the lower operating pressures, AS/NZS 2885 does not apply for the Secondary Natural Gas Mains. These mains are operated and maintained in accordance with AS/NZS 4645 [12]. Part 1 of AS/NZS 4645:2018 [26] includes the network management requirements for the life cycle of a gas distribution network (including operation and maintenance) and Part 2 [27] specifies the requirements for design, construction and testing of steel pipes.

6.5.1 Prevention of Mechanical Failure

Systems and processes to ensure the pipeline structural integrity for the design life of a pipeline such as the Gore Bay Pipeline are included in Section 6 of AS/NZS 2885.3:2012 [28] and are included as part of the pipeline management system. Similar requirements for the natural gas distribution mains are included in Part 2 of AS/NZS 4645:2018 [27].

The Gore Bay Pipeline is inspected using 'intelligent pigging' and repaired as required (Refer to Section 4.3).

6.5.2 Corrosion Prevention

Systems and processes to ensure the pipeline structural integrity for the design life of a pipeline such as the Gore Bay Pipeline are included in Section 6 of AS/NZS 2885.3:2012 [28]. Similar requirements for the natural gas distribution mains are included in Part 2 of AS/NZS 4645:2018 [27]. These should include corrosion protection systems.

Two key control measures are typically implemented by pipeline operators to minimise the likelihood of failure due to corrosion: cathodic protection systems and external pipe coatings.

The Gore Bay Pipeline is inspected using 'intelligent pigging' (Refer to Section 4.3). It is coated and equipped with a cathodic protection system (Refer to Section 4.3).

The Secondary Natural Gas Mains are cathodically protected (CP test points were observed during the site inspection). These mains are typically coated with High-Density Polyethylene (HDPE) or a Tri-laminate product and are internally lined to reduce frictional loses and provide some internal corrosion protection [12].

6.5.3 Prevention of Damage due to Ground Movement and Other Failures

Normal loads (e.g. due to the internal and external pressure, weight of soil, traffic loads, etc.) and occasional loads (e.g. due to flood, earthquake, transient pressures in liquid lines and land movement due to other causes) are considered during design of a pipeline (as per AS/NZS 2885.1:2018 [15] and AS/NZS 4645:2018 [27]). Additional depth of cover may also be required where the minimum depth of cover cannot be attained because of the action of nature (e.g. soil erosion, scour).

All the pipelines are located on relatively flat stable land within road corridors. The potential for ground movement is low.

6.5.4 Prevention of Damage due to Third Party Activity

Section 11 of AS 2885.3:2012 [28] requires a Safety Management Study to be undertaken to assess the risks associated with threats to the pipeline and to instigate appropriate measures to manage the identified threats.

Two key control measures are typically implemented by pipeline operators to minimise the likelihood of impact from TPA: the 'Before You Dig Australia' (BYDA) process and periodic patrols.

The probability of leak on impact depends on the pipeline wall thickness. The depth of cover may also reduce the likelihood of impact.

6.5.5 Mitigation Control Measures

Section 11 of AS 2885.3:2012 [28] requires the development and implementation of an Emergency Response Plan as part of the pipeline management system. Similar requirements for the natural gas distribution mains are included in Section 9 of AS/NZS 4635.1:2018 [26].

An Emergency Response Plan should typically detail the response and recovery strategies and procedures to address all pipeline related emergency events, including: loss of containment; full-bore pipeline rupture; fires; and, natural events.

Leaks may be detected during visual inspections, incident notifications and/or by instrumented monitoring systems. If a leak is detected, then the pipelines can be isolated by closing automated and/or manual valves (Refer to Sections 4.3 and 4.4).

6.6 Major Incidents for Risk Analysis

The list of MAEs) included in the risk analysis is provided in Table 10.

Table 10: List of Major Accident Events

MAE	Potential Consequences
Release of Gasoline, Jet Fuel or Diesel from Viva Gore Bay Pipeline *	Pool Fire, Jet Fire, Flash Fire and/or Explosion
Release of Natural Gas from Jemena Secondary Main (350 mm Diameter)	Jet Fire, Flash Fire and/or Explosion
Release of Natural Gas from Jemena Secondary Main (150 mm Diameter)	Jet Fire, Flash Fire and/or Explosion
Release of Natural Gas from Jemena Secondary Main (100 mm Diameter)	Jet Fire, Flash Fire and/or Explosion

* Modelled as Heptane (As representative material for Gasoline)

7 CONSEQUENCE ANALYSIS

7.1 Release of Flammable Liquid / Gas

7.1.1 Representative Hole Diameter

Representative hole diameters were selected for the consequence modelling. These were selected to align with the leak frequency data (Refer to Appendix C), which includes four hole size categories: Pinhole (≤ 25 mm); Small Hole (> 25 mm to ≤ 75 mm), Large Hole (> 75 mm to ≤ 110 mm); and, Rupture (> 110 mm). The representative hole diameter/s in each hole size category were selected based on a review of the available historical data (Refer to Appendix B.1):

Leaks from underground pipelines in the Pinhole size category tend to be larger for TPA incidents (i.e. typically c. 20 mm to 25 mm) than for the other failure modes (i.e. typically less than c. 10 mm). Therefore, two representative hole diameters were selected in this category: 25 mm for TPA and 10 mm for all other failure modes.

Table 11: Representative Hole Diameters Selected for Consequence Analysis

<table>
<tr><th rowspan="2">Pipeline/s</th><th rowspan="2">Diameter (mm)</th><th colspan="4">Representative Hole Diameter (mm)</th></tr>
<tr><th>Pinhole
(≤ 25 mm)</th><th>Small Hole
(> 25 mm to ≤ 75 mm)</th><th>Large Hole
(> 75 mm to ≤ 110 mm)</th><th>Rupture
(> 110 mm)</th></tr>
<tr><td>Gore Bay Pipeline</td><td>300</td><td>10 or 25*</td><td>75</td><td>110</td><td>Full bore</td></tr>
<tr><td rowspan="3">Secondary Natural Gas Mains</td><td>350</td><td>10 or 25*</td><td>75</td><td>110</td><td>Full bore</td></tr>
<tr><td>150</td><td>10 or 25*</td><td>75</td><td>110</td><td>Full bore</td></tr>
<tr><td>100</td><td>10 or 25*</td><td>75</td><td colspan="2">Full bore</td></tr>
</table>

* 10 mm for all failure modes except TPA. 25 mm for TPA only.

7.1.2 Rate of Release

Release events were modelled using SAFETI. The estimated release rates are tabulated below for each representative hole size.

Table 12: Representative Hole Diameters Selected for Consequence Analysis

MAE	Hole Diameter (mm)	Release Rate [kg/s]
Release of Gasoline, Jet Fuel or Diesel from Viva Gore Bay Pipeline	10	4.8
	25	29.8
	75	175.9 *
	110	175.9 *
	FBR	175.9 *
Release of Natural Gas from Jemena Secondary Main (350 mm Diameter)	10	0.14
	25	0.86
	75	7.70
	110	16.6
	FBR	167.7

MAE	Hole Diameter (mm)	Release Rate [kg/s]
Release of Natural Gas from Jemena Secondary Main (150 mm Diameter)	10	0.14
	25	0.86
	75	7.70
	110	16.6
	FBR	30.8
Release of Natural Gas from Jemena Secondary Main (100 mm Diameter)	10	0.14
	25	0.86
	75	7.70
	FBR	13.7

* Limited to transfer rate.

7.1.3 Height and Orientation of Release

The SAFETI software does not permit entry of a release height below 0 m; therefore, all releases from the underground pipeline were modelled at a release height of 0 m (i.e. ground level). This is not a significant factor for the typical burial depth (Refer to Section 4.3).

A release of high pressure gas or liquid from a buried pipeline would result a crater and would be orientated upwards from the crater [29].

7.1.4 Duration of Release

Gasoline and Methane are flammable and any adverse impact will occur quickly (fire or explosion); therefore, the duration of exposure is not as critical as it would be if there were a toxic material in the pipelines (i.e. where the adverse impact can significantly increase for longer exposure durations).

The isolation time and duration of release is not specified in the QRA as these will be significantly longer than the period of exposure required for an adverse effect to people (Refer to Appendix A.6) and the time required for each representative release case to reach steady state.

7.2 Fire Modelling

The SAFETI software package (Version 9.0) was used to model all the representative release events included in the risk analysis.

The key data and assumptions used to model the representative fire events are included in Appendix A.4.

7.2.1 Pool Fire

Example distances to heat radiation levels of 4.7, 14, 21 and 35 kW/m^2 are tabulated in Appendix B.1.1 for the representative pool fire events included in the risk analysis.

The calculated distance to a heat radiation level of 4.7 kW/m^2 for a FBR of the Gore Bay Pipeline is comparable to the corresponding reported measurement length of 132 m (Refer to Section 4.3).

7.2.2 Jet Fire

Example distances to heat radiation levels of 4.7, 12.5, 23 and 35 kW/m^2 are tabulated in Appendix B.1.2 for representative jet fire events included in the risk analysis.

The worst-case jet fire is a full-bore rupture (FBR) of the 350 mm Secondary Natural Gas Main due to its relatively large diameter and release rate.

7.2.3 Flash Fire

Example distances to the upper flammability limit (UFL), lower flammability limit (LFL) and ½LFL concentrations are tabulated in Appendix B.1.3 for representative flash fire events included in the risk analysis.

Only the 'horizontally' orientated releases of natural gas have the potential to exceed the LFL or ½LFL concentrations at ground level. These distances are relatively large for the FBR events (e.g. up to several hundred metres for FBR of the 350 mm diameter main); however, the potential hazard area for a flash fire is offset by the relatively narrow plume widths.

7.3 Vapour Cloud Explosion

When a flammable vapour cloud ignites, the flame front advances as the cloud burns. If there are obstacles in the path of the flame front, the level of turbulence increases causing accelerated burning and thus the flame front accelerates, reaching speeds of 100-200 m/s. The whole combustion process occurs over a period of less than a second, but this short burst of high speed flame front results in a blast wave, resulting in a pressure above the atmospheric pressure on the target surface (referred to as blast overpressure).

The blast wave can cause damage to the structure and injury/ fatality to exposed individuals and is commonly called vapor cloud explosion (VCE).

The 3-D obstruction model in SAFETI was used to estimate the overpressure for a VCE and a medium level of congestion (Equivalent to TNO Model curve number 4) was assumed to simulate entry of the gas or vapour into a building and the subsequent confined explosion. The maximum calculated overpressure using TNO Model curve number 4 is 10 kPa.

8 FREQUENCY AND LIKELIHOOD ANALYSIS

8.1 Likelihood of Liquid or Gas Release

The likelihood of a liquid or gas release (i.e. leak) from each of the pipelines is tabulated in Table 13 (Also refer to Appendix C.1) and was estimated based on a review of relevant data sources. The primary data sources included:

- Department of Industry, Resources and Energy, New South Wales, *2018-19 Licensed Pipelines Performance Report* [30]. This includes data for all licensed pipelines in NSW for the 5-year period: 2014/15 to 2018/19.
- UK Health and Safety Executive (HSE), Research Report (RR) 1035 [23].
- British Standards Institute (2013) [31].

Table 13: Leak Frequencies

MAE	Leak Frequency (per km per yr)				
	Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
Release of Gasoline, Jet Fuel or Diesel from Viva Gore Bay Pipeline	5.4E-05	2.7E-05	2.2E-05	8.8E-06	**1.12E-04**
Release of Natural Gas from Jemena Secondary Main (350 mm Diameter)	3.5E-04	4.9E-06	2.7E-07	2.6E-06	**3.6E-04**
Release of Natural Gas from Jemena Secondary Main (150 mm Diameter)	4.9E-04	4.9E-06	2.7E-07	2.6E-06	**5.0E-04**
Release of Natural Gas from Jemena Secondary Main (100 mm Diameter)	7.9E-04	4.9E-06	2.7E-07	2.6E-06	**8.0E-04**

8.2 Probability of Ignition

The ignition probabilities adopted in the risk analysis are listed in and were based on a review of relevant ignition probability data and ignition probability correlations (Refer to Appendix C).

Table 14: Ignition Probabilities

MAE	Hole Diameter (mm)	Release Rate [kg/s]	Total Ignition Probability	Immediate Ignition Probability	Delayed Ignition Probability
Release of Gasoline, Jet Fuel or Diesel from Viva Gore Bay Pipeline	10	4.8	0.0122	0.0061	0.0061
	25	29.8	0.0393	0.0197	0.0197
	75	175.9 *	0.0700	0.0350	0.0350
	110	175.9 *	0.0700	0.0350	0.0350
	FBR	175.9 *	0.0700	0.0350	0.0350

MAE	Hole Diameter (mm)	Release Rate [kg/s]	Total Ignition Probability	Immediate Ignition Probability	Delayed Ignition Probability
Release of Natural Gas from Jemena Secondary Main (350 mm Diameter)	10	0.14	0.0013	0.0006	0.0006
	25	0.86	0.0049	0.0025	0.0025
	75	7.70	0.0257	0.0129	0.0129
	110	16.6	0.0458	0.0229	0.0229
	FBR	167.7	0.2599	0.1300	0.1300
Release of Natural Gas from Jemena Secondary Main (150 mm Diameter)	10	0.14	0.0013	0.0006	0.0006
	25	0.86	0.0049	0.0025	0.0025
	75	7.70	0.0257	0.0129	0.0129
	110	16.6	0.0458	0.0229	0.0229
	FBR	30.8	0.0721	0.0361	0.0361
Release of Natural Gas from Jemena Secondary Main (100 mm Diameter)	10	0.14	0.0013	0.0006	0.0006
	25	0.86	0.0049	0.0025	0.0025
	75	7.70	0.0257	0.0129	0.0129
	FBR	13.7	0.0396	0.0198	0.0198

* Limited to transfer rate.

8.3 Likelihood of Representative MIs

The likelihood of each representative release scenario included in the risk analysis is tabulated in Appendix C.3.

9 RISK ANALYSIS

9.1 Individual Risk of Fatality

The 0.5 x 10^{-6} per annum (p.a.) cumulative individual fatality risk contour for the Gore Bay Pipeline and the Secondary Natural Gas Mains is shown in Figure 9. This value is the risk criterion for sensitive land uses in HIPAP No.10 [2].

The risk contour for 0.5x10^{-6} p.a. does not reach the Melrose park High School site and satisfies the risk criterion.

A cumulative individual fatality risk of 1 x 10^{-6} p.a., which is the risk criterion for residential land uses in HIPAP No.10 [2], is not reached.

9.2 Risk of Acute Toxic Injury or Irritation

No events with the potential to cause acute toxic injury or irritation were identified for inclusion in the risk analysis (Also refer to Section 6.4.7); therefore the proposed development complies with the relevant DPHI risk criteria (Refer to Section 5.4.2).

9.3 Risk of Property Damage and Accident Propagation (Exceeding 14 kPa)

The cumulative risk of property damage and accident propagation (Overpressure exceeding 14 kPa) does not reach 50 x 10^{-6} p.a. This criterion does not apply to the proposed development (Refer to Section 5.4.3).

9.4 Risk of Property Damage and Accident Propagation (Exceeding 23 kW/m^2)

The cumulative risk of property damage and accident propagation (Heat radiation exceeding 23 kW/m^2) does not reach 50 x 10^{-6} p.a. This criterion does not apply to the proposed development (Refer to Section 5.4.3).

9.5 Risk of Injury (Exceeding 7 kPa)

The cumulative risk of injury (Overpressure exceeding 7 kPa) does not reach 50 x 10^{-6} p.a.; therefore the proposed development complies with the relevant DPHI risk criterion (Refer to Section 5.4.2).

9.6 Risk of Injury (Exceeding 4.7 kW/m^2)

The cumulative risk of injury (Heat radiation exceeding 4.7 kW/m^2) does not reach 50 x 10^{-6} p.a.; therefore the proposed development complies with the relevant DPHI risk criterion (Refer to Section 5.4.2).

Figure 9: Individual Fatality Risk Contours

9.7 Risk Impact at Proposed High School Buildings

Risk ranking points were selected at four locations alone the School perimeter, covering all four sides. Risk levels and contributors were evaluated. The results are summarised in Table 15.

Table 15: Risk Levels at Site Boundary

Location on School Site Boundary	Risk/Year	Risk Contributors
North West	2.37E-10	Jemena 350 mm Pipeline
South East	2.92E-08	Jemena 150 mm (FBR) Pipeline
South West	1.68E-08	Jemena 150 mm (FBR) Pipeline
North East	1.95E-08	Jemena 100 mm (FBR) Pipeline Jemena 350 mm Pipeline

The following observations are made:

1. The risk levels are between $1x10^{-9}$ and $1x10^{-8}$ per annum and one to two orders of magnitude less than the target criteria.
2. The Vivas Gore Bay oil pipeline does not contribute to the individual risk at the High School as it is outside the Measurement Length for the pipeline (>132m).
3. The risk contribution arises from the gas pipelines that are part of the distribution network and operate at much lower pressures (1050 kPag). These are not licensed pipelines and a risk assessment is not required by PS 24-005 [4].

The maximum thermal radiation levels calculated at the risk ranking points are listed in Table 16.

Table 16: Maximum Thermal Radiation at Site Boundary

Location on School Site Boundary	Max Radiation Intensity (kW/m2)	Risk Contributors	Frequency at Max radiation Intensity
West	12.0	Jemena 350 mm Pipeline	4.69E-09
South	35	Jemena 350 mm Pipeline	5.76E-08
North	24.9	Jemena 350 mm Pipeline	4.56E-09
East	35	Jemena 350 mm Pipeline	5.23E-08

Only a single event, a full bore rupture of the Jemena 350mm gas pipeline, contributes to the risk. The target frequency for exceeding 4.7 kW/m^2 is 5E-05 per year. The calculated frequencies are 3-4 orders of magnitude lower than the target.

9.8 Qualitative Risk Criteria

Irrespective of the numerical value of any risk criteria level for risk assessment purposes, it is essential that certain qualitative principles be adopted concerning the land use safety acceptability of a proposed development or existing activity. The proposed development is considered to comply with the qualitative risk criteria outlined in HIPAP No. 4, as follows:

- Avoidance of all 'avoidable' risks – The pipelines are existing facilities and cannot be relocated to avoid risk exposure.
- Reduction, wherever practicable, of the risk from a major hazard, even where the likelihood of exposure is low – Risk reduction measures are proposed in Section 11.2.
- Containment, wherever possible, within the site boundary of the effects (consequences) of the more likely hazardous events – The effects (consequences) of the more likely hazardous events (i.e. the smallest representative hole sizes) are generally limited to the roadways in which they are located).
- Recognition that if the risk from an existing installation is already high, further development should not be permitted if it significantly increases that existing risk – The risk to the proposed development meets the individual and societal risk criteria, and risk reduction measures are proposed in Section 11.2.

9.9 Societal Risk

It is possible that an incident at a hazardous facility may affect more than a single individual off-site, especially in the case of a full-bore rupture of a high-pressure pipeline, and the potential exists for multiple fatalities.

The societal risk concept evolved from the concept of 'risk aversion', i.e. society is prepared to tolerate incidents that cause single fatalities at a more frequent interval (e.g. motor vehicle accidents) than for incidents causing multiple fatalities (e.g. an aircraft accident).

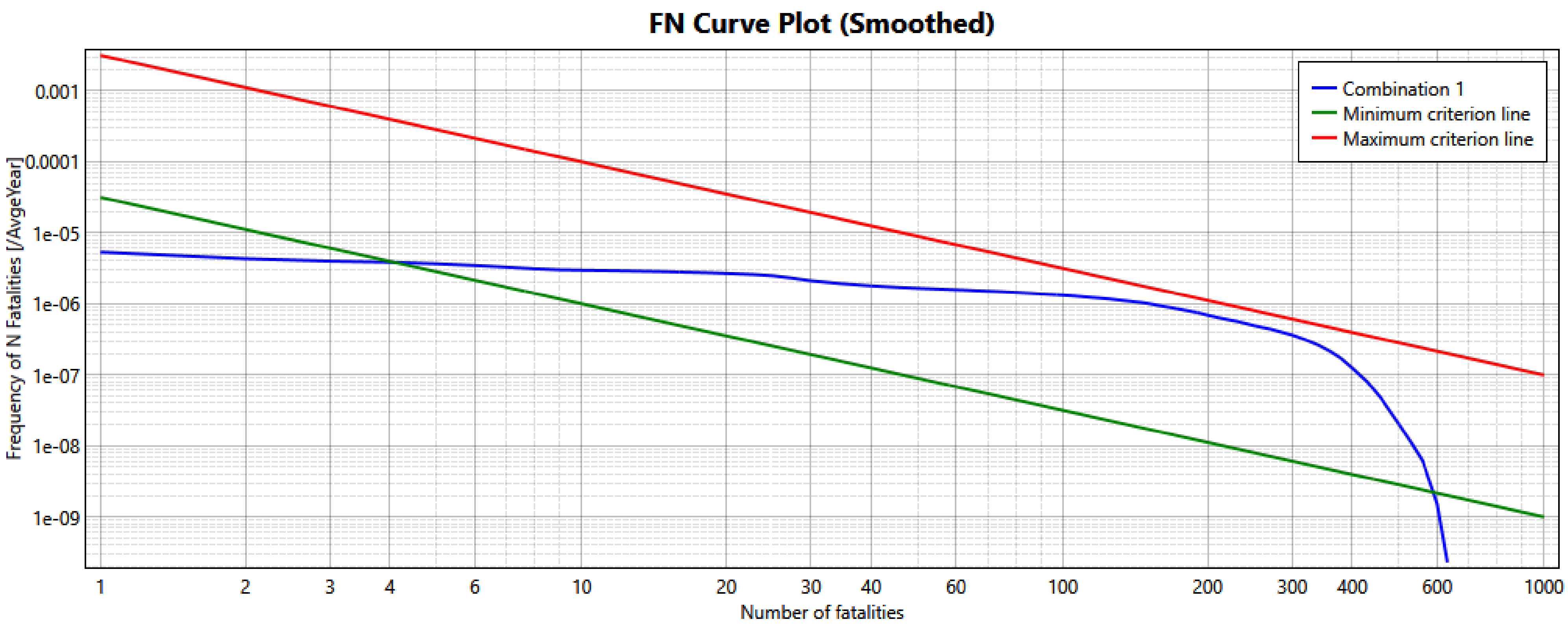
Two parameters are required to define societal risk: (a) Number of fatalities that may result from an incident; and (b) the frequency (likelihood) of occurrence of the incident.

Societal risk can be represented by F-N curves, which are plots of the cumulative frequency (F) of various accident scenarios against the number (N) of casualties associated with the modelled incidents. In other words, 'F' represents the frequency of exceedance of number of fatalities, N.

The F-N plot is cumulative in the sense that, for each frequency on the plot, N is the number of fatalities that could be equalled ***or exceeded***, and F is the frequency of exceedance of the specified number of fatalities.

F-N curve for the proposed development were generated and shown in Figure 10.

Figure 10: Societal Risk F-N Curve



9.10 Evaluation of Societal Risk

The following observations can be made from Figure 10.

1. Up to N= 4, the curve falls in the negligible risk region, and thereafter falls mostly in the ALARP region.
2. The maximum number of fatalities is 630, at 10^{-10} p.a., in the negligible risk region, and does not reach the upper limit criterion of N = 1000.
3. The societal risk for the proposed school satisfies the risk criteria in HIPAP No.10 [2].

10 RISK-BASED DESIGN LOADS FOR FIRES AND EXPLOSIONS

Since the incident heat radiation on the school building from a gas pipeline rupture can exceed levels that can cause damage, an analysis was undertaken to determine if fire protection in addition to that required by the Construction Code of Australia is required.

An "exceedance analysis" is the method to determine the design thermal and blast loads on a target structure.

10.1 Exceedance Curves Methodology

There are two methods available for determining the design accidental load (DAL) for fires and explosions [32]:

(a) Consequence-Based

This approach only takes account of the impact of the maximum credible event for each building, irrespective of its frequency. A thermal load in kW/m^2 and a blast side-on overpressure in kPa are selected for the building design. The worst credible event (Consequence-Based) approach can lead to fire or blast loads that are far too large to be accommodated by the structures to be protected.

If we used the consequence based approach, it is not possible to have temporary buildings on the open area of Melrose Park Public School.

(b) Risk-Based

This approach considers both the consequences and the frequencies of *all* the potential fire and explosion scenarios that impact on a specific building. It enables design of the structures to resist reasonable thermal radiation values and lower overpressure values, accepting explicitly a certain residual risk of exceeding the thermal radiation or explosion overpressure design value.

The most common Risk-Based method includes the development of Exceedance Curves.

Heat flux or overpressure exceedance curves represent the cumulative frequency of exceeding specified heat flux or overpressure value at a given location. The use of exceedance curves requires to set a target value not for a heat flux or overpressure, but for the frequency that a building is subject to an accident load higher than the design load.

The exceedance curve approach was developed by the UK Chemical Industry Association [33] and is widely used for determining the thermal radiation load and blast overpressure load for Occupied Buildings Risk Assessment (OBRA). One of the strengths of the exceedance curve approach is that it displays the range of potential scenarios, rather than a single event. This method has been endorsed by the HSE in the UK [34].

The cumulative frequency is used because the risk-based approach requires identification of a hazard level which will not be exceeded at a given frequency. This is different from identifying a discrete hazard level which occurs at a particular frequency. It is expressed as a heat flux that would not be exceeded at a target frequency.

The exceedance curve is generated as follows:

- Select a target location.
- Construct a table of the frequency - heat flux pairs for all fire scenarios from all three pipelines.

- Sort the table in descending order of heat flux and calculate the cumulative frequency with which the given heat flux would be exceeded.
- Read off from the exceedance curve the heat flux corresponding to the target frequency. This becomes the risk-based design accidental load for the structure for fires, for a building at that location.
- Construct similar curves for all temporary building locations and select the largest heat flux among them as the design accidental load.

A similar procedure is applied for the overpressure exceedance curve.

10.2 Setting Target Frequency for Exceedance Analysis

The UK Chemical Industries Association Guidance [33] requires buildings to be designed to resist overpressure scenarios characterized by a frequency of 10^{-4} occurrences/y and suggests that less frequent events need not to be considered. UKOOA & UK HSE [34] state that a frequency between 10^{-4} and 10^{-5} exceedance per year can be considered a reasonable target frequency.

It is clear that 10^{-5} p.a. is the lowest frequency suggested for buildings in an industrial site. Benucci et al. [35] have suggested blast load exceedance frequencies are 10^{-5} per annum for Unmanned Buildings and 10^{-6} p.a. for Manned Buildings.

It is considered conservative to select a frequency between 10^{-5} p.a. and 10^{-6} p.a. for the sheltered walkway, which is not normally occupied.

For the present study, the following cumulative frequency has been adopted:

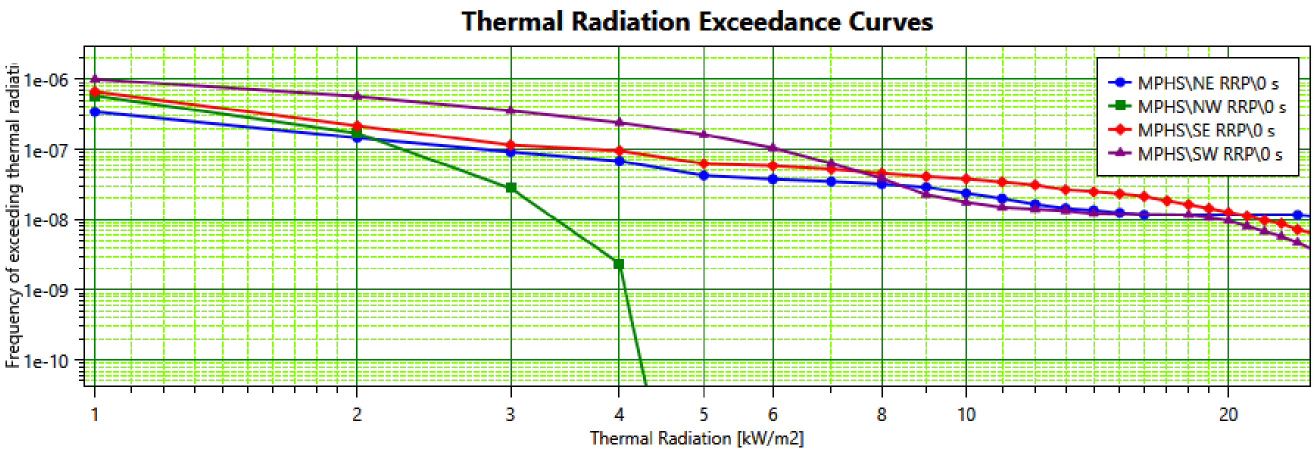
Occupied building: 1×10^{-6} p.a.

The same frequency is used for fires and explosions.

10.3 Exceedance Analysis for Fire Load on School Buildings

The exceedance curve for accident load for thermal radiation is generated in SAFETI 9.0 and provided in Figure 11.

Figure 11: Thermal Radiation Exceedance Curve at Site Boundary



The following design accident loads were identified:

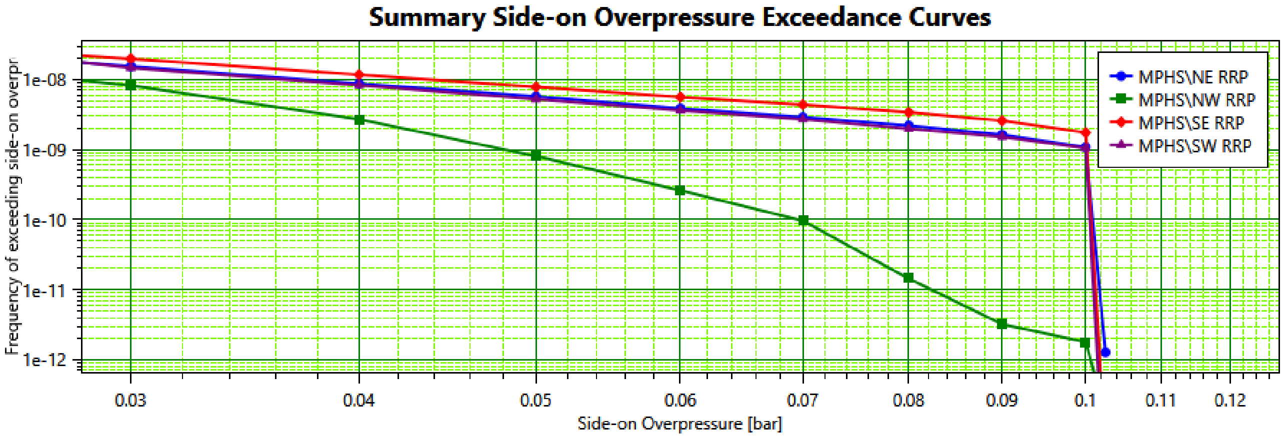
- At 1×10^{-6} p.a., the DAL is 1 kW/m^2. Any building can withstand this load and no additional fire protection is necessary.

- The frequency with which a thermal radiation of 4.7 kW/m^2 is exceeded is 1.8x10^{-7} p.a. at the Southwest corner of the site.

10.4 Exceedance Analysis for Explosion Load on School Buildings

The exceedance curve for accident load for explosion overpressure is generated in SAFETI 9.0 and provided in Figure 12.

Figure 12: Explosion Overpressure Exceedance Curves



The following observations are made:

- No explosion overpressure exceeds 1x10^{-6} p.a.
- Explosion overpressure of 0.07 is exceeded at a cumulative frequency of 4.37x10^{-9} p.a. on the south eastern border of the school site which is negligible.
- There is no explosion overpressure damage from any of the pipelines to the school buildings.

11 FINDINGS AND RECOMMENDATIONS

11.1 Compliance with NSW DPHI Risk Criteria for Land Use Safety Planning

- The maximum individual fatality risk is 0.5 x 10^{-6} p.a. and this only occurs at two locations where the Gore Bay Pipeline changes direction (Refer to Figure 9). These do not affect the proposed school site. The maximum individual fatality risk is approximately 3.52 x 10^{-8} p.a. at the southern boundary of the proposed school site. Therefore, the proposed development satisfies the individual fatality risk criteria in HIPAP No.10 [2].
- The entirety of the F-N curve is in the 'Negligible' or 'ALARP' regions and complies with the DPHI's indicative societal risk criteria (Refer to Section 9.9).
- There is no risk contribution from the Viva Gore Bay pipeline on the Melrose park High School. In the event of a fire, smoke may disperse towards the school site depending on the wind direction. Shelter indoors would protect against smoke exposure.
- The main risk contribution (very low) arises from the Jemena secondary gas mains. These operate at low pressures (maximum pressure 1050 kPag). The risk of thermal radiation from gas pipeline release and fire affecting the school is negligible.

11.2 Recommendations

There are no recommendations relating to the infrastructure design for the MPHS Project.

1. A SMS must be conducted with Viva Energy and other stakeholders (Project Manager, SINSW, construction contractor) in accordance with AS 2885.6-2018 [3], once the construction plan is developed, and the outcomes implemented.
2. Consultation with Jemena should be undertaken with the primary aim of protecting the 350mm primary gas line during the construction of the Project, after a construction plan is ready.
3. The MPHS emergency plan must include pipeline rupture as a scenario and develop an appropriate shelter in place policy to prevent the potential for injuries from people exposed to radiated heat flux in the open.

12 REFERENCES

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Appendices

Appendix A Assumptions

It is necessary to make technical assumptions during a risk analysis. These assumptions typically relate to specific data inputs (e.g. material properties, equipment failure rates, etc.) and modelling assumptions (e.g. release orientations, impairment criteria, etc.).

To comply with the general principles outlined in Section 2.2 of HIPAP No. 6, all steps taken in the risk analysis should be: "*traceable and the information gathered as part of the analysis should be well documented to permit an adequate technical review of the work to ensure reproducibility, understanding of the assumptions made and valid interpretation of the results*". Therefore, details of the key assumptions adopted for the risk analysis are provided in this Appendix.

Each assumption is numbered and detailed separately. The basis for each assumption is explained together with its potential impact on the risk results and the Major Accident Events (MAEs) potentially affected. Key references are also listed for each assumption, where relevant.

It is important that the assumptions be supported by:

- experimental data in the literature, where available;
- actual operating experience, where available;
- similar assumptions made by experts in the field and a general consensus among risk analysts; and
- engineering judgement of the analyst.

The main objectives are to minimise uncertainty in the risk estimate as far as is possible, and to ensure that the assumptions result in a 'conservative best estimate' of the risk. Such an approach is consistent with the following extract from Section 5 of HIPAP No. 6: "*In the consequence analysis and throughout the hazard analysis, the analyst must be conscious of the uncertainties associated with the assumptions made. Assumptions should usually be made on a 'conservative best estimate' basis. That is, wherever possible the assumptions should closely reflect reality. However, where there is a substantial degree of uncertainty, assumptions should be made which err on the side of conservatism.*"

Table 17: List of Assumptions by Subject

Subject	No.	Assumption
Operational Data	1	Pipeline Operating Conditions
	2	Utilisation of Pipelines
Locational Data	3	Representative Wind Speeds, Wind Directions and Stability Classes
	4	Ambient Conditions
	5	Surface Roughness Length
	6	Total Population (Day and Night)
	7	Indoor / Outdoor Population Distribution (Day and Night)
Risk Analysis Methodology	8	Location and Segmentation of Pipelines
Consequence Analysis	9	Representative Materials
	10	Pressure / Pumping Rate for Release Modelling
	11	Representative Hole Diameters for Release Modelling
	12	Location of Release
	13	
	14	Maximum Extent of Flash Fire
	15	Isolation Time and Duration of Release
	16	
	17	3D Explosion Model Parameters
Likelihood Analysis	18	Likelihood of Release (Loss of Containment)
	19	Ignition Probability
	20	Probability of VCE or Flash Fire
Vulnerability Parameters	21	Exposure to Heat Radiation from a Fire (Indoor or Outdoor)
	22	Exposure to Flash Fire (Indoor or Outdoor)
	23	Exposure to Explosion Overpressure (Indoor or Outdoor)

A.1 Operational Data

Assumption No. 1: Pipeline Operating Conditions
Subject: Operational Data
Assumption/s: • All pipeline operating conditions (pressure, temperature, etc.) are as reported in Sections 4.3 and 4.4.
Justification and Impact/s of Assumption/s: • All operational data for the Viva Gore Bay pipeline was sourced from publicly available information, including the information provided in the BYDA response. • All operational data for the Jemena Secondary Natural Gas Mains was sourced from publicly available information, including the information provided in the BYDA response. • Operating conditions (particularly operating pressure) are required to undertake the release and dispersion modelling.
MAE/s Affected: • All.
Reference/s: • AECOM, *Environmental Impact Statement*, *Clyde Terminal Conversion Project, Appendix F, Preliminary Hazard Analysis*, Jan 2013. • AECOM, Gore Bay Terminal Modification, EIS Scoping Report, 25 Jan 2012. • Jemena, *BYDA Response*, BYDA Sequence Number 102261874, 28 Sept. 2020. • Viva Energy Australia, ASX Release, *Clyde and Gore Bay Site Visit Presentation*, 23 Nov. 2018. • Viva Energy Australia, *BYDA Response*, BYDA Sequence Number 102261877, 28 Sept. 2020. • Arriscar Pty Ltd, *Hazard Analysis of High Pressure Pipelines at Melrose Park Precinct,* Document J-000429-HA, Revision B, 4 November 2020.

Assumption No. 2: Utilisation of Pipelines
Subject: Operational Data
Assumption/s: • The Gore Bay Pipeline is utilised 100% of the time. • The Jemena Natural Gas Mains are utilised 100% of the time.
Justification and Impact/s of Assumption/s: • Utilisation data is required to undertake the release and dispersion modelling and to estimate the release frequency. • The Gore Bay Pipeline only operates during a transfer from a ship. It is conservative to assume 100% utilisation.
MAE/s Affected: • All.
Reference/s: • AECOM, *Environmental Impact Statement*, *Clyde Terminal Conversion Project, Appendix F, Preliminary Hazard Analysis*, Jan 2013. • AECOM, Gore Bay Terminal Modification, EIS Scoping Report, 25 Jan 2012.

A.2 Locational Data

Assumption No. 3: Representative Wind Speeds, Wind Directions and Stability Classes

Subject: Locational Data

Assumption/s:

- The probabilistic distribution of wind speed and wind direction for the representative stability classes is provided in Table 18 and Table 19, based on the Bureau of Meteorology (BoM) meteorological data for Parramatta.
- The data was split into daytime and night-time conditions.
- Note: For the BoM meteorological data, night is defined as being the hour before dusk to the hour after sunrise. This varies depending on time of year; however, the average night-time duration is 58% of the time. Therefore, the average daytime duration is 42% of the time.

Justification and Impact/s of Assumption/s:

- The BoM meteorological data for Parramatta (Station ID: 066124) was processed in accordance with the methodology provided by the Victorian EPA.
- Wind speed typically has minimal impact on jet fires due to momentum jet effects of a sonic release. However, higher wind speeds may cause the 'tilting' of the flame from a pool fire. An allowance for flame tilt is included in the SAFETI model.
- The downwind gas concentrations, and hence the hazard ranges for dispersion of flammable gas or vapour, vary with wind speed and weather stability class. Therefore, multiple representative wind speed and stability class categories are included in accordance with standard practice for undertaking a quantitative risk assessment (QRA).
- The day/night split of the weather data is required to allow for the fact that there is little or no occupancy of the school premises at night.
- The BoM meteorological data for the Olympic Park weather station was not used because some data required to determine the stability class is not monitored at this station (e.g. cloud cover).

MAE/s Affected:

- All.

Reference/s:

- Exemplary Energy manipulation of BoM data for Parramatta (Station ID: 066124) and World Met Station Number, WMO Index 94765. Used years 2010 – 2014.
- Stability categories calculated as per VIC EPA publication 1459. Sunrise and Sunset times obtained from NASA Jet Propulsion Laboratories' "Horizons" Ephemeris programme.
- Bureau of Meteorology, http://www.bom.gov.au/climate/averages/tables/cw_066124.shtml.

Table 18: Probability of Representative Stability Classes and Wind Speeds (Day)

Stab. Class	Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
B	1.8	0.022	0.013	0.012	0.011	0.013	0.009	0.009	0.008	0.010	0.009	0.012	0.014	0.021	0.021	0.021	0.019	0.225
D	7.5	0.007	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.006	0.005	0.008	0.008	0.013	0.013	0.012	0.007	0.103
D	1.6	0.024	0.011	0.020	0.032	0.038	0.033	0.029	0.023	0.030	0.014	0.027	0.028	0.032	0.026	0.028	0.022	0.416
D	4.1	0.005	0.001	0.008	0.020	0.018	0.029	0.038	0.035	0.027	0.005	0.007	0.015	0.022	0.015	0.007	0.006	0.256
Total		0.060	0.028	0.044	0.066	0.073	0.075	0.079	0.068	0.072	0.034	0.055	0.065	0.087	0.075	0.068	0.054	**1.0**

Table 19: Probability of Representative Stability Classes and Wind Speeds (Night)

Stab. Class	Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
D	7.3	0.034	0.024	0.026	0.025	0.025	0.023	0.023	0.022	0.031	0.029	0.034	0.034	0.039	0.033	0.037	0.036	0.475
D	0.7	0.020	0.010	0.025	0.017	0.019	0.021	0.023	0.022	0.031	0.017	0.026	0.026	0.026	0.016	0.017	0.022	0.339
D	3.8	0.001	0.000	0.001	0.001	0.001	0.003	0.006	0.010	0.007	0.002	0.002	0.004	0.006	0.004	0.002	0.001	0.052
E	2.6	0.001	0.001	0.002	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.019
F	0.7	0.008	0.005	0.006	0.006	0.006	0.006	0.005	0.005	0.007	0.006	0.008	0.008	0.010	0.008	0.009	0.010	0.114
Total		0.064	0.040	0.060	0.050	0.053	0.054	0.059	0.060	0.078	0.056	0.072	0.074	0.083	0.061	0.066	0.071	**1.0**

Assumption No. 4: Ambient Conditions

Subject: Locational Data

Assumption/s:

- The typical ambient conditions (temperature, atmospheric pressure, solar radiation and relative humidity) are based on the Bureau of Meteorology (BoM) meteorological data for Parramatta.
- The typical ambient conditions (temperature, atmospheric pressure, solar radiation and relative humidity) are listed in Table 20 and Table 21.

Table 20: Average Temperature, Relative Humidity and Solar Radiation (Day)

Stability Class	Wind Speed (m/s)	Average Temp (°C)	Average Solar Radiation (W/m^2)	Average Relative Humidity (%)
B	1.8	21.5	606.8	59.5
D	7.5	21.8	471.8	45.6
D	1.6	17.0	268.6	61.7
D	4.1	19.8	383.2	75.7

Table 21: Average Temperature, Relative Humidity and Solar Radiation (Night)

Stability Class	Wind Speed (m/s)	Average Temp (°C)	Average Solar Radiation (W/m^2)	Average Relative Humidity (%)
D	7.3	17.4	18.8	58.0
D	0.7	13.5	6.38	79.4
D	3.8	16.4	8.97	91.0
E	2.6	15.1	0.00	84.7
F	0.7	13.3	0.00	91.7

Justification and Impact/s of Assumption/s:

- The average ambient temperature is a required input for the SAFETI model. The temperature of the material in each pipeline is similar; therefore, the average ambient temperature does not have a significant impact on the consequence calculations.
- The average relative humidity is a required input for the SAFETI model. This is used in thermal radiation calculations to attenuate the heat radiation.
- The average solar radiation is a required input for the SAFETI model.

MAE/s Affected:

- All.

Reference/s:

- Exemplary Energy manipulation of BoM data for Parramatta (Station ID: 066124) and World Met Station Number, WMO Index 94765. Used years 2010 – 2014.
- Stability categories calculated as per VIC EPA publication 1459. Sunrise and Sunset times obtained from NASA Jet Propulsion Laboratories' "Horizons" Ephemeris programme.
- Bureau of Meteorology, http://www.bom.gov.au/climate/averages/tables/cw_066124.shtml.

Assumption No. 5: Surface Roughness Length

Subject: Locational Data

Assumption/s:

- The roughness length for different surface types, as listed in the SAFETI user manual, is shown below in Table 22.

Table 22: Surface Roughness Length

Description	Roughness Length (m)
Open water, at least 5 km	0.0002
Mud flats, snow, no vegetation, no obstacles	0.005
Open flat terrain, grass, few isolated objects	0.03
Low crops; occasional large obstacles, x/h > 20	0.1
High crops, scattered large obstacles, 15<x/h<20	0.25
Parkland, bushes, numerous obstacles, x/h<15	0.5
Regular large obstacle coverage (suburb, forest)	1
City centre with high- and low-rise buildings	3

- The developments proposed in the Melrose Park precinct are predominantly low-rise and high-rise buildings. Therefore, a roughness length of 3 m is a representative value for this location.

Justification and Impact/s of Assumption/s:

- The surface roughness affects the dispersion analysis. As the surface roughness increases, a release of gas or vapour will disperse more quickly with increasing distance from the source. Therefore, it is necessary in SAFETI to select a surface roughness length that is representative of the types of terrain and obstacles near the source of release.
- It is not possible to define different surface roughness lengths for different locations within a single SAFETI model. Only a single representative value can be defined for the entire area.

MAE/s Affected:

- Dispersion modelling for all relevant MAEs.

Reference/s:

- Aerial photographs of study area.
- City of Parramatta, Urban Design City Strategy Unit, *Melrose Park Master Plan*, Drawing No. A01, Revision N, 4 Sept. 2020.
- SAFETI software documentation.

Assumption No. 6: Total Population (Day and Night)

Subject: Locational Data

Assumption/s:

- The risk analysis includes the estimated population within the Melrose Park Precinct. Residential populations located outside the Melrose Park Precinct (within the maximum estimated hazard range) are also included in the risk analysis.
- **Proposed Residential Apartment Buildings *within* Melrose Park Precinct** – The population in each proposed residential apartment building is conservatively based on an occupancy rate of 2.2 persons per apartment, with 6,850 apartments in Melrose Park North and 4,238 apartments in Melrose Park South (based on the Master Plan). 20% of this population is assumed to be present during the day and 100% is present during the night.
- **Existing Residential Areas Outside the Melrose Park Precinct** – The population in each residential area *outside* the Melrose Park Precinct (within the maximum estimated hazard range) is given in Table 23. The majority of these dwellings are residential houses.

Table 23: Surrounding Residential Population

Statistical Area 1	Description	Total Population	No People per Dwelling	% Home Day
1150333	Melrose Park	524	3.1	22
1150320	Melrose Park	454	2.7	22
1147751	Ermington	268	2.9	31
1147744	Ermington	568	2.9	19
1147726	Ermington	454	3.1	20

- **Town Centre** - The population in the Melrose Park town centre is based on 1 person 30 m^2 of GFA, with 100% present during day and 10% present during the night. Note: The maximum population for the Melrose Park town centre was based on a maximum GFA of 30,000 m^2.
- **Existing Melrose Park Primary School** – 100% of the total population (1000 students and 59 staff) are located at the local school during the day. 0% are present at night. Minimal personnel in weekends.
- **Proposed new Melrose High School** - 100% of the total population (1000 students and 59 staff) are located at the local school during the day. 0% are present at night. Minimal personnel in weekends.

Justification and Impact/s of Assumption/s:

- The occupancy rate and % of the population present during the day and night was estimated from 2016 census data for Melrose Park and Ermington.
- The % of people present during the day was estimated from: (i) the number of employed people minus the number of employed people who worked from home or did not travel to work; (ii) the number of children aged 5-14, who would be at school; and, (iii) an assumption that 20% of the people who are not employed or did not report an employment status are not at their home in the precinct.
- The total population and the % of the total population present during the day and night is required for estimation of the societal risk.

Assumption No. 6: Total Population (Day and Night)
MAE/s Affected: • All (Note: This assumption is only applicable to the calculation of societal risk).
Reference/s: • Information provided in the Parramatta Structural Plan for Melrose Park Urban Redevelopment project • Australian Bureau of Statistics, 2016 census data for Melrose Park and Ermington. • School population provided by School Infrastructure NSW

Assumption No. 7: Indoor / Outdoor Population Distribution (Day and Night)

Subject: Locational Data

Assumption/s:

- The % of people located indoors and outdoors during the day and night is dependent on the type of use, as follows:
  - **Proposed Residential Apartment Buildings in Melrose Park Precinct** – 90% of the daytime population is indoors and 10% is outdoors. 99% of the night-time population is indoors and 1% is outdoors.
  - **Existing Residential Areas Outside the Melrose Park Precinct** – 90% of the daytime population is indoors and 10% is outdoors. 99% of the night-time population is indoors and 1% is outdoors.
  - **Town Centre** – 90% of the daytime population is indoors and 10% is outdoors. 90% of the night-time population is indoors and 10% is outdoors.
  - **Melrose Park School** – For 80% of the daytime hours, 100% of the population is indoors. For 20% of the daytime hours, 100% of the population is outdoors. Note: The indoor / outdoor population distribution is not required for night-time as the total population is 0 (Refer to Assumption No. 6).
- All population is located at ground level.

Justification and Impact/s of Assumption/s:

- The proportion of people located indoors and outdoors will affect the societal risk analysis, as the vulnerability to fire, explosion, etc. varies depending on location.
- The default values recommended by the TNO ['Purple Book'] for residential and industrial areas are tabulated below.

Table 24: Proportion of Population Indoor and Outdoor During Day and Night [TNO]

Location	Day (8am to 6:30pm)	Night (6:30pm to 8am)
Indoor	93%	99%
Outdoor	7%	1%

- The % of the total population located indoors and outdoors was estimated from similar risk analyses. It is reported in these analyses that the % of people indoors and outdoors is 90% indoors and 10% outdoors during the day, which differs slightly from the TNO data, but is typically justified as being more applicable for Australian environmental conditions. Similarly, it is reported in these analyses that the % of people indoors and outdoors is 95 to 99% indoors and 1 to 5% outdoors during the night.

MAE/s Affected:

- All (Note: This assumption is only applicable to the calculation of societal risk).

Reference/s:

- TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition.

A.3 Risk Analysis Methodology

Assumption No. 8: Location and Segmentation of Pipelines
Subject: Risk Analysis Methodology
Assumption/s: • All pipelines are physically located on the Melrose Park Precinct Master Plan layout, using the GIS functionality within SAFETI, based on the indicative locations provided by the BYDA information and the APGA Australian Pipeline Database. • Incidents were distributed along the pipeline at 25 m intervals.
Justification and Impact/s of Assumption/s: • Standard approach for linear sources.
MAE/s Affected: • All.
Reference/s: • SAFETI software documentation.

A.4 Consequence Analysis

Assumption No. 9: Representative Materials
Subject: Consequence Analysis
Assumption/s: • Gasoline is modelled as 100% Heptane. • Natural gas is modelled as 100% Methane.
Justification and Impact/s of Assumption/s: • The composition and materials used affect the magnitude of the consequences. Materials containing multiple components are simplified for modelling purposes by choosing a representative component to best approximate the variable composition. Modelling a representative material rather than a multi-component material reduces complexity, limits the potential for inconsistencies and ultimately has a minimal effect on the results. • The Gore Bay Pipeline is used to transfer Gasoline, Diesel and Jet Fuel. Gasoline was selected for the risk analysis as it is the most conservative product transferred in this pipeline. • Natural gas typically contains 85 to 95% methane.
MAE/s Affected: • All.
Reference/s: • https://www.uniongas.com/about-us/about-natural-gas/chemical-composition-of-natural-gas

Assumption No. 10: Pressure / Pumping Rate for Release Modelling
Subject: Consequence Analysis
Assumption/s: • A release of Gasoline from the Gore Bay Pipeline is modelled at 6,500 kPag (MAOP), with the maximum release rate limited to the pumping rate (c. 19 Ml/day). • A release of Natural Gas from the Jemena Secondary Mains is modelled at 1,050 kPag (MAOP).
Justification and Impact/s of Assumption/s: • The release rate is dependent on the pressure and the MAOP is the maximum pressure permitted under an existing licence. Therefore, use of the MAOP is a conservative, yet realistic, basis on which to model release rates; however, the rate of discharge from a liquid pipeline will be limited by the maximum capacity of the pump. • The pressure used to model the release rates was based on the pipeline pressure (Refer to Section 4).
MAE/s Affected: • All.
Reference/s: • AECOM, *Environmental Impact Statement*, *Clyde Terminal Conversion Project, Appendix F, Preliminary Hazard Analysis*, Jan 2013. • AECOM, Gore Bay Terminal Modification, EIS Scoping Report, 25 Jan 2012. • Jemena, *DBYD Response*, DBYD Sequence Number 102261874, 28 Sept. 2020. • Viva Energy Australia, ASX Release, *Clyde and Gore Bay Site Visit Presentation*, 23 Nov. 2018. • Viva Energy Australia, *DBYD Response*, DBYD Sequence Number 102261877, 28 Sept. 2020.

Assumption No. 11: Representative Hole Diameters for Release Modelling

Subject: Consequence Analysis

Assumption/s:

- Consequence modelling is based on the following representative hole diameters:

Table 25: Representative Hole Diameters Selected for Consequence Analysis

Pipeline/s	Material/s	Pipeline Diameter (mm)	Representative Hole Diameter (mm)			
			Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)
Gore Bay Pipeline	Gasoline / Jet Fuel / Diesel	300	10 or 25*	75	110	Full bore
Jemena Secondary Mains	Natural Gas	350	10 or 25*	75	110	Full bore
		150	10 or 25*	75	110	Full bore
		100	10 or 25*	75	Full bore	

* 10 mm for all failure modes except Third Party Activity (TPA). 25 mm for TPA only.

Justification and Impact/s of Assumption/s:

- The representative hole diameters were selected to align with the leak frequency data (Refer to Appendix C), which includes four hole size categories: Pinhole (≤ 25 mm); Small Hole (> 25 mm to ≤ 75 mm), Large Hole (> 75 mm to ≤ 110 mm); and, Rupture (> 110 mm). The representative hole diameter/s in each hole size category were selected based on a review of the available historical data (Refer to Appendix B.1).
- Leaks from underground pipelines in the Pinhole size category tend to be larger for TPA incidents (i.e. typically c. 20 mm to 25 mm) than for the other failure modes (i.e. typically less than c. 10 mm). Therefore, two representative hole diameters were selected in this category: 25 mm for TPA and 10 mm for all other failure modes.

MAE/s Affected:

- All.

Reference/s:

- Refer to Appendix B.1.

Assumption No. 12: Location of Release from Underground Pipelines
Subject: Consequence Analysis
Assumption/s: • High pressure liquid or gas releases from an underground pipeline create a crater on the ground. The direction of release for underground pipeline failures from the crater is predominantly vertical. • The location of failure on the pipe can be taken as: - Top of the pipe (unobstructed releases); or - Middle of the pipe (on the side – obstructed releases) • The release frequency is distributed between the two locations (37% horizontally impinged from the middle of the pipe and 63% vertically from the top of the pipe for all release cases except non-TPA events with a hole size less than or equal to 25mm, which are all modelled as horizontally impinged from the middle of the pipe). • All releases from underground (UG) pipelines are modelled at a release height of 0 m above ground level.
Justification and Impact/s of Assumption/s: • The position of the crater depends on the location of the hole on the pipe and three locations (top, middle and bottom) may be modelled using the 'Long Pipeline' Model in SAFETI (Note: This model cannot currently be used for liquid pipelines). Top releases are taken as non-obstructed releases and middle / bottom releases are taken as obstructed releases. • Impingement reduces the momentum of the release and the dispersion modelling is dominated by the representative wind conditions. • The UK HSE [RR 1034] reports that some data from UKOPA includes the 'hole circumferential position' for releases from underground pipelines. Based on the 71 recorded incidents (All pipelines and materials) and average crater dimensions, an unobstructed release (c. up to +/- 71^{o} from vertical) was estimated to occur for 63% of the releases and an obstructed release was estimated to occur for the balance (37% of releases). The distribution is not reported for different failure modes. • The SAFETI software does not permit entry of a height of release below 0 m. • Modelling releases from underground (UG) pipelines at a release height of 0 m above ground level is generally conservative as the resultant point of release will be closer to the potential receptors. However, this is not a significant factor for the typical burial depths of the pipelines in the Melrose Park Precinct (Refer to Section 4). • The default release height in the SAFETI software is 1 m.
MAE/s Affected: • All.
Reference/s: • SAFETI software documentation. • UK HSE, 2015, *Review of the Event Tree Structure and Ignition Probabilities used in HSE's Pipeline Risk Assessment Code MISHAP*, Research Report (RR) 1034.

Assumption No. 13: Formation of Circular Pools
Subject: Consequence Analysis
Assumption/s: • All liquid releases (which rain out) form a circular pool.
Justification and Impact/s of Assumption/s: • The Melrose Park Precinct is relatively flat with a slight grade along Hope Street and Waratah Street.
MAE/s Affected: • All MAEs where a liquid pool forms.
Reference/s: • Current topography of Melrose Park Precinct.

Assumption No. 14: Maximum Extent of Flash Fire
Subject: Consequence Analysis
Assumption/s: • The maximum extent of a flash fire is defined by the downwind and crosswind distances from the release location to a concentration equal to 50% of the lower flammability limit (LFL) concentration.
Justification and Impact/s of Assumption/s: • The peak to mean concentration within the gas cloud is approximately 2:1, and hence, while the average concentration is ½ LFL, there may be locations within the cloud where the concentration can be LFL, and hence ignition is possible. • The formation of localised higher concentrations is more applicable when the cloud passes around obstacles. This is particularly relevant where there are large obstacles (such as the multi-storey buildings in the proposed Melrose Park Precinct).
MAE/s Affected: • All MAEs with a flash fire as a potential outcome.
Reference/s: • SAFETI software documentation.

Assumption No. 15: Isolation Time and Duration of Release
Subject: Consequence Analysis
Assumption/s: • Isolation time and duration of release is not specified as these will be longer than the period of exposure required for an adverse effect to people (Refer to Section A.6) and time required for each representative release case to reach steady state.
Justification and Impact/s of Assumption/s: • Gasoline and natural gas are flammable and any adverse impact will occur quickly (fire or explosion); therefore, the duration of exposure is not as critical as it would be if there were toxic materials in the pipeline (i.e. where the adverse impact can significantly increase for longer exposure durations). • The assumption is justified from the consequence calculations, using a 30 second exposure time (user specified) compared to isolation valve closure times which typically vary from minutes (full bore rupture case) to hours (small to medium leaks).
MAE/s Affected: • All.
Reference/s: • SAFETI software documentation.

Assumption No. 16: Shielding by Intervening Structures
Subject: Consequence Analysis
Assumption/s: • The presence of intervening structures (e.g. buildings) does not shield other receptors from the heat radiation from a jet fire.
Justification and Impact/s of Assumption/s: • In the SAFETI software, it is not possible to take account of the potential protection provided by intervening structures. • People located indoors are typically less vulnerable to fire, which is a relevant consideration for the societal risk assessment (Refer to Assumption No. 21).
MAE/s Affected: • All MAEs with a pool fire or jet fire as a potential outcome.
Reference/s: • SAFETI software documentation.

Assumption No. 17: 3D Explosion Model Parameters
Subject: Consequence Analysis

Assumption/s:
• The maximum explosive mass in a flammable gas or vapour cloud is the maximum mass between the LFL and UFL concentration for that section of the cloud that overlaps a congested area.
• The peak side-on overpressure resulting from an explosion is estimated using the Extended Explosion Modelling option in the SAFETI software.
• The blast strength is estimated based on the obstructed volume (%) and potential obstructions in each congested area. The following congested areas are included in the QRA:
  • **Buildings** - A medium level of congestion is assumed to simulate entry of the gas or vapour into the building and the subsequent confined explosion. This equates to TNO Model curve number 4.
  • **Open Spaces** - A relatively low level of congestion is assumed for the open spaces. This equates to TNO Model curve number 2.
• Only overpressure effects are included. Projectiles and whole-body displacement are not included.

Justification and Impact/s of Assumption/s: • The explosive mass and blast strength are key parameters for modelling the overpressure from a VCE. • There are no significantly congested locations in the study area; however, a confined explosion could occur if gas or vapour enters a building. • The open space between the buildings in the study area is not strictly a congested area; however, the presence of vehicles, trees etc. at ground level may contribute to flame acceleration and the formation of an overpressure if ignition occurs. Therefore, TNO Model curve number 2 was assumed to apply, which is the default value in the SAFETI software. • The 3D Obstructed Region Explosion Modelling option considers the interactions between the flammable cloud and obstructed regions that have been defined for the study area. This is more valid than simple models (e.g. TNT equivalence) which do not consider these interactions.
MAE/s Affected: • All MAEs with a VCE as a potential outcome.
Reference/s: • Centre for Chemical Process Safety, Estimating the flammable mass of vapour clouds", American Institute of Chemical Engineers, 1999. • TNO, VROM, 'Yellow Book'. • SAFETI software documentation.

A.5 Likelihood Analysis

Assumption No. 18: Likelihood of Release (Loss of Containment)
Subject: Likelihood Analysis
Assumption/s: • The likelihood of each representative release is provided in Appendix C.3. • The UK HSE pipeline failure rate data is the primary data used for the risk assessment.
Justification and Impact/s of Assumption/s: • The estimated likelihood of release (or loss of containment) is a critical and significant input for the risk analysis. The risk results are directly proportional to this input. • Generic failure rate data for cross-country pipelines from the UK, USA and Europe were reviewed. The UK data incorporates the European data. There are two sources of data from the UK: (a) HSE recommended data for land use safety planning (RR 1035); and (b) British Standards Institute PD 8010-3:2009+A1:2013. The HSE data is primarily used in this study, which is slightly more conservative than the NSW performance data for licenced pipelines. • The HSE data identifies four contributors to pipeline failure: (a) mechanical failure; (b) corrosion; (c) ground movement/other; and (d) Third Party Activity (TPA). • The justification for the data used in this risk analysis is provided in Appendix C.1.
MAE/s Affected: • All.
Reference/s: • Refer to Appendix C.1.

Assumption No. 19: Ignition Probability
Subject: Likelihood Analysis
Assumption/s: • The probability of ignition for each representative release is provided in Appendix C.2.
Justification and Impact/s of Assumption/s: • The estimated probability of ignition is a critical and significant input for the risk analysis. The risk results are directly proportional to this input. • The justification for the data used in this risk analysis is provided in Appendix C.2.
MAE/s Affected: • All.
Reference/s: • Refer to Appendix C.2.

Assumption No. 20: Probability of VCE or Flash Fire
Subject: Likelihood Analysis
Assumption/s: • Ignition of a free gas or vapour cloud is modelled as an explosion (Probability = 0.4) or a flash fire (Probability = 0.6).
Justification and Impact/s of Assumption/s: • Ignition of a free gas cloud may demonstrate characteristics of a flash fire and/or an explosion. This is modelled as two separate events: as a pure flash fire and a pure explosion. • The assumed probabilities are consistent with the guidance in the TNO 'Purple Book' and are the default values in the SAFETI software.
MAE/s Affected: • All MAEs with clouds in an obstructed region.
Reference/s: • SAFETI software documentation. • TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition.

A.6 Vulnerability Parameters

Assumption No. 21: Exposure to Heat Radiation from a Fire (Indoor or Outdoor)

Subject: Vulnerability Parameters

Assumption/s:

- For individuals located outdoors, the probability of fatality is based on the following probit equation [TNO 'Purple Book']:

$$Y = -36.38 + 2.56 \ln\left(I^{1.333} t\right)$$

  Where Y is the probit value, *I* is the heat radiation intensity (W/m^2) and t is the exposure duration (seconds).
- A maximum exposure duration of 30 seconds is applicable for individuals located outdoors.
- The probability of fatality for an individual located outdoors (30 seconds exposure), as calculated using the above probit equation, is as follows:

Table 26: Probability of Fatality for Exposure to Heat Radiation (Outdoor)

Heat Radiation Intensity (kW/m^2)	Probit	Probability of Fatality
4.7	1.19	0
12.6	4.55	0.32
15.9	5.35	0.63
23.0	6.61	0.94
35.0	8.04	1.0

- For the calculation of societal risk:
  - The probability of fatality for individuals located outdoors is factored by 0.14 (SAFETI default) to allow for the protection provided by clothing and the possibility of seeking shelter behind obstacles.
  - The probability of fatality for an individual located indoors is 0 at less than 35 kW/m^2 and 1.0 at 35 kW/m^2 or greater.

Assumption No. 21: Exposure to Heat Radiation from a Fire (Indoor or Outdoor)

Justification and Impact/s of Assumption/s:

- The probit equation adopted for the risk analysis is generally consistent with the following data from HIPAP No. 4.

Table 27: Effects of Thermal Radiation

Heat Radiation Intensity [kW/m^2]	Effect/s
1.2	Received from sun in summer at noon.
1.6	Minimum necessary to be felt as pain.
4.7	Pain in 15 to 20 seconds, 1st degree burns in 30 seconds. Injury (second degree burns) to person who cannot escape or seek shelter after 30s exposure.
12.6	High chance of injury. 30% chance of fatality for extended exposure. Melting of plastics (cable insulation). Causes the temperature of wood to rise to a point where it can be ignited by a naked flame after long exposure. Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure.
23.0	Fatality on continuous exposure. 10% chance of fatality on instantaneous exposure. Spontaneous ignition of wood after long exposure. Unprotected steel will reach thermal stress temperatures, which can cause failure. Pressure vessel needs to be relieved or failure would occur.
35.0	25% chance of fatality on instantaneous exposure.
60.0	Fatality on instantaneous exposure.

- It is reported in the TNO ‘Purple Book’ that people indoors are assumed to be protected from heat radiation until the building catches fire. The threshold for the ignition of buildings in the TNO ‘Purple Book’ is set at 35 kW/m^2 and if the building is set on fire, all the people inside the building are assumed to die (i.e. The probability of fatality indoors is 1 if the heat radiation exceeds 35 kW/m^2 and it is 0 if the heat radiation is less than 35 kW/m^2).

MAE/s Affected:

- All MAEs with a pool fire or jet fire as a potential outcome.

Reference/s:

- TNO, VROM, *Methods for the determination of possible damage*, ‘Green Book’, CPR16E.
- TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition.

Assumption No. 22: Exposure to Flash Fire (Indoor or Outdoor)
Subject: Vulnerability Parameters
Assumption/s: • For calculation of location-specific individual risk, the probability for fatality = 1 for any individual located within the flammable cloud (Distance to LFL concentration). • For calculation of societal risk, the probability for fatality for any individual located within the flammable cloud (Distance to LFL concentration) is 1 (outdoor) or 0.1 (indoor).
Justification and Impact/s of Assumption/s: • The assumed probabilities differ from the guidance in the TNO 'Purple Book' and the default values in the SAFETI software. In both cases, the probability of fatality is set at 1 for all individuals (outdoor or indoor). This was considered too conservative. The probability of fatality indoors was set at 0.1 to take account of the possibility of open doors / windows and/or failure to evacuate.
MAE/s Affected: • All MAEs with a flash fire as a potential outcome.
Reference/s: • SAFETI software documentation. • TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition.

Assumption No. 23: Exposure to Explosion Overpressure (Indoor or Outdoor)

Subject: Vulnerability Parameters

Assumption/s:

- The probability of fatality from exposure to the peak side-on overpressure from an explosion is as shown in Table 28 (Person located outdoors) and Table 29 (Person located indoors).

Table 28: Probability of Fatality from Exposure to Peak Side on-Overpressure (Outdoor)

Overpressure (kPa)	Probability of Fatality	Source
30	1.0	SAFETI software (default value)

Table 29: Probability of Fatality from Exposure to Peak Side on-Overpressure (Indoor)

Overpressure (kPa)	Probability of Fatality	Source
10	0.025	SAFETI software (default value)
30	1.0	SAFETI software (default value)

Justification and Impact/s of Assumption/s:

- When calculating location-specific individual injury or fatality risk contours (peak individual risk), all individuals must be considered to be located outdoors for 100% of the time since this is the underlying basis for the NSW DPHI's individual risk criteria. Vulnerability parameters for individuals located indoors are only applicable for the calculation of societal risk.
- The probability of fatality is higher for an individual located in a conventional building than when outdoors due to the higher chance of harm from collapse of the structure.
- The NSW DPHI's injury/damage risk criterion for explosion overpressure is as follows: "Incident explosion overpressure at residential and sensitive use areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year".

Incidents Affected:

- All incidents with a VCE as a potential outcome.

Reference/s:

- NSW Department of Planning and Infrastructure, Jan 2011, Hazardous Industry Planning Advisory Paper (HIPAP) No. 4, *Risk Criteria for Land Use Safety Planning*.
- SAFETI software documentation.
- Oil & Gas Producers Association (OGP), Risk Assessment Data Directory, Report No. 434-14.1, *Vulnerability to Humans*, March 2010.
- Chemical Industries Association (CIA), 2003, *Guidance for the location and design of occupied buildings on chemical manufacturing sites*, 2nd. ed.

Appendix B Consequence Analysis Results

B.1 Representative Hole Diameters

Representative hole diameters were selected for the consequence modelling. These were selected to align with the leak frequency data (Refer to Appendix C), which includes four hole size categories: Pinhole (≤ 25 mm); Small Hole (> 25 mm to ≤ 75 mm), Large Hole (> 75 mm to ≤ 110 mm); and, Rupture (> 110 mm). The representative hole diameter/s in each hole size category were selected based on a review of the following available historical data.

Example hazard ranges for the modelled release cases are tabulated below.

B.1.1 Pool Fire Consequence Analysis Results

Table 30: Example Pool Fire Consequence Analysis Results

Release Scenario	Time	Weather	Height of Interest (m)	Pool Diameter (m)	Downwind Distance to 4.7 kW/m^2 at Height of Interest (m)	Downwind Distance to 12.5 kW/m^2 at Height of Interest (m)	Downwind Distance to 23 kW/m^2 at Height of Interest (m)	Downwind Distance to 35 kW/m^2 at Height of Interest (m)
Release of High-Pressure Gasoline from Viva Gore Bay Pipeline								
10 mm (MID)	Day	B1.8	0	8.5	30.6	18.4	11.3	8.0
		D7.5		8.5	35.4	25.7	14.0	10.0
		D1.6		8.5	30.0	17.9	11.0	7.9
		D4.1		8.5	32.9	22.6	12.8	9.1
25 mm (MID)	Day	B1.8	0	21	41.2	25.7	20.2	17.6
		D7.5		21	44.2	26.5	22.1	19.8
		D1.6		21	40.8	25.3	19.8	17.2
		D4.1		21	43.2	26.4	21.4	19.0
75 mm (MID)	Day	B1.8	0	85	109.0	74.0	62.0	56.0
		D7.5		85	119.0	79.0	66.0	60.0
		D1.6		85	109.0	74.0	61.0	55.0
		D4.1		85	114.0	77.0	64.0	58.0
110 mm (MID)	Day	B1.8	0	90	114.0	78.0	65.0	59.0
		D7.5		90	126.0	82.0	69.0	63.0
		D1.6		90	114.0	77.0	64.0	58.0
		D4.1		90	120.0	80.0	67.0	61.0
FBR (MID)	Day	B1.8	0	100	125.0	85.0	71.0	64.0
		D7.5		100	137.0	90.0	75.0	69.0
		D1.6		100	124.0	84.0	71.0	64.0
		D4.1		100	131.0	88.0	73.0	67.0

B.1.2 Example Jet Fire Consequence Analysis Results

Table 31: Example Jet Fire Consequence Analysis Results

Release Scenario	Time	Weather	Height of Interest (m)	Flame Length (m)	Downwind Distance to 4.7 kW/m² at Height of Interest (m)	Downwind Distance to 12.5 kW/m² at Height of Interest (m)	Downwind Distance to 23 kW/m² at Height of Interest (m)	Downwind Distance to 35 kW/m² at Height of Interest (m)
Release of High-Pressure Gasoline from Viva Gore Bay Pipeline								
25 mm (TOP)	Day	B1.8	0	35.6	60.9	32.4	12.7	2.4
		D7.5		24.8	59.9	39.5	30.5	26.2
		D1.6		36.6	61.8	32.1	11.1	1.7
		D4.1		28.4	56.7	36.4	25.1	15.5
75 mm (TOP)	Day	B1.8	0	76.0	123.2	62.6	20.7	4.8
		D7.5		53.1	120.7	77.8	61.1	49.8
		D1.6		78.2	125.2	62.1	18.2	3.9
		D4.1		60.7	115.8	72.3	46.6	24.8
110 mm (TOP)	Day	B1.8	0	76.0	123.2	62.6	20.7	4.8
		D7.5		53.1	120.7	77.8	61.1	49.8
		D1.6		78.2	125.2	62.1	18.2	3.9
		D4.1		60.7	115.8	72.3	46.6	24.8
FBR (TOP)	Day	B1.8	0	76.0	123.2	62.6	20.7	4.8
		D7.5		53.1	120.7	77.8	61.1	49.8
		D1.6		78.2	125.2	62.1	18.2	3.9
		D4.1		60.7	115.8	72.3	46.6	24.8

Release Scenario	Time	Weather	Height of Interest (m)	Flame Length (m)	Downwind Distance to 4.7 kW/m² at Height of Interest (m)	Downwind Distance to 12.5 kW/m² at Height of Interest (m)	Downwind Distance to 23 kW/m² at Height of Interest (m)	Downwind Distance to 35 kW/m² at Height of Interest (m)
Release of Natural Gas (Methane) from Jemena Secondary Mains								
10 mm (MID)	Day	B1.9	0	4.8	2.5	2.3	2.2	2.1
		D7.5		4.8	2.3	2.2	2.1	1.7
		D4.0		4.8	2.4	2.2	2.1	2.1
		D1.6		4.8	2.4	2.2	2.1	1.9
25 mm (MID)	Day	B1.9	0	10.6	6.6	4.8	4.4	4.0
		D7.5		10.6	5.8	4.6	4.3	4.0
		D4.0		10.6	6.6	4.7	4.3	4.0
		D1.6		10.6	6.3	4.7	4.3	4.0
25 mm (TOP)	Day	B1.9	0	9.7	5.8	n/a	n/a	n/a
		D7.5		6.7	10.2	5.6	n/a	n/a
		D4.0		9.9	5.5	n/a	n/a	n/a
		D1.6		7.7	9.0	2.0	n/a	n/a
75 mm (MID)	Day	B1.9	0	28.1	27.6	16.7	12.6	11.2
		D7.5		30.1	27.3	16.3	13.4	12.2
		D4.0		27.8	27.8	16.9	12.5	11.1
		D1.6		28.8	27.3	16.5	12.8	11.6
75 mm (TOP)	Day	B1.9	0	25.8	19.2	n/a	n/a	n/a
		D7.5		18.0	28.8	15.8	4.6	n/a
		D4.0		26.3	18.7	n/a	n/a	n/a
		D1.6		20.5	25.8	8.6	n/a	n/a
110 mm (MID)	Day	B1.9	0	39.2	42.3	25.8	18.5	16.1
		D7.5		42.5	42.4	25.7	19.7	17.9
		D4.0		38.8	42.7	26.0	18.6	16.0

Release Scenario	Time	Weather	Height of Interest (m)	Flame Length (m)	Downwind Distance to 4.7 kW/m² at Height of Interest (m)	Downwind Distance to 12.5 kW/m² at Height of Interest (m)	Downwind Distance to 23 kW/m² at Height of Interest (m)	Downwind Distance to 35 kW/m² at Height of Interest (m)
		D1.6		40.4	42.0	25.6	18.8	16.7
110 mm (TOP)	Day	B1.9	0	36.2	28.7	n/a	n/a	n/a
		D7.5		25.3	41.4	22.7	7.8	n/a
		D4.0		36.9	28.1	n/a	n/a	n/a
		D1.6		28.8	37.3	13.6	n/a	n/a
FBR (MID) – 100 mm	Day	B1.9	0	36.1	38.2	23.3	16.8	14.7
		D7.5		39.0	38.2	23.1	17.9	16.3
		D4.0		35.7	38.5	23.5	16.7	14.6
		D1.6		37.2	37.9	23.0	17.2	15.3
FBR (TOP) – 100 mm	Day	B1.9	0	33.3	26.0	n/a	n/a	n/a
		D7.5		23.2	37.8	20.8	6.9	n/a
		D4.0		34.0	25.4	n/a	n/a	n/a
		D1.6		26.5	34.0	12.1	n/a	n/a
FBR (MID) – 150 mm	Day	B1.9	0	51.2	58.3	35.7	25.5	21.3
		D7.5		56.0	58.9	35.8	26.7	23.9
		D4.0		50.7	58.8	36.0	25.8	21.2
		D1.6		53.0	57.9	35.4	25.4	22.2
FBR (TOP) – 150 mm	Day	B1.9	0	47.6	39.6	n/a	n/a	n/a
		D7.5		33.2	55.5	30.6	11.5	n/a
		D4.0		48.6	39.0	n/a	n/a	n/a
		D1.6		37.9	50.1	19.1	n/a	n/a
FBR (MID) – 350 mm	Day	B1.9	0	102.3	129.9	80.3	58.0	45.1
		D7.5		112.0	133.8	82.8	60.1	49.9
		D4.0		101.3	130.0	80.4	58.1	45.2

Release Scenario	Time	Weather	Height of Interest (m)	Flame Length (m)	Downwind Distance to 4.7 kW/m² at Height of Interest (m)	Downwind Distance to 12.5 kW/m² at Height of Interest (m)	Downwind Distance to 23 kW/m² at Height of Interest (m)	Downwind Distance to 35 kW/m² at Height of Interest (m)
		D1.6		105.8	129.8	80.4	58.3	45.6
FBR (TOP) – 350 mm	Day	B1.9	0	100.0	93.7	n/a	n/a	n/a
		D7.5		69.8	121.4	67.3	31.1	11.1
		D4.0		102.1	93.2	n/a	n/a	n/a
		D1.6		79.6	112.2	48.5	n/a	n/a

B.1.3 Example Flash Fire Consequence Analysis Results

Table 32: Example Flash Fire Consequence Analysis Results

Release Scenario	Time	Weather	Height of Interest (m)	Mass Flow Rate (kg/s)	Distance to UFL at Height of Interest (m)	Distance to LFL at Height of Interest (m)	Distance to ½ LFL at Height of Interest (m)
Release of High-Pressure Gasoline from Viva Gore Bay Pipeline							
25 mm (TOP)	Day	B1.8	0	29.8	Not Reached	Not Reached	Not Reached
		D7.5			Not Reached	Not Reached	Not Reached
		D1.6			Not Reached	Not Reached	Not Reached
		D4.1			Not Reached	Not Reached	Not Reached
75 mm (TOP)	Day	B1.8	0	175.9 *	Not Reached	Not Reached	Not Reached
		D7.5			Not Reached	Not Reached	Not Reached
		D1.6			Not Reached	Not Reached	Not Reached
		D4.1			Not Reached	Not Reached	Not Reached
110 mm (TOP)	Day	B1.8	0	175.9 *	Not Reached	Not Reached	Not Reached
		D7.5			Not Reached	Not Reached	Not Reached
		D1.6			Not Reached	Not Reached	Not Reached
		D4.1			Not Reached	Not Reached	Not Reached
FBR (TOP)	Day	B1.8	0	175.9 *	Not Reached	Not Reached	Not Reached
		D7.5			Not Reached	Not Reached	Not Reached
		D1.6			Not Reached	Not Reached	Not Reached
		D4.1			Not Reached	Not Reached	Not Reached

Release Scenario	Time	Weather	Height of Interest (m)	Mass Flow Rate (kg/s)	Distance to UFL at Height of Interest (m)	Distance to LFL at Height of Interest (m)	Distance to ½ LFL at Height of Interest (m)
Release of Natural Gas (Methane) from Jemena Secondary Mains							
10 mm (MID)	Day	B1.8	0	0.14	1.8	4.4	7.1
		D7.5			1.9	4.7	7.5
		D1.6			2.6	7.7	15.3
		D4.1			2.3	6.7	12.1
25 mm (MID)	Day	B1.8	0	0.86	3.8	10.0	16.6
		D7.5			4.5	11.2	18.0
		D1.6			5.6	18.2	35.5
		D4.1			5.2	15.3	27.1
25 mm (TOP)	Day	B1.8	0	0.86	n/a	n/a	n/a
		D7.5			n/a	n/a	n/a
		D1.6			n/a	n/a	n/a
		D4.1			n/a	n/a	n/a
75 mm (MID)	Day	B1.8	0	7.70	10.3	28.1	46.7
		D7.5			12.9	34.4	55.8
		D1.6			14.8	52.2	98.1
		D4.1			14.5	44.2	75.2
75 mm (TOP)	Day	B1.8	0	7.70	n/a	n/a	n/a
		D7.5			n/a	n/a	n/a
		D1.6			n/a	n/a	n/a
		D4.1			n/a	n/a	n/a
110 mm (MID)	Day	B1.8	0	16.6	14.8	40.1	66.6
		D7.5			19.1	51.4	83.3
		D1.6			21.2	75.0	143.5

Release Scenario	Time	Weather	Height of Interest (m)	Mass Flow Rate (kg/s)	Distance to UFL at Height of Interest (m)	Distance to LFL at Height of Interest (m)	Distance to ½ LFL at Height of Interest (m)
		D4.1			21.1	64.1	108.8
110 mm (TOP)	Day	B1.8	0	16.6	n/a	n/a	n/a
		D7.5			n/a	n/a	n/a
		D1.6			n/a	n/a	n/a
		D4.1			n/a	n/a	n/a
FBR (MID) – 100 mm	Day	B1.8	0	13.7	13.5	36.7	61.0
		D7.5			17.3	46.5	75.4
		D1.6			19.4	68.4	129.9
		D4.1			19.2	58.4	99.2
FBR (TOP) – 100 mm	Day	B1.8	0	13.7	n/a	n/a	n/a
		D7.5			n/a	n/a	n/a
		D1.6			n/a	n/a	n/a
		D4.1			n/a	n/a	n/a
FBR (MID) – 150 mm	Day	B1.8	0	30.8	19.8	53.6	89.1
		D7.5			26.3	70.9	115.7
		D1.6			28.5	102.3	198.0
		D4.1			28.4	87.1	150.1
FBR (TOP) – 150 mm	Day	B1.8	0	30.8	n/a	n/a	n/a
		D7.5			n/a	n/a	n/a
		D1.6			n/a	n/a	n/a
		D4.1			n/a	n/a	n/a
FBR (MID) – 350 mm	Day	B1.8	0	167.7	45.9	122.7	205.3
		D7.5			63.3	169.9	277.7
		D1.6			41.2	58.0	69.6

Release Scenario	Time	Weather	Height of Interest (m)	Mass Flow Rate (kg/s)	Distance to UFL at Height of Interest (m)	Distance to LFL at Height of Interest (m)	Distance to ½ LFL at Height of Interest (m)
		D4.1			65.9	204.4	355.9
FBR (TOP) – 350 mm	Day	B1.8	0	167.7	n/a	n/a	n/a
		D7.5			n/a	n/a	n/a
		D1.6			n/a	n/a	n/a
		D4.1			n/a	n/a	n/a

* Limited to process flow rate

Appendix C Likelihood Analysis - Data and Results

C.1 Likelihood of Release from Underground Pipelines

The likelihood of a release (i.e. leak) from each underground pipeline was estimated based on a review of relevant data sources. The primary data sources included:

- Department of Industry, Resources and Energy, New South Wales, *2018-19 Licensed Pipelines Performance Report*. This includes data for all licensed pipelines in NSW for the 5-year period: 2014/15 to 2018/19; and
- UK Health and Safety Executive (HSE), 2015, *Update of Pipeline Failure Rates for Land Use Planning Assessments*, Research Report (RR) 1035.
- British Standards Institute, 2013, *Pipeline Systems – Part 3: Steel Pipelines on Land – Guide to the Application of Pipeline Risk Assessment to Proposed Developments in the Vicinity of Major Accident Hazard Pipelines Containing Flammables – Supplement to PD 8010-1:2004*, PD 8010-3:2009+A1:2013.

The leak frequency data reported in RR1035 was adopted for the QRA as it is slightly more conservative than the NSW performance data for licenced pipelines and it includes the leak frequency for four hole size categories (pinhole, small hole, large hole and rupture), four failure mode categories (mechanical failure, corrosion, ground movement / other and third party activity), and in some cases for varying pipe diameters and / or wall thicknesses.

Leak frequency data could not be derived for the Gore Bay Pipeline using the approach in the British Standards Institute PD 8010-3:2009+A1:2013 since some of required input data (e.g. pipe wall thickness) was not available for the risk analysis. Similarly, this approach could not be fully applied to the Natural Gas Secondary Mains since it cannot be used for pipelines with a diameter less than c. 200 mm and the rupture and leak frequencies due to 'TPA' cannot be estimated for pipelines with a design factor less than 0.3.

The leak frequency data reported in RR1035 has been based on:

- An analysis of pipeline failure data from multiple organisations, including:
  - CONCAWE (CONservation of Clean Air and Water in Europe);
  - UKOPA (United Kingdom Onshore Pipeline Operators' Association); and
  - EGIG (European Gas pipeline Incident Group).
- A conservative, yet realistic, analysis of the available data. For example:
  - For failure mode categories where zero failures have occurred, assumptions have been made to estimate the chance of a failure, even if not seen historically (over the observation period).
  - Only the most recent 22 years of historical incident data was analysed to ensure a consistent pipeline population and to remove the older incident data, which may not be as representative of current practice.
  - Incident data for pipelines carrying products at elevated temperatures was excluded from the analysis.

- Although the location of failures (e.g. rural or urban) may be recorded in the various databases, it is recognised that there is insufficient data to estimate the leak frequency for different locations.
- The recommended failure rates for specific materials have been derived from the most appropriate dataset (e.g. for a specific substance the failure rates for corrosion may derived from the CONCAWE products dataset, whilst the mechanical failure rates may be derived from the UKOPA dataset).

C.1.1 Gasoline Pipelines

NSW Performance Report

The average leak frequency from the 2019 NSW Performance Report for all licensed pipelines in NSW for the 5-year period 2014/15 to 2018/19 is 8.2E-05 per km per year.

The NSW Performance Report includes pipelines regulated under the Pipelines Act 1967 and the Pipelines Regulation 2013. The Gore Bay Pipeline is not regulated under this Act and Regulation and therefore its data is not included in the NSW Performance Report.

Other similar liquid fuel pipelines are included in NSW Performance Report and AS 2885 is the primary standard applied to these pipelines and the Gore Bay Pipeline. Therefore, a similar level of performance might be applicable for the Gore Bay Pipeline.

UK HSE (RR1035)

The total leak frequency data reported in Section 7.5 of RR1035 for underground gasoline pipelines is marginally higher than the average leak frequency from the 2019 NSW Performance Report.

The UK HSE (RR1035) data (Refer to Table 33) was adopted in the risk analysis for the Gore Bay Pipeline in the Melrose Park Precinct.

Table 33: Leak Frequencies for Underground Gasoline Pipelines

Failure Mode	Pipeline Diameter (mm)	Wall Thickness (mm)	Leak Frequency (per km per yr)				
			Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
Mechanical Failure	All	All	8.2E-06	1.0E-05	1.0E-05	4.1E-06	3.2E-05
Corrosion	All	All	1.2E-05	1.2E-05	1.2E-05	2.1E-06	3.8E-05
Ground Movement / Other	All	All	1.2E-05	2.5E-06	1.5E-07	2.5E-06	1.7E-05
TPA	All	All	2.2E-05	2.4E-06	1.0E-07	1.0E-07	2.5E-05
		Total Leak Frequency =	5.4E-05	2.7E-05	2.2E-05	8.8E-06	**1.1E-04**
		% =	48.3	24.0	19.8	7.8	

C.1.2 Secondary Natural Gas Mains

NSW Performance Report

The average leak frequency from the 2019 NSW Performance Report for all licensed pipelines in NSW for the 5-year period 2014/15 to 2018/19 is 8.2E-05 per km per year. The NSW Performance

Report includes pipelines regulated under the Pipelines Act 1967 and the Pipelines Regulation 2013. This includes some high-pressure Natural Gas pipelines.

Jemena's Secondary Natural Gas Mains are not licensed high-pressure pipelines in NSW and typically operate at lower pressures than the Natural Gas pipelines included in the NSW Performance Report.

UK HSE (RR1035)

The leak frequencies reported by the UK HSE in RR1035 are based on an analysis of the UKOPA incident data. The UKOPA data applies for natural gas pipelines operating at above 800 kPa (absolute) and is therefore applicable for Jemena's higher pressure Secondary Natural Gas Mains in the Melrose Park Precinct (i.e. secondary mains operating at up to 1050 kPag).

The total leak frequency data reported in Section 7.1 of RR1035 for 100 to 350 mm diameter pipelines with wall thickness < 5 mm (Refer to Table 34) is approximately 4 to 10 times greater than the average leak frequency from the 2019 NSW Performance Report. This difference appears to be reasonable as the NSW Performance Report data only applies to licensed high-pressure pipelines and Jemena's Secondary Natural Gas Mains are not licensed pipelines in NSW.

The UK HSE (RR1035) data (Refer to Table 34) was adopted in the risk analysis for the higher pressure Secondary Natural Gas Mains in the study area (i.e. secondary mains operating at up to 1050 kPag).

Table 34: Leak Frequencies for Underground Natural Gas Pipelines

Failure Mode	Pipeline Diameter (mm)	Wall Thickness (mm)	Leak Frequency (per km per yr)				
			Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
Mechanical Failure	< 115	All	4.5E-04	1.0E-08	1.0E-08	1.0E-08	4.5E-04
	127 to < 273		1.5E-04	1.0E-08	1.0E-08	1.0E-08	1.5E-04
	≥ 305		8.7E-06	1.0E-08	1.0E-08	1.0E-08	8.7E-06
Corrosion	All	< 5	3.1E-04	1.0E-08	1.0E-08	1.0E-08	3.1E-04
		5 to < 10	3.3E-05	1.0E-08	1.0E-08	1.0E-08	3.3E-05
		≥ 10	1.0E-07	1.0E-08	1.0E-08	1.0E-08	1.3E-07
Ground Movement / Other	All	All	1.2E-05	2.5E-06	1.5E-07	2.5E-06	1.7E-05
TPA	All	All	2.2E-05	2.4E-06	1.0E-07	1.0E-07	2.5E-05
Total Freq. =	100	< 5	7.9E-04	4.9E-06	2.7E-07	2.6E-06	**8.0E-04**
% =			99.0	0.6	0.0	0.3	
Total Freq. =	150	< 5	4.9E-04	4.9E-06	2.7E-07	2.6E-06	**5.0E-04**
% =			98.4	1.0	0.1	0.5	
Total Freq. =	350	< 5	3.5E-04	4.9E-06	2.7E-07	2.6E-06	**3.6E-04**
% =			97.8	1.4	0.1	0.7	

Table 35: Leak Frequencies for Secondary Natural Gas Main (350 mm Diameter)

Failure Mode	Approx. Leak Frequency (per km per yr)				
	Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
Mechanical Failure	4.2E-04	1.9E-05	0.0E+00	0.0E+00	4.4E-04
Corrosion	3.0E-04	7.6E-05	0.0E+00	0.0E+00	3.8E-04
Ground Movement / Other	8.0E-07	8.0E-07	8.0E-07	3.1E-07	2.7E-06
TPA	No Data	No Data	No Data	No Data	No Data
Total Leak Freq. =	≥ 7.2E-04	≥ 9.6E-05	≥ 8.0E-07	≥ 3.1E-07	≥ **8.20E-04**
% =	88.2	11.7	0.10	0.04	

C.2 Ignition Probability

The ignition probabilities adopted in the risk analysis are listed below. This was based on a review of relevant ignition probability data and ignition probability correlations (Refer to Sections C.2.1 - C.2.3).

Gasoline

1. The total ignition probability was based on OGP Scenario 1, which is release rate dependent (Refer to Section C.2.1).

   The US DoT data (Refer to Section C.2.2) is exclusively for underground cross-country pipelines carrying flammable or combustible liquids. Some data is also reported by UKOPA; (Refer to Section C.2.1); however, this includes liquids and gases.

   OGP Scenario 1 was adopted for the risk analysis since the maximum total ignition probability (0.07) is more conservative than the UKOPA data (total ignition = 0.047) and the US DoT data for gasoline (viz. total ignition prob. = 0.03 (all releases)).

2. The total ignition probability was split 50:50 for immediate ignition: delayed ignition.

   The OGP data assumes an immediate ignition probability of 0.001. A 50:50 split was assumed for the risk analysis.

Natural Gas

1. The total ignition probability was based on OGP Scenario 3, which is release rate dependent (Refer to Section C.2.1).

   The correlation proposed by Acton & Baldwin (Refer to Section C.2.3) is more conservative for smaller leaks; however, the OGP data is more conservative for ruptures and is more consistent with the EGIG and UK HSE data (Refer to Section C.2.3) for the calculated full bore rupture release rates.

2. The total ignition probability was split 50:50 for immediate ignition: delayed ignition.

   The OGP data assumes an immediate ignition probability of 0.001. A 50:50 split appears to be more consistent with other data sources (e.g. Acton & Baldwin, UK HSE – Refer to Section C.2.3).

Ignition data is usually reported by hole size rather than failure mode and inconsistent reporting of immediate ignition due to TPA (which is sometimes reported to be the highest immediate ignition probability and sometimes not) means it was not possible to estimate the immediate ignition probability based on failure mode.

C.2.1 Ignition Probability Data for Above Ground or Underground Cross-Country Pipelines – Various Materials

United Kingdom Onshore Pipeline Operators' Association (UKOPA), Major Accident Hazard Pipelines (1962-2014)

The definition of a Major Accident Hazard Pipeline (MAHP) from the Pipelines Safety Regulations 1996 (PSR 96) includes various materials (e.g. including natural gas at >8 bar, flammable liquids, etc.). The pipeline may be above or below ground.

There were 9 out of 192 (4.7%) product loss incidents that resulted in ignition.

Table 36: Ignition Probability - UKOPA

Hole Size Class #	Total Number of Incidents	Number of Incidents with Ignition	Total Ignition Probability	Total Ignition Probability
Full Bore and Above	7	1	0.14	0.09
110mm – Full Bore	4	0	0.0	
40mm – 110mm	7	1	0.14	0.03
20mm – 40mm	23	0	0.0	
6mm – 20mm	31	3	0.10	0.05
0 – 6mm	118	4	0.03	
Unknown	2	0	0.0	0.0
Total =	192	9	0.047	0.047

OGP, Ignition Probabilities for Pipe-Liquid-Industrial (Scenario 1: Liquid Releases from onshore pipeline in industrial area)

The following data applies for releases of flammable liquids that do not have any significant flash fraction (10% or less) if released from onshore cross-country pipelines running through industrial or urban areas.

The OGP Data applies for cross-country pipelines. Although not explicitly stated, it is assumed the pipeline may be above ground or underground.

These curves represent “total” ignition probability. The method assumes that the immediate ignition probability is 0.001 and is independent of the release rate.

Table 37: Ignition Probability – OGP Scenario 1

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

OGP, Ignition Probabilities for Pipe-Gas-LPG-Industrial (Scenario 3: Gas or LPG release from onshore pipeline in an industrial or urban area)

The following data applies for releases of flammable gases, vapours or liquids significantly above their normal (Normal Atmospheric Pressure (NAP)) boiling point from onshore cross-country pipelines running through industrial or urban areas.

The OGP Data applies for cross-country pipelines. Although not explicitly stated, it is assumed the pipeline may be above ground or underground.

These curves represent "total" ignition probability. The method assumes that the immediate ignition probability is 0.001 and is independent of the release rate.

Table 38: Ignition Probability – OGP Scenario 3

Release Rate (kg/s)	Total Ignition Probability
0.1	0.0010
0.2	0.0017
0.5	0.0033
1	0.0056
2	0.0095
5	0.0188
10	0.0316
20	0.0532
50	0.1057
100	0.1778
200	0.2991
500	0.5946
1000	1.0000

C.2.2 Ignition Probability Data for Underground Cross-Country Pipelines – Flammable or Combustible Liquids

US Department of Transportation (DoT), Pipeline and Hazardous Materials Safety Administration (PHMSA), Accident Reports - Hazardous Liquid Pipeline Systems (January 2010 to September 2017)

Reporting of data is required by 49 CFR Part 195. An accident report is required for each failure in a pipeline system subject to this part in which there is a release of the hazardous liquid or carbon dioxide transported resulting in any of the following:

(a) Explosion or fire not intentionally set by the operator.

(b) Release of 5 gallons (19 litres) or more of hazardous liquid or carbon dioxide, except that no report is required for a release of less than 5 barrels (0.8 cubic meters) resulting from a pipeline maintenance activity if the release is:

(1) Not otherwise reportable under this section;

(2) Not one described in §195.52(a)(4);

(3) Confined to company property or pipeline right-of-way; and

(4) Cleaned up promptly;

(c) Death of any person;

(d) Personal injury necessitating hospitalisation;

(e) Estimated property damage, including cost of clean-up and recovery, value of lost product, and damage to the property of the operator or others, or both, exceeding $50,000.

Table 39: Ignition Probability – US DoT

Liquid	Leak			Mechanical Puncture			Other			Rupture			Total		
	# with Ignition	# with no ignition	Prob. of Ignition	# with Ignition	# with no ignition	Prob. of Ignition	# with Ignition	# with no ignition	Prob. of Ignition	# with Ignition	# with no ignition	Prob. of Ignition	# with Ignition	# with no ignition	Prob. of Ignition
Diesel, Fuel Oil, Kerosene or Jet Fuel	0	101	0.0	0	13	0.0	1	10	0.1	0	7	0	1	131	0.01
Gasoline (Non-Ethanol)	0	96	0.0	1	8	0.1	2	5	0.4	0	6	0	3	115	0.03

C.2.3 Ignition Probability Data for Underground Cross-Country Pipelines – Natural Gas

Acton M R and Baldwin P J - Ignition Probability for High Pressure Gas Transmission Pipelines (7th International Pipeline Conference, IPC2008-64173, Sept 29 – Oct 3, 2008)

Note: Cited in IGEM/TD/2, Assessing the Risks from High Pressure Natural Gas Pipelines and HSE CRR 1034.

An analysis of historical data for rupture incidents shows the ignition probability increases linearly with pd^2. The correlation derived for rupture releases takes the form:

$P_{ign} = 0.0555 + 0.0137\ pd^2;\ 0 \le pd^2 \le 57$

$P_{ign} = 0.81;\ pd^2 > 57$

P_{ign} = probability of ignition

p = pipeline operating pressure (bar)

d = pipeline diameter for ruptures (m)

The probability of ignition P_{ign}, calculated as detailed above, is then generally apportioned as 0.5 for immediate ignition and 0.5 for delayed ignition, where delayed ignition occurs after 30 seconds.

This correlation is for ignition by all causes and is applicable to underground cross-country pipelines carrying high pressure natural gas. It does not take the location of the pipeline (e.g. rural or urban) or the cause of failure (e.g. external) into consideration. The following data was combined to derive the correlation:

- Transmission pipeline incident data recorded between 1970 and 2004; and
- US Office of Pipeline Safety Office (OPS) data between 2002 and 2007.

The authors state that the total ignition probability for releases caused by external interference, such as excavating machinery, is much lower than releases caused by other means (viz. 0.11 vs. 0.34 for pipeline ruptures from 1970 to 2004).

For puncture releases (all causes), the same ignition probability relationship may be applied, with d equal to the release hole diameter and with the pd^2 value halved, reflecting the difference between the two sources following a rupture and the single source contributing to a puncture release.

Table 40: Ignition Probability – Acton & Baldwin

Pipeline Diameter (mm)	Operating Pressure (bar)	Equivalent Hole Diameter (mm)	pd^2	Probability of Immediate Ignition	Probability of Delayed Ignition	Total Ignition Probability
350	10.5	FBR	1.29	0.037	0.037	0.073
		110	0.13	0.028	0.028	0.056
		75	0.06	0.028	0.028	0.056
		25	0.01	0.028	0.028	0.056
		10	0.00	0.028	0.028	0.056
150	10.5	FBR	0.24	0.029	0.029	0.059
		110	2.48	0.028	0.028	0.056
		75	1.69	0.028	0.028	0.056
		25	0.01	0.028	0.028	0.056
		10	0.00	0.028	0.028	0.056
100	10.5	FBR	0.11	0.028	0.028	0.057
		75	0.75	0.028	0.028	0.056
		25	0.25	0.028	0.028	0.056
		10	0.10	0.028	0.028	0.056

EGIG (9th Report, 2015), Natural Gas Transmission Pipelines (1971-2013)

Although the pipeline definition does not preclude above ground pipelines, the data is predominantly for underground natural gas transmission pipelines with a maximum operating pressure > 15 bar.

In the period 1970 - 2013, only 5% of the gas releases recorded as incidents in the EGIG database ignited.

Table 41: Ignition Probability – EGIG

Hole Size Class		Total Ignition Probability
Rupture (FB and Above)	All diameters	0.139
	<= 16 inches	0.103
	> 16 inches	0.32
Hole (>20 mm to FB)		0.023
Pinhole / Crack (Up to 20 mm)		0.044

UK HSE (RR 1034) - Typical Event Tree Probabilities for Natural Gas

The following data is proposed in RR 1034 for the UK HSE's computer program MISHAP. This program is used by the UK HSE to calculate the level of risk around Major Accident Hazard Pipelines (MAHPs), particularly in land use planning (LUP) assessments.

A MAHP may be above or below ground; however, the MISHAP model appears to be primarily for underground pipelines. The probabilities are not reported for varying hole sizes or operating pressures (i.e. are not release rate dependent) and appear to be only applicable for larger release events (i.e. ruptures).

For example, the literature cited in RR 1034 indicates an overall ignition probability between 0.2 and 0.5 for larger releases of natural gas, depending on the degree of confinement. On this basis, the total ignition probability proposed in CR 1034 for natural gas is 0.44.

It is reported in RR 1034 that the risk associated with VCE events is negligible because the development of MISHAP (and its predecessors) was based on areas with low congestion and confinement (e.g. rural pipelines), which are not conducive for creating the large flammable clouds required for a VCE. It is acknowledged in RR 1034 that this may require further review.

The proposed conditional probability value for delayed remote ignition is zero. It is reported in RR 1034 that this is "to take into account the reasoning that natural gas is unlikely to form a significant vapour cloud due to its buoyant nature".

Table 42: Ignition Probability – UK HSE (RR 1034)

Outcome	Probability of Outcome
Immediate ignition, fireball and jet fire	0.250
Delayed ignition and jet fire	0.188
Delayed ignition, flash fire and jet fire	0.000
No ignition	0.563

Note: Some of the sources cited in RR 1034 with an overall ignition probability between 0.2 and 0.5 are relatively old (c. mid 1980s - See below). This data would also appear to confirm that the total ignition probability proposed for natural gas in MISHAP is for a worst-case rupture event on a larger transmission pipeline.

Table 43: Ignition Probability – Data Cited by UK HSE (RR 1034)

<table>
<tr><th>Data source</th><th colspan="2">Ignition probability</th></tr>
<tr><td rowspan="2">World-wide, Townsend & Fearnehough (1986)</td><td>Leaks</td><td>0.1</td></tr>
<tr><td>Ruptures</td><td>0.5</td></tr>
<tr><td rowspan="2">US Gas, Jones (1986)</td><td>Ruptures</td><td>0.26</td></tr>
<tr><td>All sizes</td><td>0.16</td></tr>
<tr><td rowspan="5">European Gas, European Gas Pipeline Incident Data Group (1988)</td><td>Pinholes / cracks</td><td>0.02</td></tr>
<tr><td>Holes</td><td>0.03</td></tr>
<tr><td>Ruptures < 16”</td><td>0.05</td></tr>
<tr><td>Ruptures ≥ 16”</td><td>0.35</td></tr>
<tr><td>All sizes</td><td>0.03</td></tr>
</table>

C.3 Likelihood of Representative Release Scenarios

The estimated likelihood of each representative release scenario is listed in Table 44, Table 45, Table 46 and Table 47.

Table 44: Release Frequency – Gore Bay Pipeline

Leak Scenario	Release Frequency (per km per year)		
	TPA	All Other Failure Modes	Total Release Frequency
10mm MID	-	3.22E-05	3.22E-05
25mm MID	8.14E-06	-	8.14E-06
25mm TOP	1.39E-05	-	1.39E-05
75mm MID	8.88E-07	9.07E-06	9.95E-06
75mm TOP	1.51E-06	1.54E-05	1.69E-05
110mm MID	3.70E-08	8.20E-06	8.23E-06
110mm TOP	6.30E-08	1.40E-05	1.40E-05
FBR MID	3.70E-08	3.22E-06	3.26E-06
FBR TOP	6.30E-08	5.48E-06	5.54E-06
Total	2.46E-05	8.76E-05	**1.12E-04**

Table 45: Release Frequency – Jemena Secondary Natural Gas Main (350 mm Diameter)

Leak Scenario	Release Frequency (per km per year)		
	TPA	All Other Failure Modes	Total Release Frequency
10mm MID	-	3.31E-04	3.31E-04
25mm MID	8.14E-06	-	8.14E-06
25mm TOP	1.39E-05	-	1.39E-05
75mm MID	8.88E-07	9.32E-07	1.82E-06
75mm TOP	1.51E-06	1.59E-06	3.10E-06
110mm MID	3.70E-08	6.29E-08	9.99E-08
110mm TOP	6.30E-08	1.07E-07	1.70E-07
FBR MID	3.70E-08	9.32E-07	9.69E-07
FBR TOP	6.30E-08	1.59E-06	1.65E-06
Total	2.46E-05	3.36E-04	**3.60E-04**

Table 46: Release Frequency – Jemena Secondary Natural Gas Main (150 mm Diameter)

Leak Scenario	Release Frequency (per km per year)		
	TPA	All Other Failure Modes	Total Release Frequency
10mm MID	-	4.72E-04	4.72E-04
25mm MID	8.14E-06	-	8.14E-06
25mm TOP	1.39E-05	-	1.39E-05
75mm MID	8.88E-07	9.32E-07	1.82E-06
75mm TOP	1.51E-06	1.59E-06	3.10E-06
110mm MID	3.70E-08	6.29E-08	9.99E-08
110mm TOP	6.30E-08	1.07E-07	1.70E-07
FBR MID	3.70E-08	9.32E-07	9.69E-07
FBR TOP	6.30E-08	1.59E-06	1.65E-06
Total	2.46E-05	4.77E-04	**5.02E-04**

Table 47: Release Frequency – Jemena Secondary Natural Gas Main (100 mm Diameter)

Leak Scenario	Release Frequency (per km per year)		
	TPA	All Other Failure Modes	Total Release Frequency
10mm MID	-	7.72E-04	7.72E-04
25mm MID	8.14E-06	-	8.14E-06
25mm TOP	1.39E-05	-	1.39E-05
75mm MID	8.88E-07	9.32E-07	1.82E-06
75mm TOP	1.51E-06	1.59E-06	3.10E-06
FBR MID	7.40E-08	9.95E-07	1.07E-06
FBR TOP	1.26E-07	1.69E-06	1.82E-06
Total	2.46E-05	7.77E-04	**8.02E-04**