Preliminary Hazard Analysis of Gas Pipelines Risk to Austral Public School Upgrade

For School Infrastructure NSW

19 December 2024

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Summary

School Infrastructure NSW (SINSW) has proposed a major upgrade of the existing Austral Public School (APS) at Austral, NSW. The existing school is located at 205 Edmondson Avenue, Austral NSW 2179.

SINSW have engaged Arriscar Pty Limited (Arriscar) to undertake a Preliminary Hazard Analysis (PHA) to determine the level of risk presented to the proposed Austral Public School upgrade (the Activity) from two nearby high-pressure gas transmission pipelines:

1. Jemena Gas Central Trunk Main (CTM).
2. Jemena Eastern Gas Pipeline (EGP).

The study focused on potential gas releases from the pipelines on the Activity.

Conclusions

The PHA made the following conclusions:

- The combined risk from both gas pipelines did not exceed any locational specific risk in relation to fatality, injury, or property damage at the school boundary.
- The gas pipelines do not contribute to societal risk at the school.
- Thermal radiation exceeding 4.7 kW/m^2 from a full bore rupture of the CTM can reach the school eastern boundary. The school emergency plan should include evacuation to a safe location towards the west of the school site, in the event of a gas release from the pipeline and fire.
- There is no thermal radiation impact on the Activity from a failure of the EGP and fire.
- The Activity can safely accommodate the proposed student and staff population.

Recommendations

There are no recommendations for risk mitigation for the Activity in relation to the pipelines.

The following recommendation is made in relation to APS:

1. The school emergency plan must include pipeline rupture as a scenario and develop an appropriate emergency assembly area on the western side of the school (inside or outside), to prevent the potential for injuries from people exposed to radiated heat flux in the open.

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Notation

Abbreviation	Description
ALARP	As Low As Reasonably Practicable
ALBV	Automatic Line Break Valve
APD	Australian Pipeline Database
APGA	Australian Pipelines and Gas Association
API	American Petroleum Institute
APS	Austral Public School
Arriscar	Arriscar Pty Limited
AS	Australian Standard
BoM	Bureau of Meteorology
BS	British Standard
BYDA	Before You Dig Australia
CDL	Critical Defect Length
CH_4	Methane
COLA	Covered Outdoor Learning Area
CONCAWE	European Oil Company Organisation for Environment, Health an d Safety *(Belgium)*
CTM	Central Trunk Main
DHB	Demountables
DN	Diameter Nominal
DoE	Department of Education
DoT	Department of Transportation (USA)
DP	Deposited Plan
DPHI	NSW Department of Planning, Housing and Infrastructure
EGP	Eastern Gas Pipeline
EP&A Act	Environmental Planning and Assessment Act 1979
FBR	Full-bore Rupture
F-N	Frequency vs. Number of fatalities exceeded
ha	hectares
HAZID	Hazard Identification
HDD	Horizontal Directional Drilling
HIPAP	Hazardous Industry Planning Advisory Paper
HP	High Pressure
HSE	(UK) Health and Safety Executive
ID	Identification
km	Kilometre
kp	Kilometre point

Abbreviation	Description
kPa	Kilopascal
kW/m^2	Kilowatts per square metre
LFL	Lower Flammable Limit
LSIR	Location Specific Individual Risk
m	Metre
m/s	Metres per second
MAOP	Maximum Allowable Operating Pressure
mg/m^3	Milligrams per cubic metre
MI	Major Accident Event
MLV	Main Line Valve
mm	millimetre
MPag	Mega-Pascals gauge
N.R.	Not Reachable
NA	Not Available
NAP	Normal Atmospheric Pressure
NCC	National Construction Code
OGP	International Oil & Gas Producers' Association
OSHA	Occupational Safety and Health Administration (USA)
OSHC	Outside School Hours Care
PHA	Preliminary Hazard Analysis
P_{ign}	Probability of Ignition
QRA	Quantitative Risk Assessment
REF	Review of Environmental Factors
RR	Research Report
SEARs	Secretary's Environmental Assessment Requirements
SEPP	State Environmental Planning Policy
SINSW	School Infrastructure New South Wales
SMS	Safety Management Study
T&I SEPP	Transport and Infrastructure State Environmental Planning Policy
TNT	Tri-nitro Toluene
TPA	Third Party Activity
UFL	Upper Flammability Limit
UKOPA	UK Onshore Pipelines Association
v/v	Volume fraction
VCE	Vapour Cloud Explosion
µm	Micro-metre

1 INTRODUCTION

1.1 Background

School Infrastructure NSW (SINSW) is planning to undertake upgrade to existing Austral Public School (APS) at Austral, NSW. The subject site is located in the Local Government Area of the City of Liverpool, at 205 Edmondson Avenue, Austral, NSW 2179.

There are two high pressure gas pipelines operated by Jemena Australia in the vicinity of the school site, and may pose a risk to the school.

This Preliminary Hazard Analysis (PHA) of gas pipelines has been prepared to support a Review of Environmental Factors (REF) for the Department of Education (DoE) for the Austral Public School upgrade (the Activity). The purpose of the REF is to assess the potential environmental impacts of the Activity prescribed by *State Environmental Planning Policy (Transport and Infrastructure) 2021* (T&I SEPP) as "development permitted without consent" on land carried out by or on behalf of a public authority under Part 5 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The activity is to be undertaken pursuant to Chapter 3, Part 3.4, Section 3.37 of the T&I SEPP.

The proposed Activity is for upgrade to the existing APS at 205 Edmondson Avenue, Austral, NSW, 2179 (the site).

The purpose of this report is to conduct a hazard analysis of the gas pipelines and assess the risk posed from potential gas release on the school infrastructure. SINSW have engaged Arriscar Pty Limited (Arriscar) to undertake this PHA.

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 Scope of the Study

The scope of this study included undertaking a PHA on the impact on the proposed upgrades from the following high pressure gas pipelines, in accordance with Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 [1].

1. Jemena Gas Central Trunk Pipeline (CTM).
2. Jemena Eastern Gas Pipeline (EGP).
3. The requirement of AS 2885-2008 [2], in the event of a change in land use in the vicinity of the pipelines.
4. An evaluation of the impact of potential gas releases from the pipelines on the Activity after a risk assessment in accordance with HIPAP No. 10 [3].

There are two pipelines in the one corridor; therefore, the potential for incident escalation between the two pipelines is also included in the assessment.

The study focuses only on the proposed upgrade and does not include existing buildings.

1.5 Objectives

The principal objective of the study was to perform a PHA covering the gas pipelines and in accordance with the NSW HIPAP guidelines [1]. This included:

- Identification of gas release hazards from the high-pressure gas pipelines in the vicinity of the Activity;
- Development of gas release scenarios that may impact on the proposed school structures;
- Quantification of the harmful effects of fires and explosions from gas releases.
- Assessment of structural impact on the school infrastructure.

1.6 Planning Circular 24-005

The pipelines in the vicinity of APS are 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 DESCRIPTION OF THE ACTIVITY AND SURROUNDING LAND USES

2.1 Site Location

APS is located at 205 Edmondson Avenue, Austral on the south-eastern corner of the intersection between Edmondson Avenue and Tenth Avenue. The site has an area of 2.986 ha and comprises of 6 allotments, legally described as:

- Lot 1 DP 398105
- Lot 1 DP 398106
- Lot 1 DP 509613
- Lot 1 DP 512119
- Lot 2 DP 509613
- Lot 865 DP2475

The site currently comprises an existing co-educational primary (K-6) public school with:

- 8 permanent buildings;
- 14 demountable structures;
- interconnected paths;
- covered walkways;
- play areas: and
- at-grade parking.

The Austral Community Pre-school is also located within the site.

The existing buildings are clustered in the northern part of the site, ranging between 1 to 2 storeys in height. There is a sports oval in the south-eastern portion of the site, and a densely vegetated informal play area located in the south-western portion of the site.

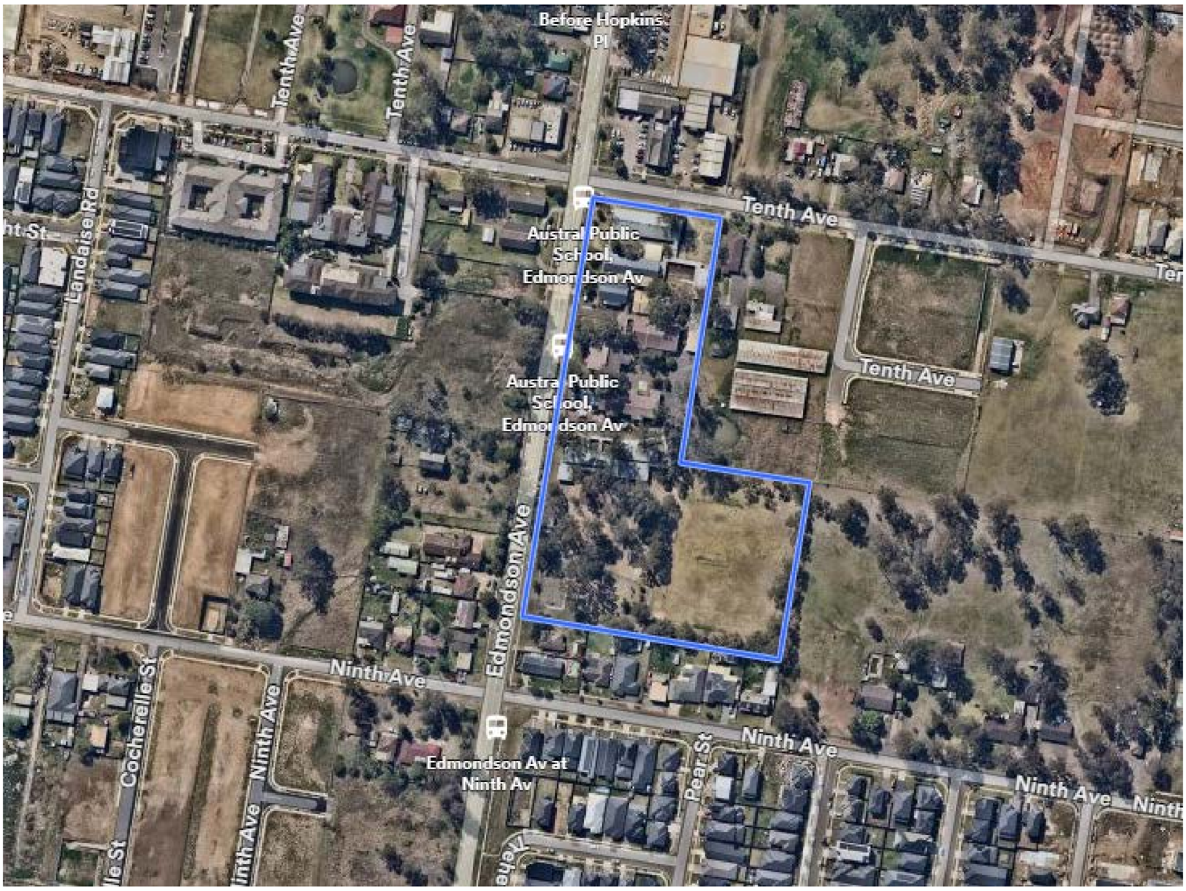
Following completion of the Activity, the school will accommodate up to 1072 students and 70 staff (teaching and support staff).

The site has two (2) street frontages:

- Main gate on Edmondson Avenue (western boundary)
- Access gate on Tenth Avenue (northern boundary)

A locality map is shown in Figure 1 Ref. [5].

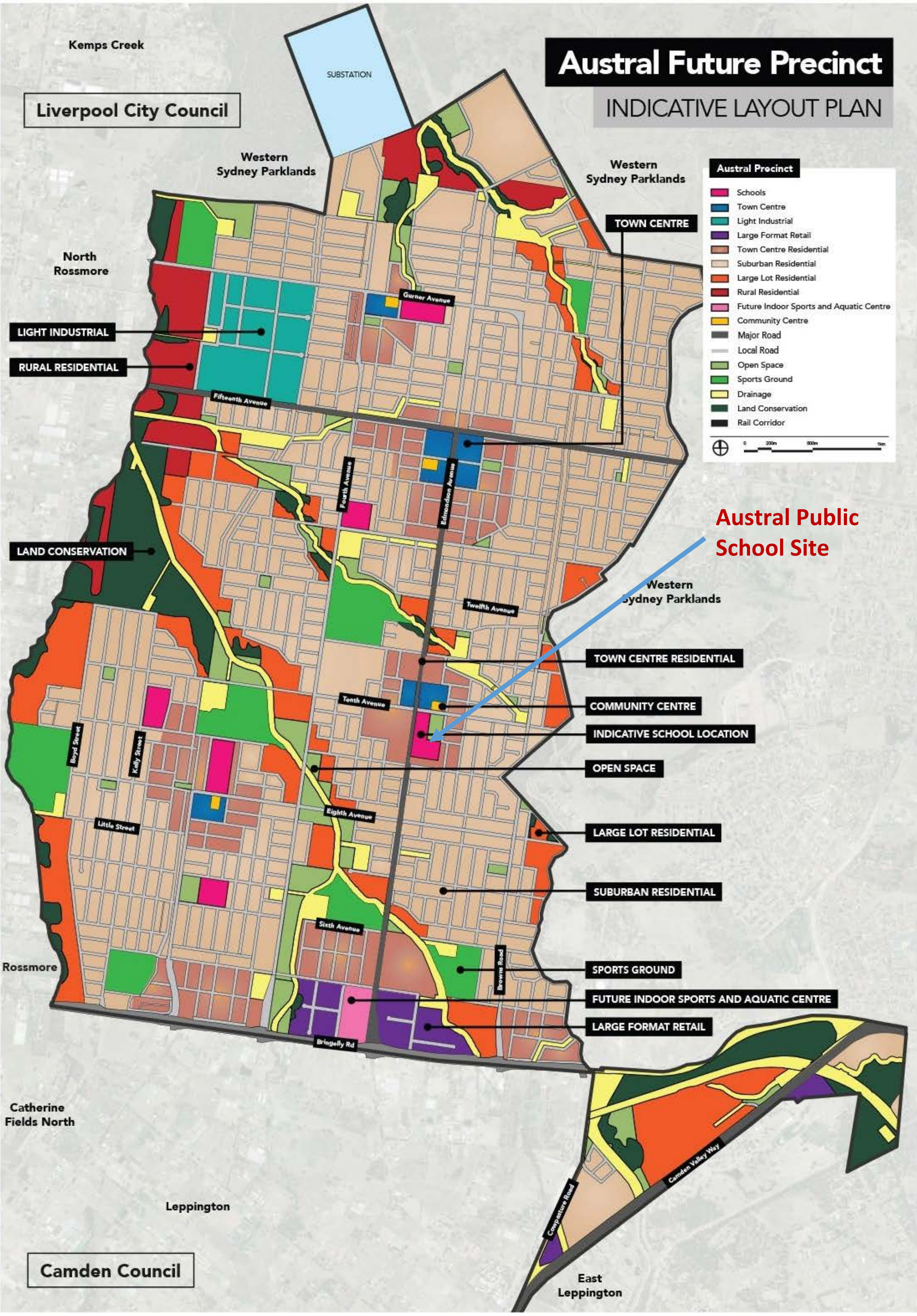
Figure 1: Locality Map of APS Site



According to the planned future Austral Precinct [6], all of the land surrounding the school will have residential developments (suburban residential and large lot residential).

The Austral future precinct plan, including the school site, is shown in Figure 2.

Figure 2: Austral Public School and Austral Future Precinct Map



2.2 Outline of APS upgrade

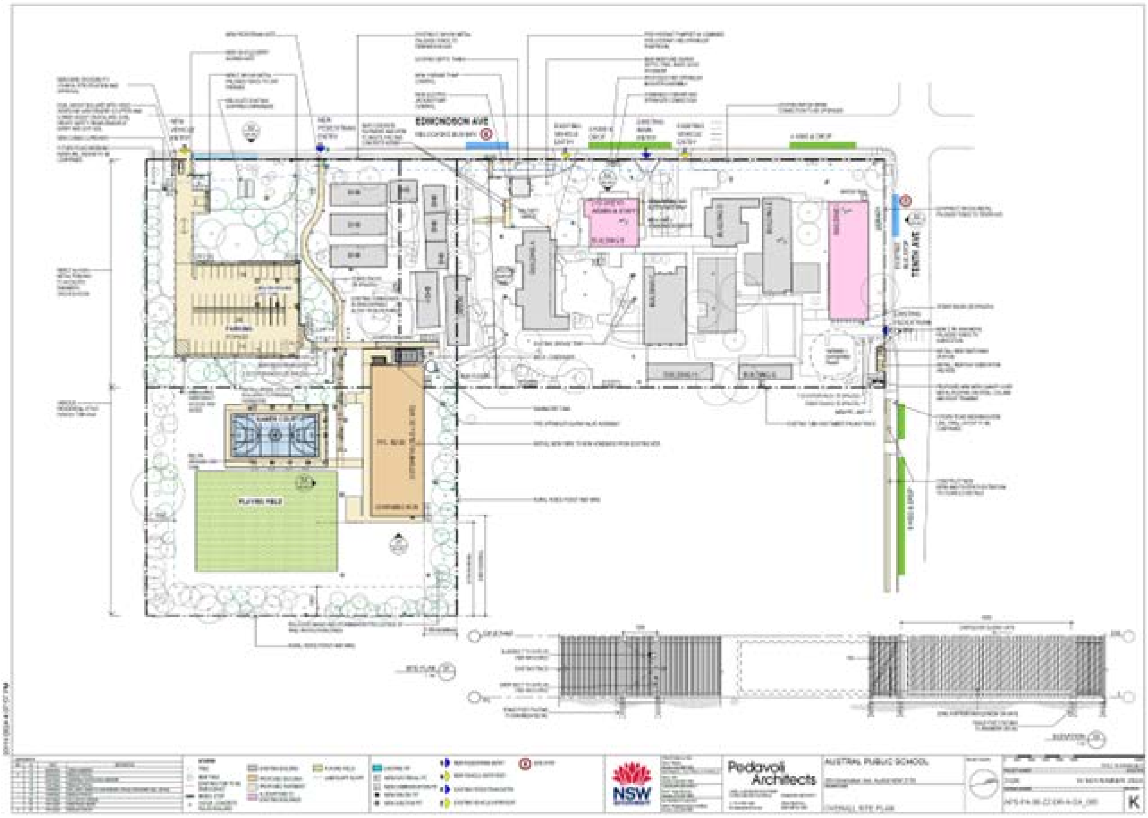
The proposed Activity involves alterations and additions to the existing APS, including the following:

- Demolition of existing structures and removal of trees, as well as other site preparation works;
- The erection of a new 3-storey building comprising teaching spaces that includes 20 permanent teaching spaces and 3 support teaching spaces;
- Conversion of the first floor of Building B from a Library to staff annex (staff room) and minor modifications on the ground floor;
- Refurbishment and change of school function of Building I from classrooms to a Library;
- At-grade parking (57 new spaces, including 1 accessible space);
- New driveway and access gate from Edmondson Road;
- Erection of a substation within the site on the northern boundary;
- Upgrade of the sports field;
- Internal pathways, fencing, utility upgrades and associated works; and
- Off-site public domain improvements including retention and upgrading of the Kiss & Drop area and a temporary pedestrian road crossing on Tenth Avenue.

The intent of the Activity is to allow for upgrades to APS that will provide a CORE 35 primary school compliant with the EFSG. The works will increase the capacity of the school from 681 students and 40 FTE teachers to 734 students and 64 FTE teachers, respectively. Furthermore, provision within the expanded 734 student capacity will be made for the creation of 30 support class students places.

A site plan showing the scope of works for the proposed Activity is shown in Figure 3.

Figure 3: Proposed Site Plan



2.3 Meteorology

Meteorology used for the analysis is based on Badgerys Creek atmospheric monitoring station (ID: 60801), and is presented in Table 1.

Table 1: Average Temperature, Relative Humidity and Solar Radiation

Weather Category	Stability Class	Wind Speed (m/s)	Average Temp (°C)	Average Solar Radiation (kW/m^2)	Average Relative Humidity
Day Time					
B1.9	B	1.9	20.9	6.1	0.60
D7.5	D	7.5	21.7	4.8	0.46
D4.0	D	4.0	20.1	3.6	0.62
D1.6	D	1.6	17.3	2.6	0.76
Night Time					
7.3D	D	7.3	14.4	0	0.61
3.5D	D	3.5	13.6	0	0.82
1.1D	D	1.1	13.1	0	0.91
2.6E	E	2.6	14.2	0	0.85
1.1F	F	1.1	12.4	0	0.92

The distribution of the weather categories in relation to wind direction is shown in Table 2 (Day) and Table 3 (Night) respectively.

Table 2: Directional Distribution of Weather Categories (Day Time)

Wind Direction	Weather Category				Total
	1.9B	7.5D	4.0D	1.6D	
N	0.0452	0.0070	0.0446	0.0141	0.1109
NNE	0.0410	0.0038	0.0352	0.0096	0.0896
NE	0.0265	0.0020	0.0217	0.0063	0.0566
ENE	0.0186	0.0061	0.0252	0.0055	0.0554
E	0.0447	0.0174	0.0559	0.0174	0.1353
ESE	0.0089	0.0068	0.0316	0.0041	0.0513
SE	0.0078	0.0056	0.0280	0.0050	0.0463
SSE	0.0069	0.0044	0.0221	0.0045	0.0377
S	0.0121	0.0101	0.0417	0.0079	0.0719
SSW	0.0089	0.0098	0.0295	0.0068	0.0550
SW	0.0138	0.0151	0.0465	0.0139	0.0893
WSW	0.0120	0.0197	0.0287	0.0085	0.0689
W	0.0107	0.0221	0.0162	0.0050	0.0539
WNW	0.0062	0.0133	0.0075	0.0027	0.0297
NW	0.0069	0.0072	0.0063	0.0028	0.0233
NNW	0.0103	0.0024	0.0076	0.0045	0.0248
Total	0.2804	0.1527	0.4483	0.1186	1

Table 3: Directional Distribution of Weather Categories (Night Time)

Wind Direction	Weather Category					Total
	7.3D	3.5D	1.1D	2.6E	1.1F	
N	0.0015	0.0219	0.0210	0.0011	0.0052	0.0507
NNE	0.0003	0.0085	0.0137	0.0007	0.0031	0.0262
NE	0.0000	0.0081	0.0162	0.0010	0.0036	0.0290
ENE	0.0000	0.0101	0.0157	0.0018	0.0042	0.0318
E	0.0001	0.0100	0.0568	0.0022	0.0147	0.0838
ESE	0.0000	0.0069	0.0184	0.0019	0.0064	0.0336
SE	0.0001	0.0091	0.0230	0.0017	0.0063	0.0403
SSE	0.0003	0.0109	0.0216	0.0012	0.0056	0.0396
S	0.0017	0.0301	0.0352	0.0021	0.0075	0.0765
SSW	0.0026	0.0338	0.0275	0.0022	0.0069	0.0730
SW	0.0075	0.1052	0.0676	0.0071	0.0211	0.2084
WSW	0.0067	0.0746	0.0668	0.0053	0.0206	0.1740
W	0.0049	0.0184	0.0246	0.0010	0.0059	0.0548
WNW	0.0018	0.0107	0.0113	0.0004	0.0027	0.0269
NW	0.0011	0.0121	0.0100	0.0005	0.0022	0.0260
NNW	0.0005	0.0119	0.0095	0.0005	0.0028	0.0253
Total	0.0292	0.3823	0.4389	0.0308	0.1188	1

2.4 Gas Pipelines

2.4.1 Introduction

Two existing pipelines (other than typical street utilities) were identified:

1. Jemena Central Trunk Pipeline (CTM).
2. Jemena Eastern Gas Pipeline (EGP).

Jemena provided relevant data for the pipeline.

2.4.2 Natural Gas Pipelines

Information for the HP natural gas pipelines is listed in Table 4 [7].

Table 4: Natural Gas Pipelines

	Jemena Central Trunk Main (CTM)	Jemena Eastern Gas Pipeline (EGP)
Pipeline Owner	Jemena	Jemena
Pipeline Name	Central trunk: Wilton to Horsley Park	Eastern Gas Pipeline
Material/Product Transferred	Natural Gas	Natural Gas
Licence No.	Licence 1	PL 26
MAOP	6.895 MPa	14.895MPa
Normal Operating Pressure	4.5 – 5 MPa	14.895 MPa

	Jemena Central Trunk Main (CTM)	Jemena Eastern Gas Pipeline (EGP)
Operating Temperature	15°C	15°C
Flowrate	NA	NA
Pipeline Material	API 5LX65	Carbon Steel API 5LX 70
Pipeline Diameter	DN850	DN450
Wall Thickness	At school location 13.3 mm	At school location 11.8 mm
Depth of Cover	1200 mm	900 mm
Cathodic Protection	Impressed current	Impressed current
External Coating	Coal Tar Enamel	Fusion Bonded Epoxy
Leak Detection	NA	NA
Locations of Nearest Isolation Valves	Catherine Fields ALBV (Raby Rd) kp 30.1, Cecil Park ALBV (off Seoul Ave), kp 36	Horsley Park kp795, Menangle Park MLV kp762
Leak Detection Time	NA	NA
Leak Isolation Time	NA	NA
Inspections	Weekly	Weekly, six weekly, annually
Control Measures for 3rd Party Interference	DOC, Wall thickness, Warning Signage, BYDA, patrols	BYDA, pipeline patrols
Pigging	Yes 2014, every 10 years	ILI every 10 years or as required

2.4.3 Separation Distances

The two pipelines are adjacent to each other in the same pipeline corridor, separated by 8.5m spacing.

2.4.4 Measurement Length

The “Measurement Length” is a technical term referred to in AS 2885.6-2018 [8]:

“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 nearest pipeline is the CTM, 672m to the eastern boundary of the school. The section of the pipeline within one Measurement Length of the Austral Public School is shown in Figure 4. The reported measurement length is 766m. The Austral school site is within the measurement length of the CTM.

The reported Measurement Length for the EGP is 558 m. The pipeline is located 680m from the school and therefore the school site is not within the measurement length of the EGP. The EGP has been included in the analysis to demonstrate nature of the cumulative risk.

Models in the software SAFETI 8.61 used by Arriscar to determine the flowrate from the pipeline and the radiated heat flux arising from an ignited release may not be the same as those used by pipeline operators. The differences between the models may result in minor discrepancies between the calculated radiated heat flux at downwind distance from the source of the release.

Figure 4: Proximity of High-Pressure Transmission Pipelines to Austral Public School

Source: NSW Department of Community Service and Australian Pipeline database

https://mapprod3.environment.nsw.gov.au/arcgis/services/Planning/EPI_Primary_Planning_Layers/MapServer/WmsServer

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3 RISK ASSESSMENT METHODOLOGY

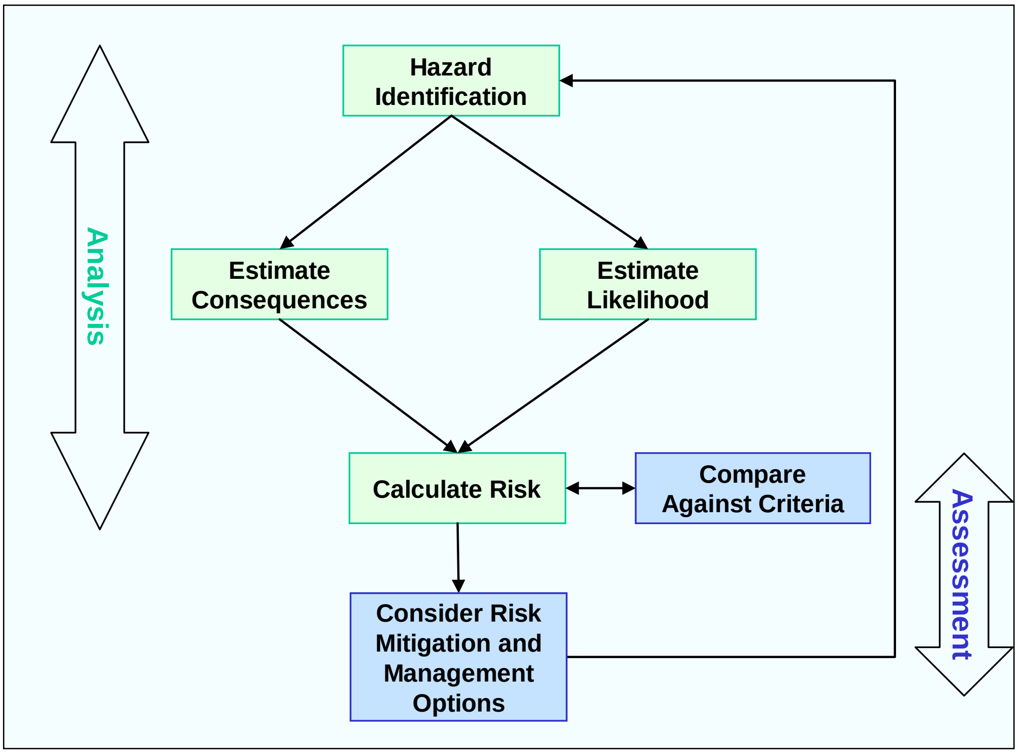
3.1 Introduction

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 DPIE's guidelines for undertaking this type of assessment [1].

Diagrammatically, the QRA process is as follows:

Figure 5: Overview of QRA Process [1]



3.2 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 MIs). In the context of the QRA, an MI 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 DPE has defined an acceptable risk criterion – Refer to Section 3.8).

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);
- 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 MIs for the 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.

3.3 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 when 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 0 (Assumption No. 3).

The SAFETI software package (v.8.61) was used for all consequence modelling and the generation of the risk contours.

3.4 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 Section A.6 (Appendix A).

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 5 [1].

Table 5: 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 6 [1]. The vulnerability criteria used in the risk analysis are included in Appendix A.6.

Table 6: 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.

3.5 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. 5.0×10^{-6} per year or 5E-06 per year) is normally used because the likelihood of a release event 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 6 and Appendix C.1.

3.6 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: 0.5x10-6 per year, 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 8.61 software package was used to generate the iso-risk contours / transects and societal risk results (Refer to Section 7).

3.7 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 0.

3.8 Quantitative Risk Criteria

3.8.1 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 DP&E [3] and [9].

Table 7: 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 DP&E has adopted a fatality risk criterion of 1×10^{-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 residential area, viz. 0.5×10^{-6} pe year.

3.8.2 Injury Risk

The DP&E 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 [9] for potential injury caused by exposure to heat radiation, explosion overpressure and toxic gas/ smoke/dust.

The DP&E'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 DP&E'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 DP&E'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.*

3.8.3 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 DPIE's criteria for risk of damage to property and accident propagation are as follows [9]:

- *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 Primary buildings should not exceed a risk of 50 in a million per year for the 14 kPa explosion overpressure level.*

3.8.4 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 gas 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).

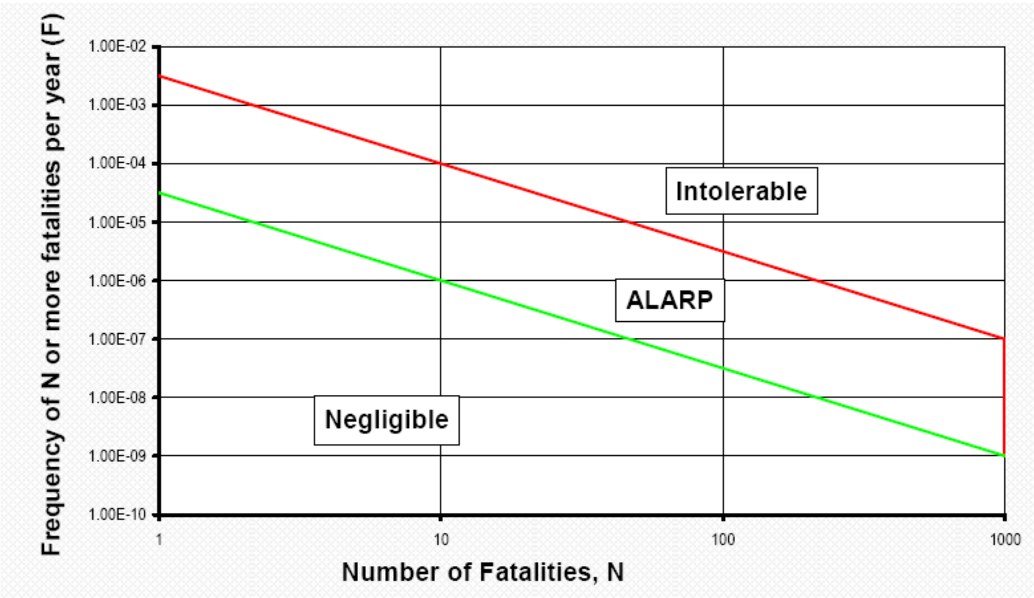
Two parameters are required to define societal risk: (a) Number of fatalities that may result from an incident; and (b) the frequency (likelihood) of occurrence of the incident.

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.

The DPE's suggested societal risk criteria (Refer to Figure 6), 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 [9] are met, the risks from the activity would be considered tolerable in the ALARP region.

Figure 6: 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.

HIPAP No.4 [9] also states that the criteria in Figure 6 are an indicative criteria and provisional only and do not represent a firm requirement in NSW.

3.9 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 [9] 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.

3.10 Approach to Achieving Study Objectives

To provide SINSW with sufficient risk-based land use safety information to understand the extent and magnitude of the potential risks from HP pipelines to the proposed school and develop suitable approaches to mitigate risks, the following approach has been taken:

1. Generate individual risk contours of sections of pipelines within 1 km of the proposed school to identify any restrictions on the land being considered for the proposed school based upon the individual risk criteria.
2. Review consequence distances of pipeline failure events to determine if the school would contribute to societal risk arising from the pipelines, if any.

4 HAZARD IDENTIFICATION

4.1 Introduction

The hazard identification was based on a review of the following:

- information on the Natural Gas pipelines (Refer to Section 2.4.2);
- properties of Natural Gas; and,
- potential failure modes and consequences if a leak were to occur from a pipeline.

These findings are presented as follows:

Section 4.2 - Properties of Natural Gas.

Section 4.3 - Pipeline Failure Modes.

Section 4.4 - Consequences.

Section 4.5 - Control Measures.

The representative Major Incidents (MIs) carried forward to the consequence analysis are listed in Section 4.6.

4.2 Properties of 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 8.

Table 8: 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 (LFL) in air (vol. %)	5.0%
Upper Flammability Limit (UFL) in air (vol. %)	15.0%

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.

4.3 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 [10]:

- **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 Section C.2.3 (Appendix C) for underground pipelines.

4.3.1 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 three HP pipelines; however, historical incident data for other pipelines (Refer to Appendix C.1) indicates this is generally a low likelihood failure mode, particularly for more recently manufactured pipelines (i.e. post 1980).

4.3.2 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 three HP pipelines; however, historical incident data for other pipelines (Refer to Appendix C.1) indicates this is a low likelihood failure mode, particularly for pipelines with a higher wall thickness (i.e. > 10 mm) and more recently manufactured pipelines (i.e. post 1980).

4.3.3 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 as a result of 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 both the HP pipelines; 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.

4.3.4 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 both the HP pipelines.

4.4 Consequences of Gas Release

4.4.1 Asphyxiation

Although non-toxic, Ethane and Methane have 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 [11]) 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.

4.4.2 Jet Fire

Release of Methane from high pressure through a hole in a pipeline may create a jet plume. The gas plume extends several metres in the direction of discharge due to its momentum jet effect, entraining air. Ignition would result in a jet fire.

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.

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

4.4.4 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.).

In the case of a gas release from the gas pipelines in the vicinity of the school, a gas cloud explosion is less likely than a flash fire due to the relatively open areas and absence of congestion surrounding the three HP pipelines; however, some built up areas (residences) were included in the QRA as potential congestion areas sources to model vapour cloud explosion.

4.4.5 Gas Ingress into Buildings

The gas plume resulting from a gas release would disperse downwind once the momentum effect is lost. If the wind direction were oriented towards the school buildings, there is potential for flammable gas to be drawn into the buildings through ventilation air intake, and through 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.

4.4.6 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. The smoke plume would rise above the building roof height.

4.4.7 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 potential for propagation and escalation was carried forward in the risk analysis for the two underground pipelines in the common easement.

4.5 Control Measures

Under the NSW Pipelines Act (1967) and Pipeline Regulations (2013), a pipeline operator must ensure the design, construction, operation and maintenance of a licensed pipeline is in accordance with the relevant provisions of Australian Standard AS 2885 [12] for gas and liquid petroleum pipelines.

A licensee must implement a pipeline management system that relates to the pipeline operated under the licence and is in accordance with the relevant provisions of AS 2885.

4.5.1 Prevention of Mechanical Failure

Operators of licensed pipelines under the NSW Pipelines Regulation 2013 are required to develop and implement systems and processes to ensure the pipeline structural integrity for the design life of the pipeline in accordance with Section 6 of AS 2885.3:2012 [13] as part of the pipeline management system.

Continual monitoring is required while the pipeline is in operation to ensure that pipeline structural integrity is maintained. They shall not be operated above the maximum allowable operating pressure (MAOP). Anomalies should be assessed, and defects repaired.

The two HP pipelines are inspected using ‘intelligent pigging’ and no loss of wall thickness has been reported [7].

4.5.2 Corrosion Prevention

Operators of licensed pipelines under the NSW Pipelines Regulation 2013 are required to develop and implement systems and processes to ensure the pipeline structural integrity for the design life of the pipeline as per Section 6 of AS 2885.3:2012, as part of the pipeline management system. This 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.

Both the Jemena gas pipelines are cathodically protected (impressed current) and monitored. The CTM has coal tar enamel coating and the EGP has epoxy fusion coating for corrosion protection.

4.5.3 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 AS2885.1:2012). To comply with AS2885.1:2012 [14], 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).

Both the pipelines have adequate wall thicknesses for the operating pressure and are located on flat stable land in the vicinity of the school. The potential for ground movement is low.

4.5.4 Prevention of Damage due to Third Party Activity

Operators of licensed pipelines under the NSW Pipelines Regulation 2013 are required to undertake a Safety Management Study (as per Section 11 of AS 2885.3:2012) to assess the risks associated with threats to the pipeline and to instigate appropriate measures to manage the identified threats. The safety management study for the CTM is reported in Ref. [7].

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 daily / weekly patrols.

Statistical data indicates that the pipelines in NSW are 100% cathodically protected with effectiveness between 95 and 100%, and that over 96% of parties contacted BYDA before any excavation work [15].

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

4.5.5 Mitigation Control Measures

Operators of licensed pipelines under the NSW Pipelines Regulation 2013 are required to develop and implement an Emergency Response Plan (as per Section 11 of AS 2885.3:2012) as part of the pipeline management system.

The Emergency Response Plan should 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 HP pipelines can be isolated by closing automated and/or manual valves (Refer to Table 4 for locations of upstream and downstream isolation valves).

4.6 MIs for Risk Analysis

The list of MIs included in the risk analysis is provided in Table 9.

Table 9: List of MIs

MI	Potential Consequences
Release of High Pressure Natural Gas (Methane) from Jemena Eastern Gas Pipeline (EGP)	Jet Fire, Flash Fire or Explosion
Release of High Pressure Natural Gas (Methane) from Jemena Central Trunk Main (CTM)	Jet Fire, Flash Fire or Explosion

5 HAZARD CONSEQUENCE ANALYSIS

5.1 Release of Flammable Liquid / Gas

5.1.1 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.1), 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 - Refer to Appendix D) 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 10: Representative Hole Diameters Selected for Consequence Analysis

Pipeline	Internal 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)
EGP	433.6	10 or 25*	75	110	Full bore
CTM	836.8	10 or 25*	75	110	Full bore

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

5.1.2 Rate of Release

Release events were modelled using the 'Long Pipeline' model in SAFETI. The release rate varies with time, decreasing as the line depressurises.

5.1.3 Height and Orientation of Release

The release of high-pressure gas from a buried pipeline would result a crater and gas would be released vertically from the crater [16].

Where above ground assets have been modelled (ALBVs and MLVs), the release has been assumed to be horizontal in the same direction as the wind, from a distance 1m above ground level. There are no above ground facilities within the area of interest.

5.1.4 Duration of Release

Methane is 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 Section A.6) and the time required for each representative release case to reach steady state.

Duration of release becomes significant only from a fire escalation point and not required for risk assessment based on short duration exposure to fire.

5.2 Fire Modelling

The SAFETI software package (Version 8.61) was used to model all the representative fire events included in the risk analysis.

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

5.2.1 Jet Fire

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

The worst fire case was for a full-bore rupture (FBR) of the CTM, because of its diameter, resulting in a large release rate.

The jet fire radiation intensity for various distances from the pipelines are shown for full bore releases in Figure 7 and Figure 8 for CTM and EGP respectively (API model). These figures are used to determine the thermal radiation impact on the school structure. The distances vary depending on the wind speed at the time of the incident. The worst case distance was found to be for high wind speeds at 7.5m/s (flame tilt by the wind).

Figure 7: Thermal Radiation for FBR of CTM

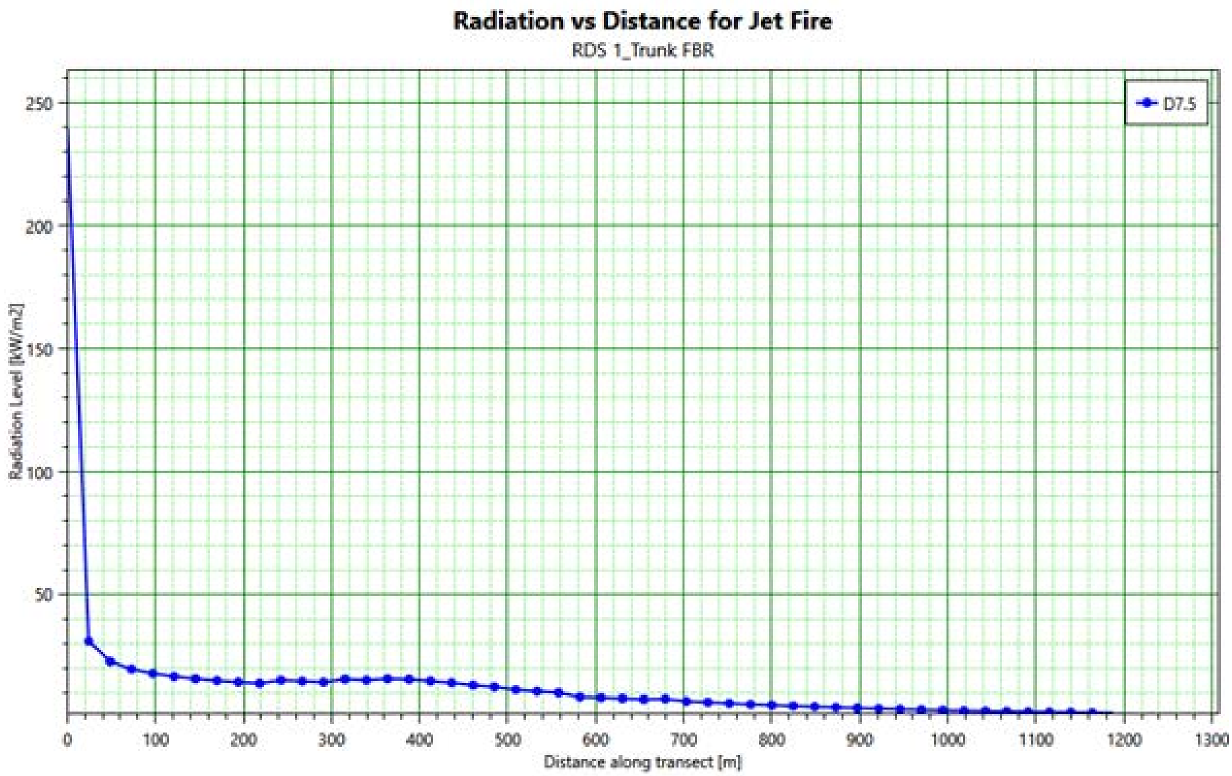
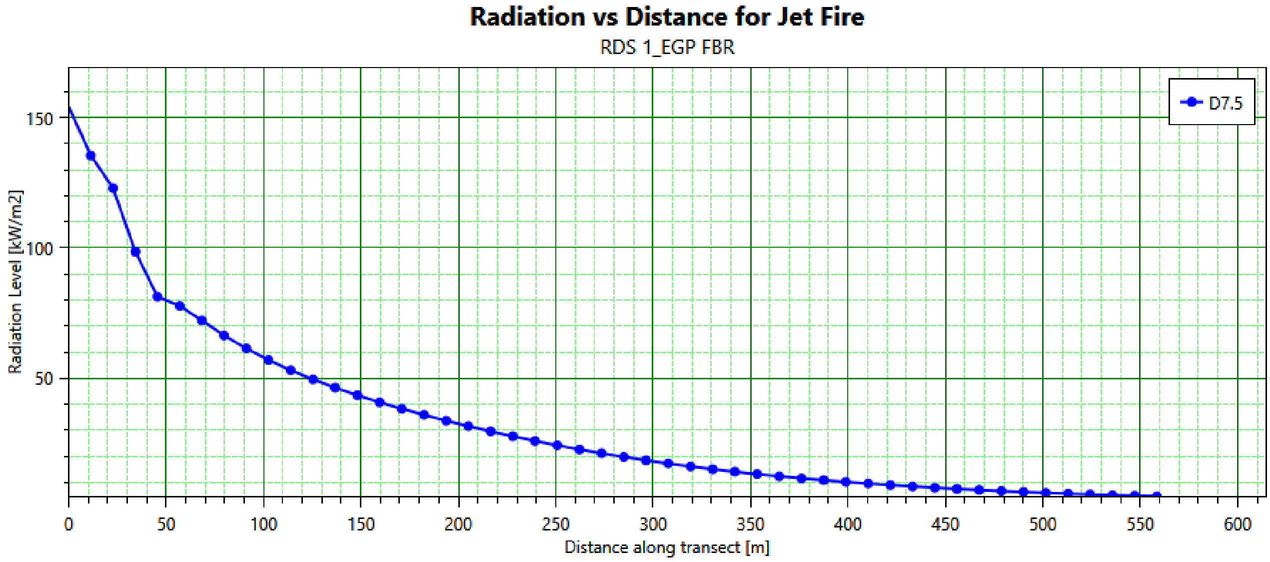


Figure 8: Thermal Radiation for FBR of EGP



The following points are of interest:

The thermal radiation at the eastern boundary of the school is 7.5 kW/m^2 for CTM FBR. There is no thermal radiation impact on the school from EGP FBR.

The thermal radiation at the nearest school building (Block G and H) is 5.1 kW/m^2 for CTM FBR.

The building impacts are further evaluated in Section 9.1.

5.2.2 Flash Fire

Example distances to the lower flammability limit (LFL) concentration are tabulated in Appendix B for representative flash fire events included in the risk analysis.

The dispersion profiles for full bore rupture cases for CTM and EGP are given in Figure 9 and Figure 10 respectively.

For CTM, the flammable cloud reaches the school, but because of cloud buoyancy, the flammable cloud rises to heights between 60 and 120m above grade when it traverses the school site.

For EGP, the corresponding heights are 75-130m.

It is concluded that there will be no adverse impact from flammable gas cloud dispersion over the Austral school site.

Figure 9: Side View of CTM Full Bore Rupture Dispersion to Lower Flammable Limit

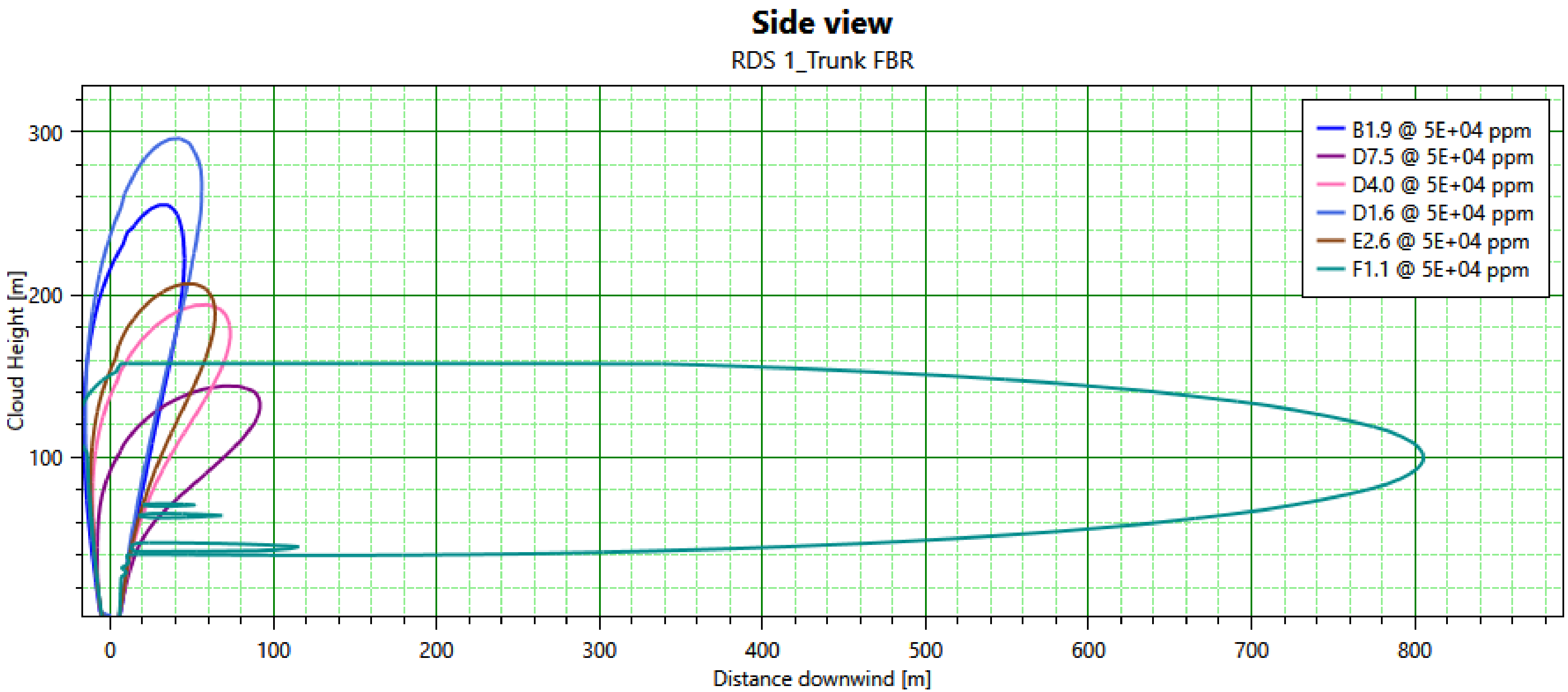
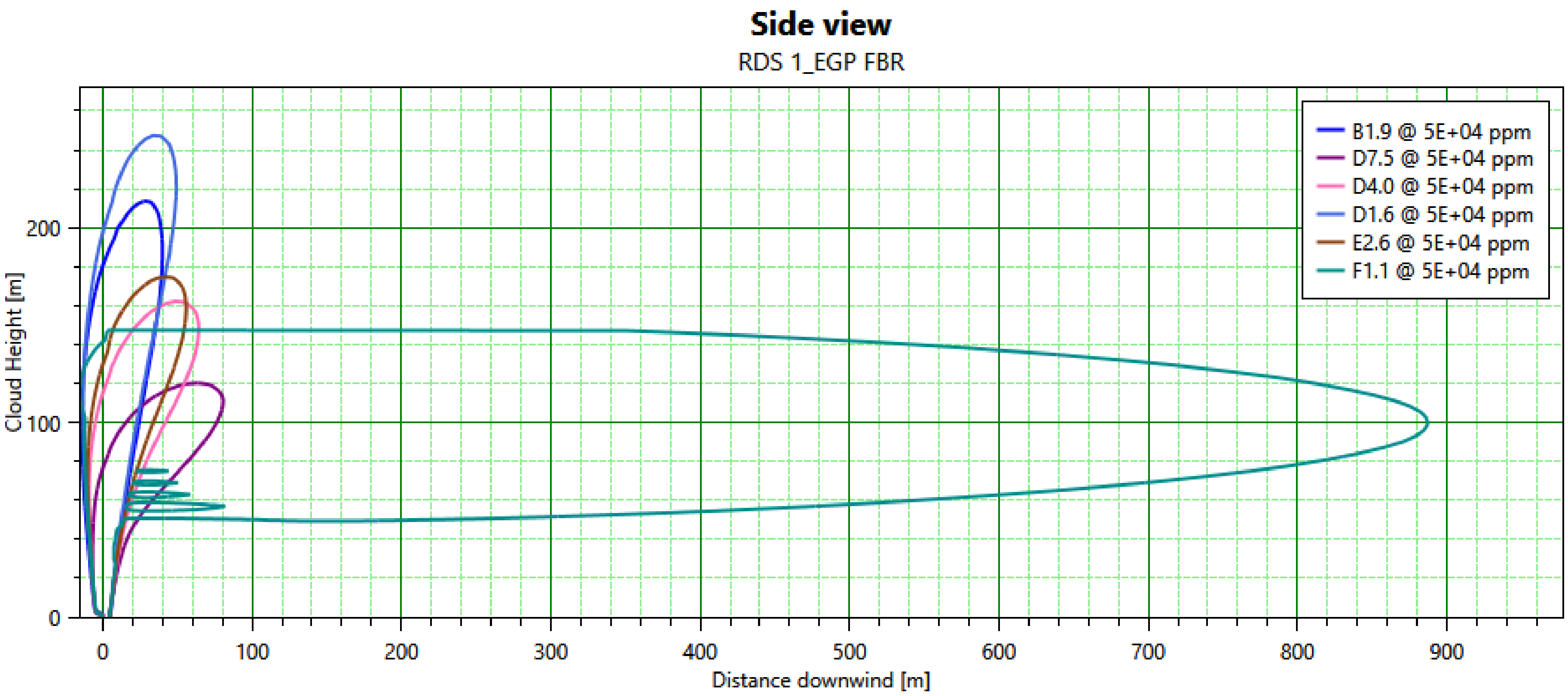


Figure 10: Side View of EGP Full Bore Rupture Dispersion to Lower Flammable Limit



5.3 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.

5.4 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 of propagation and escalation was estimated based on a review of historical incidents by Silva et al. [17], estimated crater dimensions from SAFETI and the separation distance between the CTM and the EGP in the common easement.

The results are summarised in Table 11.

Table 11: Assessment of Incident Escalation from FBR

Pipeline	Crater depth, m	Crater Length, m	Crater width, m	Distance between pipelines, m	Escalation Potential?
CTM	3	18.5	11.1	8.5	No
EGP	1.2	1.66	1.66	8.5	No

It is seen that the maximum crater radius of 5.55m for the CTM will not reach the adjacent EGP and hence the escalation between the pipelines is prevented by the soil cover.

6 Frequency and Likelihood Analysis

6.1 Likelihood of Gas Release

The likelihood of a gas release (i.e. leak) from each of the HP pipelines is tabulated in 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, *2017-18 Licensed Pipelines Performance Report* [18]. This includes data for all licensed pipelines in NSW for the 5-year period: 2013/14 to 2017/18.
- UK Health and Safety Executive (HSE), Research Report (RR) 1035 [10].
- British Standards Institute (2013) [19].
- US Department of Transportation (DoT) (2018) [20].

6.2 Probability of Ignition

The ignition probabilities adopted in the risk analysis are based on Scenario 3 “Pipe Gas LPG Industrial” described in the International Association of Offshore Oil & Gas Producers Risk Assessment Data Directory – Ignition Probabilities [21] after a review of relevant ignition probability data and ignition probability correlations (Refer to Appendix C.3).

6.3 Likelihood of Escalation in Pipeline Easement

All three pipelines are located in the same corridor. If any pipeline falls within the crater created by a rupture of the other, then the second pipeline would be exposed, with a potential for failure.

The likelihood of propagation and escalation was estimated based on a review of historical incidents by Silva et al. [17]. Estimated crater dimensions from SAFETI and have been used to estimate the likelihood of escalation to a second pipeline. The length of the crater developed was used to determine potential escalation from a release at the centreline of the pipeline in the vertical direction, while the half-width of a crater developed by a full-bore rupture (located on the centreline of the pipeline in the direction of travel). Within the area of interest, none of the pipelines cross paths, hence the potential of escalation is deemed not credible given the separation distances between each pipeline. Refer Table 12.

Table 12: Pipeline Crater Dimensions and Potential Escalation

Pipeline	Length of Crater Developed by 110 m Mid-point Release (m)	½ width of Crater Developed by Full-bore Rupture (m)	Closest Pipeline	Separation Distance	Escalation?
CTM	2.9	7.77	EGP	8.5	No
EGP	2.9	5.8	CTM	8.5	No

6.4 Likelihood of Representative MIs

The likelihood of each representative release scenario included in the risk analysis is tabulated in Appendix C.4.2.

7 RISK ANALYSIS

7.1 Individual Risk of Fatality

The combined individual risk of fatality contours for a representative segment of the three pipelines is shown in Figure 11. All three pipelines combined generate individual risk levels greater than of the risk criteria for sensitive land uses and residential land use as described in HIPAP No.10 [3], but not at the location of the proposed school. Therefore, based on the DPIE individual risk criteria, the land is suitable for sensitive land uses such as schools.

Figure 11: Cumulative LSIR Contours for CTM and EGP Combined

Source of map: Ref. maps.six.nsw.gov.au/arcgis/rest/services/public/NSW_Base_Map/MapServer

7.2 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 4.4.6); therefore any future proposed development will comply with the relevant DPE toxic injury risk and irritation criteria with respect to the high pressure transmission pipelines (Refer to Section 3.8.2).

7.3 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} per annum; therefore, any future proposed development will comply with the DPE property damage and accident propagation criteria with respect to the high pressure transmission pipelines (Refer to Section 3.8.3).

7.4 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} per annum; therefore, any future proposed development will comply with the DPE property damage and accident propagation criteria with respect to the high pressure transmission pipelines (Refer to Section 3.8.3).

7.5 Risk of Injury (Exceeding 7 kPa)

The cumulative risk of injury (Overpressure exceeding 7 kPa) does not reach 50 x 10^{-6} per annum; therefore, any future proposed development will comply with the relevant DPE risk criterion (Refer to Section 3.8.2) with respect to the high pressure gas transmission pipelines.

7.6 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} per annum; therefore, any future proposed development will comply with the relevant DPE risk criterion (Refer to Section 3.8.2) with respect to the high-pressure gas transmission pipelines.

7.7 Societal Risk

Safeti 8.61 did not generate an F-N curve, as there is no fatality risk at the school.

Societal risk, however, was analysed from a qualitative perspective.

1. SAFETI predicts a flammable cloud over the proposed school (Table 24, Scenario CTM-FBR), only for F1.1 weather category. The height of the lower boundary of the cloud is 100m above grade for the F1.1 weather condition. On a consequence basis alone no one at the school would be affected by the flammable cloud at such height.
2. The Weather Category for the dispersion to carry the cloud to the school (at a height of 100 m) is 1.1F. This is a night-time weather condition, and therefore it is not expected that significant numbers of people will be present.
3. Radiated heat flux from jet fires is insufficient to cause fatality without long exposure (much greater than 30 s). It is expected people in the open should be able to seek shelter from direct radiation from any jet fires.

From the above three points, the proposed school does not contribute to societal risk.

7.8 Qualitative Risk Criteria

The qualitative risk criteria are described in Section 4.9.

- *Avoidance of all 'avoidable' risks – The pipelines are existing facilities and cannot be relocated to avoid risk exposure.*

  Risk exposure to school is avoided by its location and separation distance from the pipelines.

- *Reduction, wherever practicable, of the risk from a major hazard, even where the likelihood of exposure is low;*

  Since there is no risk of fatality to the school population and the risk of injury is very low, additional risk reduction on the part of pipeline operators is considered warranted. Some mitigation may be provided at the school building level, and discussed in Section 8.9.

- *Containment, wherever possible, within the site boundary of the effects (consequences) of the more likely hazardous events;*

  This clause is for a hazardous development and not applicable for the Activity.

- *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 – This study has demonstrated the APS upgrade project would not be contribute to a significant increase in the existing risk.*

  The risk to the existing school is very low. The proposed Activity does not increase the incremental risk, as an F-N curve is not generated.

The proposed Activity satisfies the qualitative risk criteria.

8 THERMAL RADIATION IMPACT ON SCHOOL BUILDINGS

8.1 Incident Heat Flux on Structures

The thermal radiation values at the new school buildings from full bore ruptures of the pipelines are summarised in Table 13.

Table 13: Thermal Radiation on Nearest School Buildings @ 2m Height

Pipeline	3-storey hub	
	Distance, m	Heat flux, kW/m^2
CTM	720	5.8
EGP	732	No impact

The 3-storey hub could receive thermal radiation up to 5.8 kW/m^2. The building will be designed to comply with the requirements of the National Construction Code (NCC), and hence withstand a thermal radiation of 5.8 kW/m^2. No further action is required.

8.2 Risk Reduction Measures

The school emergency plan must consider the potential for a pipeline failure to ensure there is a coordinated response, and actions in response to a failure do not increase the potential risk. In the case of a pipeline failure, the school should nominate a safe emergency assembly area on the western side of school, either inside or outside the school buildings.

There are no risk reduction measures needed to be considered in the design for the Activity. The new structures on the property will be compliant with the NCC.

9 FINDINGS AND RECOMMENDATIONS

9.1 Findings

The findings of the assessment are that based on individual risk of fatality and individual risk of injury, the proposed Activity satisfies the risk criteria of HIPAP No.10 [3] for sensitive use development.

A pipeline failure is not expected to contribute to the risk of fatality at the school, and the risk of injury is extremely low.

The radiated heat flux experienced at the school is sufficiently low that buildings compliant with the NCC should be capable of withstanding all pipeline failure events.

There is adequate separation distance between the CTP and the EGP in the easement and a failure of one pipeline would not escalate to the adjacent pipeline.

9.2 Recommendations

The following recommendations are made as a result of the preliminary hazard analysis of pipelines in the vicinity of the proposed school:

1. The school emergency plan must include pipeline rupture as a scenario and develop an appropriate emergency assembly area on the western side of the school (inside or outside), to prevent the potential for injuries from people exposed to radiated heat flux in the open.

10 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 (MIs) 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.*"

List of Assumptions

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 Table 3.
Justification and Impact/s of Assumption/s: • All operational data for the Natural Gas pipelines (CTM and EGP) was provided by the pipeline operator, Jemena Limited. • Operating conditions (particularly operating pressure) are required to undertake the release and dispersion modelling.
MI/s Affected: • All.
Reference/s: • Data provided by Jemena Limited

Assumption No. 2 Pipeline Utilisation
Subject: Operational Data
Assumption/s: • The Natural Gas pipelines (CTM and EGP) 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.
MI/s Affected: • All.
Reference/s: • Data provided by Jemena Limited).

A.2 Locational Data

Assumption No. 3: Representative Weather Categories and Directional Distribution
Subject: Locational Data
Assumption/s: • Badgerys Creek AWS (ID: 60801) weather data is a suitable representation for meteorology at the proposed school • The probabilistic distribution of wind speed and wind direction for the representative stability classes is provided in Section 0. • Night-time is considered the period from 1 hour before sunset, to one hour after sunrise. This approximates to 10 hours daytime and 14 hours night-time. • The distribution of stability classes is presented in Section 0.
Justification and Impact/s of Assumption/s: • Meteorological data (mean cloud cover, temperature, wind speeds) is collected by the Bureau of Meteorology (BoM) for the Camden Automatic Weather Station weather station for the period 1995-2014. This raw data was rationalised into a set of wind speed/weather stability classes for dispersion calculations. Badgerys Creek weather station was selected as being the closest to the Austral school with sufficient data and most representative. • Wind will cause flames to tilt downwind. The higher the wind speed, the greater the tilt. The net effect of the tilt is to increase the heat radiation in the downwind direction. This is much more pronounced for pool fires than jet fires because jet fires have much greater momentum. An allowance for flame tilt is included in the SAFETI models for pool fires and vertical jet fires. The SAFETI model assumes horizontal jet fires are directed in the same direction as the wind. • 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).
MI/s Affected: • All.
Reference/s: • BoM meteorological data for Badgerys Creek Atmospheric Monitoring Station, ID: 60801.

Assumption No. 4: 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 14.

Table 14: 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

- A conservative roughness length of 0.5 m is applicable for the proposed school. While it is nominally in a suburban area, currently there is significant undeveloped land and parkland in the area.

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.
- While it is nominally in a suburban area, currently there is significant undeveloped land and parkland in the area.

MI/s Affected:

- Dispersion modelling for all relevant MIs.

Reference/s:

- SAFETI software documentation.

Assumption No. 5: Location of High Pressure Gas Pipelines
Subject: Locational Data
Assumption/s: • The location of both pipelines is sourced from the APGA Australian Pipeline Database

Justification and Impact/s of Assumption/s:
• The Australian Pipeline Database (APD) is made available to users to raise awareness of the location of high-pressure hydrocarbon pipelines and facilitate discussions between pipeline operators and stakeholders regarding the potential for planning and development decisions to trigger requirements in the Australian Standard, AS 2885, for pipeline Safety Management Studies.
• Use of the APD is conditional on several factors that are consistent with the objectives of this study, including:
  ◦ The APD is to be used solely for the purpose of facilitating discussion regarding planning activity and decisions in the vicinity of pipelines. **This is consistent with the objectives of this study**.
  ◦ The APD is not to be used for proving and construction activities. Before You Dig Australia enquiries must be made for these activities and any condition complied with. **It is not the intent of this study to provide detailed construction information**.
• When overlayed onto aerial photos, the APGA Pipeline database accuracy appears no less accurate than the accuracy expected of the consequence models and frequency estimates.

MI/s Affected: • All.
Reference/s: • APGA Australian Pipeline Database.

A.3 Risk Analysis Methodology

Assumption No. 6: Location and Segmentation of Pipelines
Subject: Risk Analysis Methodology
Assumption/s: • Representative release events are modelled using the 'Long Pipeline' model in SAFETI. • Events along the pipelines were spaced at 20 m
Justification and Impact/s of Assumption/s: • The 'Long Pipeline' model in SAFETI is used to estimate the time-dependent release from a long pipeline. The 'Long Pipeline' model includes inputs for use in the risk calculations, such as pipeline burial depth, leak frequency, etc. • The interval at which representative incidents are distributed along the pipelines was set at 20 m to minimise the potential for iso-risk "rings" to appear along the pipeline. • 20 m interval spacing was sufficient to prevent iso-risk rings from forming in the contour.
MI/s Affected: • All.
Reference/s: SAFETI software documentation.

A.4 Consequence Analysis

Assumption No. 7: Representative Materials
Subject: Consequence Analysis
Assumption/s: • 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 natural gas in the pipelines has been processed for domestic and industrial consumption. As part of the processing, valuable by products such as ethane, propane and butane have been removed at several major producers such as Moomba and Longford. Heavier hydrocarbons are also typically removed to prevent condensation. • Natural gas typically contains 85 to 95% methane. In 1996-97, the composition of natural gas used in Melbourne was 91.2% methane.
MI/s Affected: • All.
Reference/s: • Natural Gas: Energy for the New Millennium, Research Paper 5 1998-99, Mike Roarty, Science, Technology, Environment and Resources Group' December 1998.

Assumption No. 8: Pressure and Flow for Release Modelling
Subject: Consequence Analysis
Assumption/s: • A release of Natural Gas from the Jemena Eastern Gas pipeline (EGP) is modelled at 14.895 MPag, which is also the MAOP for the pipeline. • A release of Natural Gas from the (CTM) is modelled at 5 MPag (operating pressure is between 4.5 and 5 MPag), compared to an MAOP of 6.895 MPag. • Release events are modelled using the 'Long Pipeline' model in SAFETI and may be based on a time varying release rate (depending on hole size). • All pipelines have assumed zero flow.
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. • The pressure used to model the release rates was based on the pipeline pressure near the proposed development, as advised by the pipeline owner. • The long pipeline model assumes the input pressure is reduced by frictional losses along the pipeline length until the breach point. This results in a lower initial release rate. • Providing a flow will slow the rate of pressure reduction calculated by the long pipeline model, but this is insignificant for the initial 30 second release, the basis of which the impact for jet fire has been assumed. • A flow will increase the residual pressure the long pipeline model calculates, but as it will take much longer than 30 seconds to reach residual pressure, this is not relevant.
MI/s Affected: • All.
Reference/s: • Data provided by Jemena Limited.

Assumption No. 9: Representative Hole Diameters for Release Modelling

Subject: Consequence Analysis

Assumption/s:

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

Table 15: Representative Hole Diameters Selected for Consequence Analysis

Pipeline/s	Material	Internal 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)
Jemena Eastern Gas Pipeline (EGP)	Natural Gas	433.6	10 or 25*	75	110	Full bore
Jemena Gas Network CTM	Natural Gas	836.8	10 or 25*	75	110	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 C.1), 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 – Refer to Appendix D) 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.

MI/s Affected:

- All.

Reference/s:

- Refer to Appendix B.1.

Assumption No. 10: Location of Release for Transmission Pipelines
Subject: Consequence Analysis
Assumption/s: • High pressure gas releases would create a crater on the ground. The direction of release for underground pipeline failures from the crater is always 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% from middle of pipe and 63% from top of pipe for all release cases except non-TPA events with a hole size less than or equal to 25mm, which are modelled as 100% from middle of pipe).
Justification and Impact/s of Assumption/s: • The crater size depends on the location of the hole on the pipe and hence all three locations (top, middle and bottom) may be modelled (DNVGL, 2020). 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. ±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.
MI/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. 11: 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 100% of the lower flammability limit (LFL) concentration calculated using an 18.75s averaging time.
Justification and Impact/s of Assumption/s: • Justification is provided in (Benintendi, 20171031, p. 341): For passive dispersion models, the shorter the averaging time, the higher the centreline concentration, and there is concern that flammable concentrations may exist beyond the 100% LFL contour determined for a specific averaging time. To take into account the different averaging times, the following empirical formula is recommended for converting concentrations from 10 minute averaging time to another (Hanna et al., 1993): $\frac{C_t}{C_{600}} = \left(\frac{600}{t}\right)^{0.2}$ ...(1) where time is in seconds. C_t denotes time averaged concentration at the new averaging time of t seconds Hanna claims that experimentally: $C_{max} = 2 \times C_{600}$ ...(2) where C_{max} is the maximum peak concentration in the plume. Substituting C_{max} from (2) with $C_{600}\left(\frac{600}{t}\right)^{0.2}$ from (1) and solving for t, it is yields *t = 18.75 s.* This time should be adopted to carry out worst case predictions for the extent of 100% LFL. It is the core averaging time for flammable dispersion in SAFETI. • For the materials under consideration, flash fires are not expected to be a major contributor because the gases involved are buoyant and should ignition occur, effects from jet fires are expected to dominate.
MI/s Affected: • All MIs with a flash fire as a potential outcome.
Reference/s: • SAFETI software documentation. • Benintendi, R. (20171031). Process Safety Calculations. [VitalSource Bookshelf version]. Retrieved from vbk://9780081012291. • Hanna, S.R., Strimaitus, D.G., Chang, J., 1993. Hazard Response Modeling Uncertainty (A Quantitative Method) Vol 11 - Evaluation of Commonly Used Hazardous Gas Dispersion Models, Environics Division Air Force Engineering & Services Center, Engineering & Services Laboratory.

Assumption No. 12: Isolation Time and Duration of Release
Subject: Consequence Analysis
Assumption/s: • Isolation time and duration of release is not specified as these will be significantly 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: • Natural gas is 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 of the Long Pipeline Model, using a 30 sec. 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).
MI/s Affected: • All.
Reference/s: • SAFETI software documentation.

Assumption No. 13: 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. • This analysis is taking place during the concept stage of development of a large growth area. There is insufficient information available to determine the location of large structures that could offer protection against radiant heat. • People located indoors are typically less vulnerable to fire, which is a relevant consideration for the societal risk assessment (Refer to Assumption No. 19).
MI/s Affected: • All MIs.
Reference/s: • SAFETI software documentation.

Assumption No. 14: 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 severity of the blast is based on an unconfined blast strength of 4, with no specified obstruction region. • 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 obstructed volume (60% for a residential building) and 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. • 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 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.
MI/s Affected: • All MIs 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.

Assumption No. 15: Escalation due to Propagation Between Adjacent Pipelines
Subject: Consequence Analysis
Assumption/s: • Escalation between pipelines will only occur if the radius of the crater created by a pipeline failure is larger than the distance between the failed pipeline and the pipeline subject to escalation. • Escalation only occurs when there is propagation before sufficient mitigation of the initial fire.
Justification and Impact/s of Assumption/s: • Escalation MIs are generally lower likelihood and higher consequence events, which may affect the cumulative risk (Particularly the societal risk). • The likelihood of propagation and escalation was estimated based on a review of historical incidents, primarily from Ref. [17], estimated crater dimensions from SAFETI, and the separation distance between the CTM and the EGP in the common easement. Based on this review, propagation and escalation was not considered a credible event for inclusion in the risk assessment. • In a review of buried pipeline rupture incidents, it was found that there was 1 escalation in 8 cases of rupture when an adjacent pipeline was exposed [17].
MI/s Affected: • Escalation MIs only.
Reference/s: • E.P. Silva, M. Nele, P. F.Frutuoso e Melo, and L. Könözsy, *Underground parallel pipelines domino effect: An analysis based on pipeline crater models and historical accidents*, Journal of Loss Prevention in the Process Industries, June 2016.

A.5 Likelihood Analysis

Assumption No. 16: 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. • The contribution to pipeline failure from ground movement has been adjusted down to allow for local conditions.
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 consistent with the NSW performance data. • The HSE data identifies four contributors to pipeline failure: (a) mechanical failure; (b) corrosion; (c) ground movement/other; and (d) Third Party Activity (TPA). Of these, mechanical, corrosion and TPA are similar to conditions in Australia and hence no frequency adjustments due to local conditions are justified. • The justification for the data used in this risk analysis is provided in Appendix C.1.
MI/s Affected: • All.
Reference/s: • Refer to Appendix C.1.

Assumption No. 17: Ignition Probability
Subject: Likelihood Analysis
Assumption/s: • The probability of ignition for each representative release is based on the OGP Risk Assessment Data Directory Report No. 434 – 6.1 "Ignition Probabilities", Scenario 3 – Pipe Gas LPG Industrial and provided in Appendix C.4.1.
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 description of Scenario 3 as "Releases of flammable gases, vapour or liquids significantly above their normal (Normal Atmospheric Pressure (NAP)) boiling point from onshore cross-country pipelines running through industrial or urban areas" most closely matches the scenario involving the school and pipelines. • Further justification for the data used in this risk analysis is provided in Appendix C.4.
MI/s Affected: • All.
Reference/s: • Refer to Appendix C.4.

Assumption No. 18: Probability of VCE or Flash Fire
Subject: Likelihood Analysis
Assumption/s: • Ignition of a free gas or vapour cloud is modelled as a flash fire in uncongested areas and as a vapour cloud explosion in congested areas. • Congested areas include buildings in the vicinity of the pipelines.
Justification and Impact/s of Assumption/s: • Ignition of a free gas cloud may demonstrate characteristics of a flash fire and/or an explosion. SAFETI uses the delayed ignition probability resulting in either of the events. • Obstructed areas in the dispersing vapour cloud are defined by the user in the layout map. As the model calculates gas dispersion, it automatically calculates the consequence as vapour cloud explosion in congested areas and flash fires in uncongested areas. • The current version of SAFETI, with the 3D obstructed area module, does not require a conditional probability of an explosion given ignition.
MI/s Affected: • All MIs 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. 19: 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 in an urban setting. It is assumed after 30 seconds, the persons will have found shelter from heat radiation.
- The probability of fatality for an individual located outdoors (30 seconds exposure), as calculated using the above probit equation, is as follows:

Table 16: 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

* - SAFETI assumes fatal injuries are incurred at 35 kW/m^2 and above, regardless of the exposure duration.

Assumption No. 19: 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 17: 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.

MI/s Affected:

- All MIs 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. 20: 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.
MI/s Affected: • All MIs 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. 21: 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 18 (Person located outdoors) and Table 19 (Person located indoors).

Table 18: 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 19: 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 DPE’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 DPE’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 Environment, 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 – Example Data and 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.

B.2 Consequence Analysis Results for Representative Release Scenarios

Consequence results from the analysis are presented in the following sections. Some tables refer to a model, and have a coded tag for the model scenario:

AAA -XXXmm-BBB Release Scenario Y

AAA- Three letter code for the pipeline – MSE, CTM, or EGP as used in the body of the report.

XXX – Hole size, in mm (if not a full-bore rupture).

BBB – Location of the pipeline breach, TOP (top of pipeline), MID (90° from the top), or FBR (Full Bore Rupture)

B.2.1 Auto-Sectioning Results

SAFETI 8.61 sections the pipeline based on pressures and the location of valves. As the section of pipeline considered was relatively short (approximately 1.5 km), SAFETI determined only one representative sub-section for each pipeline.

Table 20: Sub-Section Distances for the MSE

Pipeline	Sub-section start distance from upstream end [m]	Sub-section end distance from upstream end [m]	Sub-section midpoint distance from upstream end [m]	Sub-section length [m]	Failure frequency [per km per year]
CTM	25,630	27,140	26,380	1,512	5.061×10^{-5}
EGP	28,520	29.980	29,250	1,465	5.061×10^{-5}

Table 21: Sub-section Pressures

Pipeline	Pressure at sub-section start [bar abs]	Pressure at sub-section end [bar abs]	Pressure at sub-section mid-point [bar abs]
CTM	50	50	50
EGP	150	150	150

B.2.2 Section Breach Discharge Results

Discharge rates for the initial dispersion time period are shown in **Error! Reference source not found.**. It should be noted that for the larger hole sizes (full bore rupture for the CTM and EGP, and 75 mm), the dispersion calculations used multiple release rates to represent the reduction of flowrate over time as the pipelines depressurise.

B.2.3 Jet Fire Results

Results for jet fire scenarios are tabulated in Table 22 for releases from the CTM and EGPE.

Table 22: Distances Downwind (m) to Selected Radiated Heat Flux

Scenario	Weather	Flame length [m]	Distance downwind to Specified Heat Flux (kW/ m^2], m			
			4.7	12.6	23	35
CTM-FBR	1.9B	449.1	614.4	290.2	139.1	n/a
	7.5D	318	629.4	401.5	277.5	190.1
	4.0D	365.1	634	358.8	200	112.2
	1.6D	465.4	598.3	272.6	120.2	n/a
	2.8E	409.1	644	333.1	175.2	96.24
	1.1F	498.3	576	243.9	26.98	n/a
CTM-110mm TOP	1.9B	78.66	78.46	20.99	n/a	n/a
	7.5D	55.7	100	60.37	36.05	13.02
	4.0D	64.0	93.0	43.4	15.0	n/a
	1.6D	81.5	74.4	n/a	n/a	n/a
	2.8E	71.7	85.9	30.6	n/a	n/a
	1.1F	87.3	68.8	n/a	n/a	n/a
CTM-110mm MID	1.9B	91.7	105.2	37.0	n/a	n/a
	7.5D	64.9	128.4	83.4	63.3	46.3
	4.0D	74.5	119.9	70.6	38.6	13.9
	1.6D	95.0	100.4	33.1	n/a	n/a
	2.8E	83.5	113.4	53.1	19.0	n/a
	1.1F	101.7	91.6	25.5	n/a	n/a
CTM-75mm TOP	1.9B	59.1	58.4	14.9	n/a	n/a
	7.5D	41.9	74.6	46.9	30.0	14.7
	4.0D	48.1	69.9	33.9	11.0	n/a

Scenario	Weather	Flame length [m]	Distance downwind to Specified Heat Flux (kW/ m²), m			
			4.7	12.6	23	35
	1.6D	61.3	55.2	n/a	n/a	n/a
	2.8E	53.9	64.3	22.3	n/a	n/a
	1.1F	65.6	50.2	n/a	n/a	n/a
CTM-75mm MID	1.9B	69.2	78.2	26.8	7.6	n/a
	7.5D	49.0	95.7	62.1	48.6	36.9
	4.0D	56.2	88.2	54.9	31.5	14.2
	1.6D	71.7	74.2	22.5	n/a	n/a
	2.8E	63.0	84.5	41.9	12.8	3.6
	1.1F	76.7	66.2	17.3	n/a	n/a
CTM-25mm MID	1.9B	28.6	29.4	8.4	n/a	n/a
	7.5D	20.3	37.4	24.6	20.2	16.1
	4.0D	23.3	33.4	21.5	10.0	0.9
	1.6D	29.7	27.3	5.6	n/a	n/a
	2.8E	26.1	32.2	15.6	2.6	n/a
	1.1F	31.8	22.6	n/a	n/a	n/a
CTM-10mm MID	1.9B	13.3	12.2	1.6	n/a	n/a
	7.5D	9.4	16.7	11.8	9.6	8.4
	4.0D	10.8	14.6	9.6	2.4	n/a
	1.6D	13.8	11.0	n/a	n/a	n/a
	2.8E	12.1	13.8	5.7	n/a	n/a
	1.1F	14.7	8.0	n/a	n/a	n/a
EGP-FBR	1.9B	388.1	527.6	246.5	117.6	19.8
	7.5D	274.8	558.3	362.1	258.2	184.5
	4.0D	315.5	568.7	330.2	195.0	108.0
	1.6D	402.2	513.4	231.3	101.7	n/a
	2.8E	353.6	554.3	287.4	148.1	81.7

Scenario	Weather	Flame length [m]	Distance downwind to Specified Heat Flux (kW/ m²), m			
			4.7	12.6	23	35
	1.1F	430.6	492.1	206.2	25.7	n/a
EGP-100mm TOP	1.9B	130.1	139.1	44.8	n/a	n/a
	7.5D	92.1	172.3	103.4	63.1	27.7
	4.0D	105.8	160.8	78.4	32.6	n/a
	1.6D	134.9	133.2	38.9	n/a	n/a
	2.8E	118.5	150.2	59.8	n/a	n/a
	1.1F	144.3	125.2	n/a	n/a	n/a
EGP-110mm MID	1.9B	139.0	159.4	58.7	n/a	n/a
	7.5D	98.4	191.2	121.6	82.8	53.0
	4.0D	113.0	181.6	96.7	42.8	19.8
	1.6D	144.1	153.2	51.9	n/a	n/a
	2.8E	126.6	170.8	73.1	26.7	n/a
	1.1F	154.2	143.4	39.9	n/a	n/a
EGP-75mm TOP	1.9B	94.0	96.0	27.8	n/a	n/a
	7.5D	66.6	121.2	72.8	43.7	17.0
	4.0D	76.4	112.8	53.4	19.9	n/a
	1.6D	97.4	91.4	18.7	n/a	n/a
	2.8E	85.6	104.6	38.9	n/a	n/a
	1.1F	104.3	85.1	n/a	n/a	n/a
EGP-75mm MID	1.9B	104.3	117.9	41.7	n/a	n/a
	7.5D	73.8	142.7	93.0	66.9	45.9
	4.0D	84.8	135.3	74.4	33.6	14.9
	1.6D	108.1	112.9	36.8	n/a	n/a
	2.8E	95.0	127.1	54.5	19.4	n/a
	1.1F	115.7	103.9	27.4	n/a	n/a
EGP-25mm MID	1.9B	46.4	50.2	16.1	2.0	n/a

Scenario	Weather	Flame length [m]	Distance downwind to Specified Heat Flux (kW/ m²), m			
			4.7	12.6	23	35
	7.5D	32.8	62.4	40.7	32.5	25.2
	4.0D	37.7	56.7	35.9	18.9	5.9
	1.6D	48.1	47.3	12.2	n/a	n/a
	2.8E	42.3	54.8	27.5	7.3	1.5
	1.1F	51.5	40.9	8.8	n/a	n/a
EGP-10mm MID	1.9B	22.1	22.1	5.8	n/a	n/a
	7.5D	15.6	28.4	18.9	15.7	12.9
	4.0D	18.0	25.2	16.4	7.0	n/a
	1.6D	22.9	20.4	n/a	n/a	n/a
	2.8E	20.1	24.2	11.2	1.3	n/a
	1.1F	24.5	16.	n/a	n/a	n/a

B.2.4 Flash Fire Results

Results for distances to LFL concentrations are tabulated in Table 23 and Table 24 for release from the CTM and EGP.

Table 23: Downwind distance [m] to LFL at Height of Interest (1.8 m)

Scenario	Weather	Distance downwind to LFL [m]
CTM-FBR	1.9B	5.9
	7.5D	5.6
	4.0D	5.6
	1.6D	5.5
	2.8E	5.5
	1.1F	n/a
CTM-110mm TOP	1.9B	0.7
	7.5D	0.7
	4.0D	0.7
	1.6D	0.7
	2.8E	0.7
	1.1F	0.6
CTM-110mm MID	1.9B	1.3
	7.5D	1.3
	4.0D	1.3
	1.6D	1.3
	2.8E	1.3
	1.1F	1.4
CTM-75mm TOP	1.9B	0.6
	7.5D	0.6
	4.0D	0.6
	1.6D	0.6
	2.8E	0.6
	1.1F	0.6
CTM-75mm MID	1.9B	1.2
	7.5D	1.3
	4.0D	1.2
	1.6D	1.2
	2.8E	1.2
	1.1F	1.3
CTM-25mm MID	1.9B	0.7
	7.5D	0.9
	4.0D	0.7
	1.6D	0.6
	2.8E	0.6
	1.1F	0.6
CTM-10mm MID	1.9B	0.5

Scenario	Weather	Distance downwind to LFL [m]
	7.5D	1.3
	4.0D	0.7
	1.6D	0.4
	2.8E	0.5
	1.1F	0.4
EGP-FBR	1.9B	5.2
	7.5D	4.9
	4.0D	4.9
	1.6D	4.9
	2.8E	4.8
	1.1F	n/a
EGP – 110mm TOP	1.9B	0.9
	7.5D	0.9
	4.0D	0.9
	1.6D	0.9
	2.8E	0.8
CTM-110mm MID	1.1F	1.2
	1.9B	1.2
	7.5D	1.2
	4.0D	1.2
	1.6D	1.2
	2.8E	1.2
CTM-75mm TOP	1.1F	1.4
	1.9B	0.7
	7.5D	0.7
	4.0D	0.7
	1.6D	0.7
	2.8E	0.7
CTM-75mm MID	1.1F	1.0
	1.9B	1.1
	7.5D	1.1
	4.0D	1.1
	1.6D	1.1
	2.8E	1.1
CTM-25mm MID	1.1F	1.3
	1.9B	0.8
	7.5D	1.0
	4.0D	0.9
	1.6D	0.8
	2.8E	0.8
CTM-10mm MID	1.1F	1.0
	1.9B	0.6

Scenario	Weather	Distance downwind to LFL [m]
	7.5D	1.3
	4.0D	0.7
	1.6D	0.5
	2.8E	0.5
	1.1F	0.5

Table 24: Maximum distance to LFL fraction at any height

Scenario	Weather	Max flash fire distance [m]	Height of the max flash fire distance [m]	Time [s]
CTM-FBR	1.9B	45.4	218.6	33.0
	7.5D	91.9	132.5	15.6
	4.0D	73.6	174.5	15.7
	1.6D	56.0	264.6	33.2
	2.8E	64.2	189.4	32.7
	1.1F	957.3	99.7	398.5
CTM-110mm TOP	1.9B	4.9	36.7	7.5
	7.5D	7.4	22.4	1.9
	4.0D	6.5	29.7	1.9
	1.6D	5.3	40.8	7.5
	2.8E	5.8	34.3	7.5
	1.1F	4.3	41.3	1.9
CTM-110mm MID	1.9B	8.1	36.8	7.5
	7.5D	13.0	20.7	7.5
	4.0D	11.2	28.4	7.5
	1.6D	9.1	44.1	7.5
	2.8E	9.8	33.1	7.5
	1.1F	7.4	43.1	7.5
CTM-75mm TOP	1.9B	3.7	26.3	7.5
	7.5D	5.5	15.3	1.9
	4.0D	4.9	20.7	1.9
	1.6D	4.0	29.3	7.5
	2.8E	4.3	24.3	7.5
	1.1F	3.2	30.2	1.9
CTM-75mm MID	1.9B	6.4	25.4	7.5
	7.5D	10.0	14.0	7.5
	4.0D	8.8	19.4	7.5
	1.6D	7.2	30.0	7.5
	2.8E	7.7	23.1	7.5
	1.1F	5.8	31.5	7.5
CTM-25mm MID	1.9B	2.7	9.0	7.5
	7.5D	3.8	4.8	1.9

Scenario	Weather	Max flash fire distance [m]	Height of the max flash fire distance [m]	Time [s]
	4.0D	3.4	6.9	1.9
	1.6D	2.9	10.9	7.5
	2.8E	3.1	8.5	7.5
	1.1F	2.2	12.6	7.5
CTM-10mm MID	1.9B	1.1	3.9	1.9
	7.5D	1.4	2.1	1.9
	4.0D	1.3	3.0	1.9
	1.6D	1.1	4.7	1.9
	2.8E	1.2	3.8	1.9
	1.1F	0.9	5.8	1.9
EGP-FBR	1.9B	39.9	187.4	20.6
	7.5D	80.5	111.4	20.4
	4.0D	64.2	148.8	20.5
	1.6D	49.2	221.3	20.7
	2.8E	55.8	157.3	20.5
	1.1F	972.7	99.1	548.3
EGP-110mm TOP	1.9B	9.4	66.2	7.5
	7.5D	14.7	39.0	7.5
	4.0D	13.0	52.7	7.5
	1.6D	10.6	74.5	7.5
	2.8E	11.5	58.9	7.5
	1.1F	8.9	70.8	7.5
EGP-110mm MID	1.9B	11.1	66.5	7.5
	7.5D	17.8	37.9	7.5
	4.0D	15.5	52.2	7.5
	1.6D	12.7	75.1	7.5
	2.8E	13.7	58.0	7.5
	1.1F	10.8	72.1	23.9
EGP-75mm TOP	1.9B	6.4	46.7	7.5
	7.5D	9.7	27.7	1.9
	4.0D	8.6	37.3	7.5
	1.6D	7.0	52.4	7.5
	2.8E	7.6	41.9	7.5
	1.1F	5.8	50.5	7.5
EGP-75mm MID	1.9B	8.6	45.8	7.5
	7.5D	13.6	25.9	7.5
	4.0D	11.7	35.5	7.5
	1.6D	9.6	53.1	7.5
	2.8E	10.3	40.6	7.5
	1.1F	8.0	52.0	7.5
EGP-25mm MID	1.9B	4.5	16.0	7.5
	7.5D	6.5	8.5	1.9

Scenario	Weather	Max flash fire distance [m]	Height of the max flash fire distance [m]	Time [s]
	4.0D	5.9	12.1	7.5
	1.6D	4.9	18.8	7.5
	2.8E	5.2	14.6	7.5
	1.1F	3.9	20.8	7.5
EGP-10mm MID	1.9B	2.1	6.7	1.9
	7.5D	2.7	3.3	1.9
	4.0D	2.5	5.0	1.9
	1.6D	2.1	8.0	7.5
	2.8E	2.3	6.3	1.9
	1.1F	1.8	9.9	7.5

B.2.5 Explosion Results

Explosion results are tabulated Table 25.

Table 25: Explosion distances to defined overpressures

Note: All overpressures reported are to 7 kPa side-on overpressure. Distances to 14 kPa and 21 kPa overpressures were not reachable.

Scenario	Weather	Maximum distance [m]	Diameter [m]
CTM-FBR	1.9B	187.3	307.9
	7.5D	197.7	345.9
	4.0D	205.9	386.9
	1.6D	195.5	349.5
	2.6E	1096	788.4
	1.1F	187.3	307.9
CTM-110mm TOP	1.9B	N.R.	N.R.
	7.5D	30.2	51.4
	4.0D	32.7	58.3
	1.6D	N.R.	N.R.
	2.6E	N.R.	N.R.
	1.1F	N.R.	N.R.
EGP-FBR	1.9B	66.2	123.9
	7.5D	95.1	131.8
	4.0D	94.5	146.7
	1.4D	87.9	157
	2.8E	90.9	147.5
	1.1F	853.5	310.5
EGP-100mm TOP	1.9B	N.R.	N.R.
	7.5D	24.1	38.1
	4.0D	25.5	43.2
	1.4D	26.2	48.3
	2.8E	25.3	44.6

Scenario	Weather	Maximum distance [m]	Diameter [m]
	1.1F	N.R.	N.R.
EGP – 110mm MID	1.9B	N.R.	N.R.
	7.5D	N.R.	40.5
	4.0D	27.2	45.4
	1.4D	25.5	47.3
	2.8E	26.4	46.2
	1.1F	27.8	50.7
EGP – 75mm MID	1.9B	N.R.	N.R.
	7.5D	19.5	29.6
	4.0D	20.5	33.6
	1.4D	N.R.	N.R.
	2.8E	N.R.	N.R.
	1.1F	N.R.	N.R.

Explosion overpressures of 7 kPa not reachable for smaller hole sizes and lower wind velocities.

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, *2017-18 Licensed Pipelines Performance Report*. This includes data for all licensed pipelines in NSW for the 5-year period: 2013/14 to 2017/18; 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.
- US Department of Transportation (DoT), Pipeline and Hazardous Materials Safety Administration (PHMSA), Accident Reports - Hazardous Liquid Pipeline Systems (January 2010 to September 2018).

The leak frequency data reported in RR1035 was adopted for the QRA as it is comparable to the NSW performance data 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.

The leak frequency data derived from the British Standards Institute PD 8010-3:2009+A1:2013 was not used since the leak rates (other than ruptures) are not clearly defined for all failure modes and the UK HSE does not accept the use of zero frequencies. Also, the rupture frequencies are disproportionally higher than for other hole sizes (unless factored down to account for concrete slab protection), which is not consistent with other data sources.

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

- An analysis of pipeline failure data from multiple organisations, including:
  - CONCAWE
    (European Oil Company Organisation for Environment, Health and Safety *(Belgium)*);
  - 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.2 Natural Gas

NSW Performance Report

The average leak frequency from the 2018 NSW Performance Report for all licensed pipelines in NSW for the 5-year period 2013/14 to 2017/18 is 8.2E-05 per km per year.

UK HSE (RR1035)

The total leak frequency data reported in Section 7.1 of RR1035 for underground natural gas pipelines (e.g. 5.1E-05 per km per year for a ≥ 305 mm diameter pipeline with wall thickness ≥ 10 mm) is very comparable the average leak frequency from the 2018 NSW Performance Report and was adopted in the risk analysis for the HP Natural Gas pipelines (Refer to Table 26).

Table 26: 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 Leak Frequency =	≥ 305	≥ 10	4.3E-05	4.9E-06	2.7E-07	2.6E-06	**5.1E-05**
% =			84.6	9.7	0.5	5.2	

British Standards Institute (PD 8010-3:2009+A1:2013)

The data and approach included in Annex B of PD 8010-3:2009+A1:2013 was used to estimate the leak frequencies for the HP Natural Gas Pipelines (Refer to Table 27 and Table 28). The data applicable for pipelines with a wall thickness > 10 mm to ≤ 15 mm was used.

The Jemena Gas Network pipeline was constructed prior to 1980, so the leak frequencies due to material and construction defects (mechanical failures) were not reduced by a factor of 5 for this pipeline (as per Section C.7 of PD 8010-3:2009+A1:2013).

The leak frequency for external corrosion is reported to be 0 for pipelines with a wall thickness > 10 mm to ≤ 15 mm. Leak frequency data is not reported for internal corrosion; therefore, the total leak frequencies reported in Table 27 and Table 28 may be underestimated.

For leaks or ruptures due to 'Ground Movement / Other', the landslide potential in the study area was assumed to be "low to nil" in accordance with the description in Table C.15 of PD 8010-3:2009+A1:2013.

For leaks (other than ruptures) due to 'Ground Movement / Other', the estimated leak frequency was assumed to be distributed evenly across the other hole sizes (Note: There is no guidance in PD 8010-3:2009+A1:2013 on how to distribute the non-rupture events).

For leaks (other than ruptures) due to 'TPA', the estimated leak frequency was assumed to be distributed across the smaller hole sizes and weighted to the smaller hole size categories (Note: There is no guidance in PD 8010-3:2009+A1:2013 on how to distribute the non-rupture events).

The rupture frequency due to 'TPA' was derived from the generic pipeline failure frequency, which was modified in accordance with the relevant parameters for the pipelines (i.e. location, design factor, wall thickness and depth of cover).

Table 27: Approx. Leak Frequencies for Jemena Eastern Gas Pipeline (EGP)

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	1.7E-05	0.0E+00	0.0E+00	0.0E+00	1.7E-05
Corrosion	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ground Movement / Other	2.8E-07	2.8E-07	2.8E-07	2.2E-08	8.7E-07
TPA	3.8E-05	2.5E-05	1.3E-05	8.6E-05	1.6E-04
Total Leak Freq. =	5.5E-05	2.6E-05	1.3E-05	8.6E-05	**1.8E-04**
% =	30.8	14.3	7.2	47.8	

Table 28: Approx. Leak Frequencies for Jemena Gas Network (CTM) Trunk Pipeline

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	1.7E-05	0.0E+00	0.0E+00	0.0E+00	1.7E-05
Corrosion	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ground Movement / Other	2.3E-07	2.3E-07	2.3E-07	6.8E-08	7.5E-07
TPA	1.3E-05	8.8E-06	4.4E-06	1.8E-05	4.4E-05
Total Leak Freq. =	3.0E-05	9.0E-06	4.6E-06	1.8E-05	**6.2E-05**
% =	49.3	14.6	7.5	28.6	

US Department of Transportation (DoT)

The Pipeline and Hazardous Materials Safety Administration (PHMSA), Accident Reports - Reported Data for Underground Natural Gas Steel Pipelines (January 2010 to September 2017) include incidents for Natural Gas transmission pipelines.

To enable a comparison with the UK data, the data for underground transmission pipelines was analysed and the leaks categorised using the same representative hole sizes as reported in the UK (i.e. RR1035 and PD8010). The results are reported in

Table 29.

Period of Recorded Incident Data =	7.75	years	(Jan 2010 to Sept 2017)
Total Length of Natural Gas Pipelines =	479980	km	Note: Average for 2010 to 2017

Table 29: Leak Frequencies for Underground Natural Gas Transmission Pipelines

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	2.2E-06	5.4E-07	2.7E-07	0.0E+00	3.0E-06
Corrosion	9.7E-06	0.0E+00	2.7E-07	0.0E+00	9.9E-06
Ground Movement / Other	4.0E-06	1.1E-06	0.0E+00	2.7E-07	5.4E-06
TPA	3.2E-06	7.0E-06	4.0E-06	4.0E-06	1.8E-05
Total Leak Freq. =	1.9E-05	8.6E-06	4.6E-06	4.3E-06	**3.7E-05**
% =	52.2	23.5	12.5	11.8	

C.3 Likelihood of Representative Release Scenarios

The estimated likelihood of each representative release scenario is listed in Table 30 and Table 31.

Table 30: Release Frequency – Jemena Eastern Gas Pipeline (EGP)

Leak Scenario	Release Frequency (per km per year)			Probability of scenario compared to total
	TPA	All Other Failure Modes	Total Release Frequency	
10mm MID		2.08E-05	2.08E-05	0.4110
10mm TOP		0.00E+00	0.00E+00	0.0000
25mm MID	2.20E-05		2.20E-05	0.4347
25mm TOP	0.00E+00		0.00E+00	0.0000
75mm MID	8.88E-07	9.32E-07	1.82E-06	0.0360
75mm TOP	1.51E-06	1.59E-06	3.10E-06	0.0612
110mm MID	3.70E-08	6.29E-08	9.99E-08	0.0020
110mm TOP	6.30E-08	1.07E-07	1.70E-07	0.0034
FBR	1.00E-07	2.52E-06	2.62E-06	0.0518
Total	2.46E-05	2.60E-05	**5.061E-05**	1.0000

Table 31: Release Frequency – Jemena Gas Network Central Trunk Main (CTM)

Leak Scenario	Release Frequency (per km per year)			
	TPA	All Other Failure Modes	Total Release Frequency	
10mm MID		2.08E-05	2.08E-05	0.4110
10mm TOP		0.00E+00	0.00E+00	0.0000
25mm MID	2.20E-05		2.20E-05	0.4347
25mm TOP	0.00E+00		0.00E+00	0.0000
75mm MID	8.88E-07	9.32E-07	1.82E-06	0.0360
75mm TOP	1.51E-06	1.59E-06	3.10E-06	0.0612
110mm MID	3.70E-08	6.29E-08	9.99E-08	0.0020
110mm TOP	6.30E-08	1.07E-07	1.70E-07	0.0034
FBR	1.00E-07	2.52E-06	2.62E-06	0.0518
Total	2.46E-05	2.60E-05	**5.061E-05**	1.0000

C.4 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.4.1 - **Error! Reference source not found.**).

Ethane

1. The total ignition probability was based on OGP Scenario 3, which is release rate dependent (Refer to Section C.4.1).

   No historical ignition data was identified for ethane pipelines; however, it is typically grouped with other liquefied gases such as propane.

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 QRA.

Natural Gas

1. The total ignition probability was based on OGP Scenario 3, which is release rate dependent (Refer to Section C.4.1).

   The correlation proposed by Acton & Baldwin (Refer to Section C.4.2) 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.4.2) 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.4.2).

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.4.1 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 32: 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

C.4.2 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:

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

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

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 33: 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
433.6	148.95	FBR	28.00	0.220	0.220	0.439
		110	1.80	0.034	0.034	0.068
		75	0.84	0.031	0.031	0.061
		25	0.09	0.028	0.028	0.056
		10	0.01	0.028	0.028	0.056
836.8	50	FBR	35.01	0.268	0.268	0.535
		110	77.03	0.030	0.030	0.060
		75	52.52	0.029	0.029	0.057
		25	0.03	0.028	0.028	0.056
		10	0.01	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 34: 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 35: 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 36: Ignition Probability – Data Cited by UK HSE (RR 1034)

Data source	Ignition probability	
World-wide, Townsend & Fearnehough (1986)	Leaks	0.1
	Ruptures	0.5
US Gas, Jones (1986)	Ruptures	0.26
	All sizes	0.16
European Gas, European Gas Pipeline Incident Data Group (1988)	Pinholes / cracks	0.02
	Holes	0.03
	Ruptures < 16”	0.05
	Ruptures ≥ 16”	0.35
	All sizes	0.03