Bexley North Hotel

Ethane Pipeline Risk Assessment

For Planning Ingenuity

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

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

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

Distribution List

Name	Organisation	From (Issue)	To (Issue)
Trevor Tang	Bexley North Hotel	A	Current
David Waghorn	Planning Ingenuity	A	Current

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Summary

This report is a Hazard Analysis (HA) to determine if proposed redevelopment at the Bexley North Hotel (BNH) in the suburb of Bexley North can be accommodated while satisfying the NSW Department of Planning, Industry and Environment's risk criteria as described in HIPAP 10.

Arriscar Pty Limited (Arriscar) has been requested by Planning Ingenuity, on behalf of Bexley North Hotel, to prepare a HA for the proposed development. The Bexley North Hotel development is located within the Notification Zone of the Moomba to Sydney Ethane (MSE) Pipeline that runs through the north western portion of the Bayside Council Local Government Area.

Based on a comprehensive review of pipeline safety literature, a set of failure scenarios were selected for each pipeline, varying from a small hole of 10-25mm in diameter to a full-bore rupture (FBR). Immediate ignition of release gas would result in a jet fire that will continue until the section of pipeline is isolated, and the isolated inventory depleted. A delayed ignition may result in a flash fire or vapour cloud explosion depending on congestion and may be followed by a jet fire.

Based on generic failure rates for natural gas and liquefied flammable gas pipelines in the literature, the most appropriate data was used for the risk assessment. The 'long pipeline model' in DNVGL's SAFETI 8.23 software was used. The resulting risk values were compared with the risk criteria in HIPAP No.10 [1].

The following results were obtained from the risk assessment:

- The individual risk of fatality at the BNH is less than 1.0 x 10^{-6} p.a. and does not exceed the corresponding risk criterion for residential uses and places of continuous occupancy, such as hotels in HIPAP No.10 [1].
- The individual risk of fatality at the BNH is 0.5 x 10^{-6} p.a. and exceeds the risk criterion for sensitive use in HIPAP No.10 [1]. The current planning proposal does not include sensitive land uses.
- All other individual risk levels comply with the corresponding quantitative risk criteria in HIPAP No.10 [1] (Refer to Sections 6.2 to 6.7).
- The entirety of the F-N curve is in the 'Negligible' or 'ALARP' regions and complies with the DPIE's indicative societal risk criteria (Refer Section 6.8).
- Recommendations have been made to ensure ongoing compliance with HIPAP 10.

Conclusions and Recommendations

The following recommendations are mode to ensure compliance with the HIPAP 10 land use criteria:

1. If further population intensification is considered, i.e. a significantly larger number of apartments, or increased commercial populations, than an additional risk analysis should be undertaken to ensure the societal risk criteria are still met.
2. As the 0.5x10^{-6} p.a. risk contour is exceeded at the site, sensitive land uses should not considered for this site.

Contents

List of Figures

List of Tables

Notation

Abbreviation	Description
APD	Australian Pipeline Database
APGA	Australian Pipeline and Gas Association
Arriscar	Arriscar Pty Limited
BoM	Bureau of Meteorology
BNH	Bexley North Hotel
CIA	Chemical Industries Association
Council	Bayside Council
DBYD	Dial Before You Dig
DoT	United States Department of Transport
DPIE	Department of Planning Industry and Environment
FBR	Full Bore Rupture
HAZID	Hazard Identification
HDD	Horizontal Directional Drilling
km	Kilometre
kPa	Kilo Pascals
kW/m^2	kiloWatts per square metre
LEP	Local Environmental Plan
LFL	Lower Flammable Limit
LGA	Local Government Area
LSIR	Location Specific Individual Risk
m	Metre
m/s	Metres per second
MAE	Major Accident Event
MAOP	Maximum Allowable Operating Pressure
mg/m^3	Milligrams per cubic metre
mm	millimetres
MPa	Mega Pascals
MSE	Moomba-Sydney Ethane pipeline
NSW	New South Wales
OGP	Oil and Gas Producers Association
p.a.	Per annum

Abbreviation	Description
QRA	Quantitative Risk Assessment
TPA	Third Party Activity
UK HSE	United Kingdom Health and Safety Executive
VCE	Vapour Cloud Explosion

1 INTRODUCTION

1.1 Background

The Bexley North Hotel is proposing to redevelop the site existing site at 187 Slade Road, Bexley North, NSW, [Lot 30 in DP 1222252]. The site currently consists of a single storey brick structure, the Bexley North Hotel, incorporating a drive through bottle shop and beer garden, as well as a two-storey hotel with undercroft parking [2].

Arriscar Pty Limited (Arriscar) has been requested by Planning Ingenuity, on behalf of Bexley North Hotel, to prepare a Hazard Analysis (Study) for the proposed development. The Bexley North Hotel development is located within the Notification Zone of the Moomba to Sydney Ethane (MSE) Pipeline that runs through the north western portion of the Bayside Council Local Government Area.

Undertaking a hazard analysis, including consultation with the pipeline operators, is a requirement of the Department of Planning, Industry and Environment (DPIE). The specific wording of DPIE's requirements is as follows:

1. Report on the consultation outcomes with the operator (APA Group) of high pressure dangerous goods or gas pipelines in the vicinity of the proposal with regards to Australian Standard 2885 Pipelines – Gas and liquid petroleum (AS 2885); and
2. A hazard analysis undertaken in accordance with the Department of Planning's Hazardous Industry Planning Advisory Paper No. 6, 'Hazard Analysis' and Multi-Level Risk Assessment (DoP, 2011). The hazard analysis must demonstrate that the proposed development would comply with the relevant qualitative and quantitative risk criteria detailed in the Department of Planning's Hazardous Industry Planning Advisory Paper No. 10, 'Land Use Safety Planning'.

1.2 Scope

The scope of the study included undertaking a hazard analysis for the high-pressure pipelines in the vicinity of 187 Slade Road Bexley North, in accordance with HIPAP No. 6 [3] and DPIE's specific requirements for the proposed redevelopment (Refer to Section 1.1). It included an assessment of the risks against the risk criteria for land use safety planning in HIPAP No. 10 [1].

The scope of the HA did not include preparation of a Safety Management Study (SMS), which may be required under AS 2885-2008 [4].

1.3 Objectives

The principal objective of the study was to perform a risk assessment covering the scope outlined in Section 1.2 and in accordance with the NSW HIPAP guidelines [3]. This included:

- Identification of release events from the ethane pipeline in the vicinity of the proposed development;
- Development of appropriate and relevant representative release scenarios that may impact on the proposed development;
- Quantification of the consequences of harmful effects for each representative scenario (fires, explosions, exposure to unignited gas), including the potential for impact on the proposed development;
- Quantification of the likelihood of occurrence of each representative scenario;

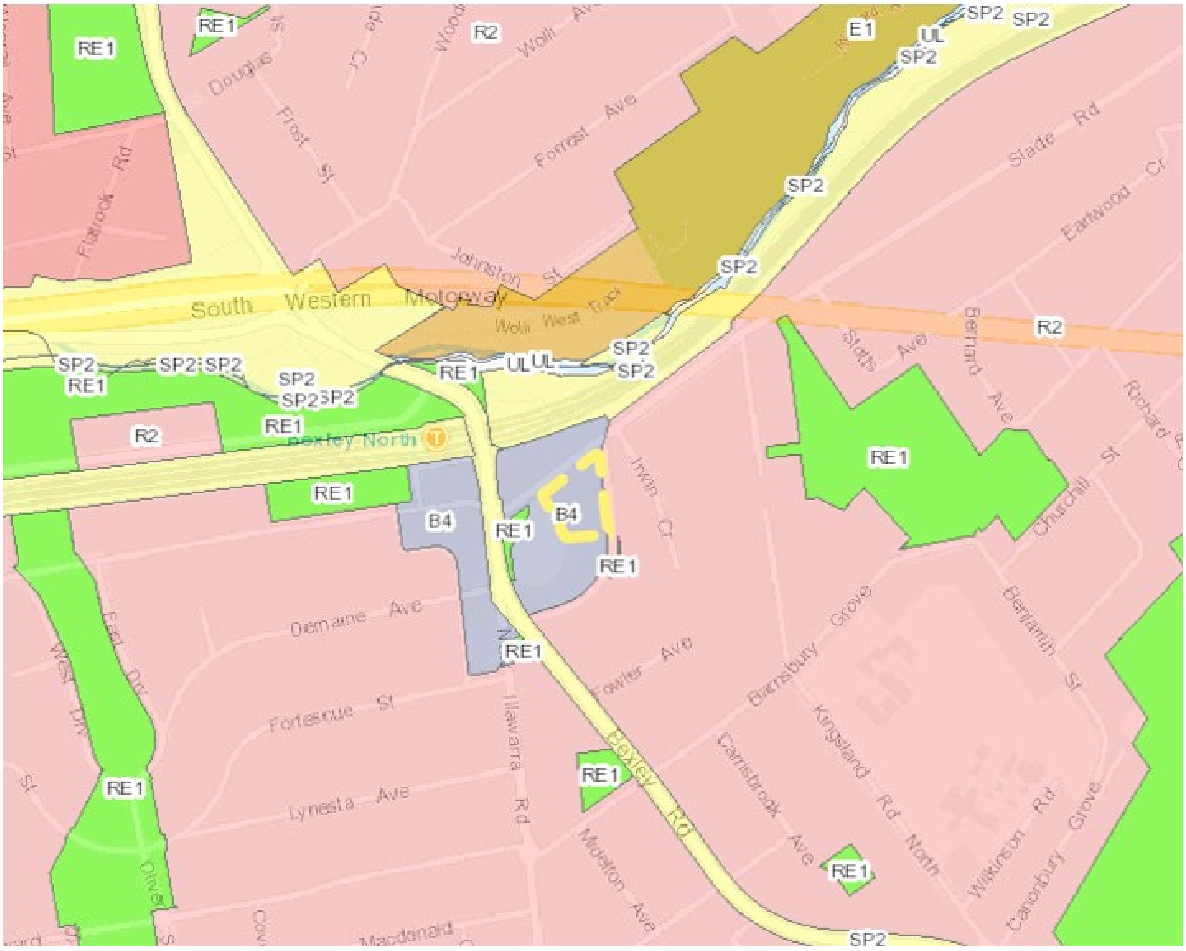
- Development and justification of assumptions for the risk assessment that are appropriate, with a focus on minimising uncertainty and obtaining a 'cautious best estimate' of risk to the proposed development;
- Generation of Location-Specific Individual Risk (LSIR) contours for comparison with the DPIE's risk criteria for land use safety planning, viz. as per HIPAP No.4 [5] and HIPAP No.10 [1]; and
- Estimation of societal risk for comparison with the DPIE's indicative risk criteria for land use safety planning, viz. as per HIPAP No. 4 [5] and HIPAP No.10 [1].

2 SITE DESCRIPTION

2.1 Existing and Surrounding Land Uses

The development at 187 Slade Road Bexley North is in the Bayside Council LGA. The current land use zoning for the site is B4 'Mixed Use'. The land surrounding the development is primarily zoned; R2 Low Density Residential, B4 Mixed Use, RE1 Public Recreation, and SP2 Special Purpose (road and rail infrastructure).

Figure 1 Current Land Use Zoning [6]



2.2 Proposed Site Location and Zoning

The proposed development is for two buildings with onsite parking and landscaping as shown in Figure 2 and Figure 3. Building 1 is a 9-level building [7] including a pub, gym, retail, and both hotel and residential apartment accommodation. Building 2 is a 5-level building including retail and residential apartment accommodation. The two buildings are connected via an underground carpark.

Figure 2 Proposed Site Layout – Ground Floor [7]

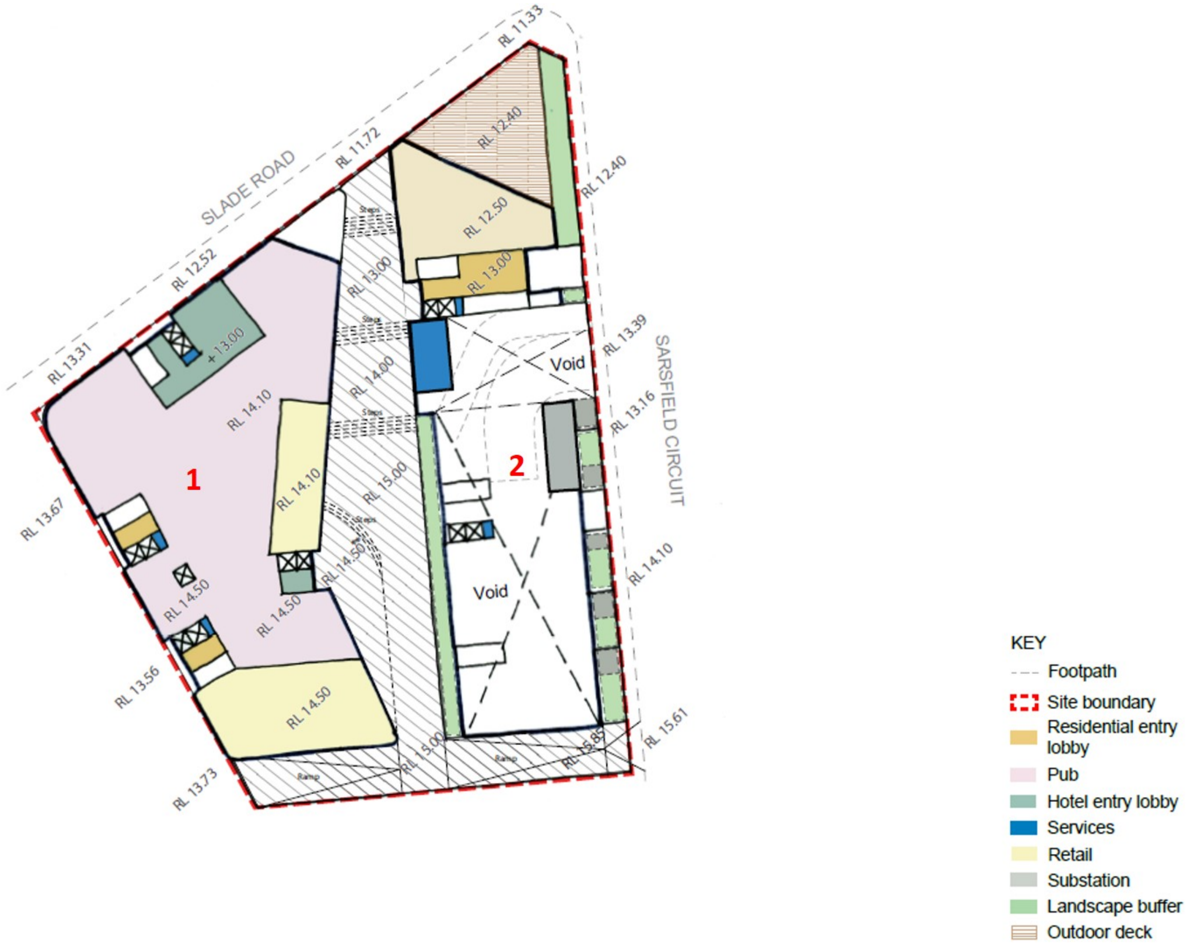
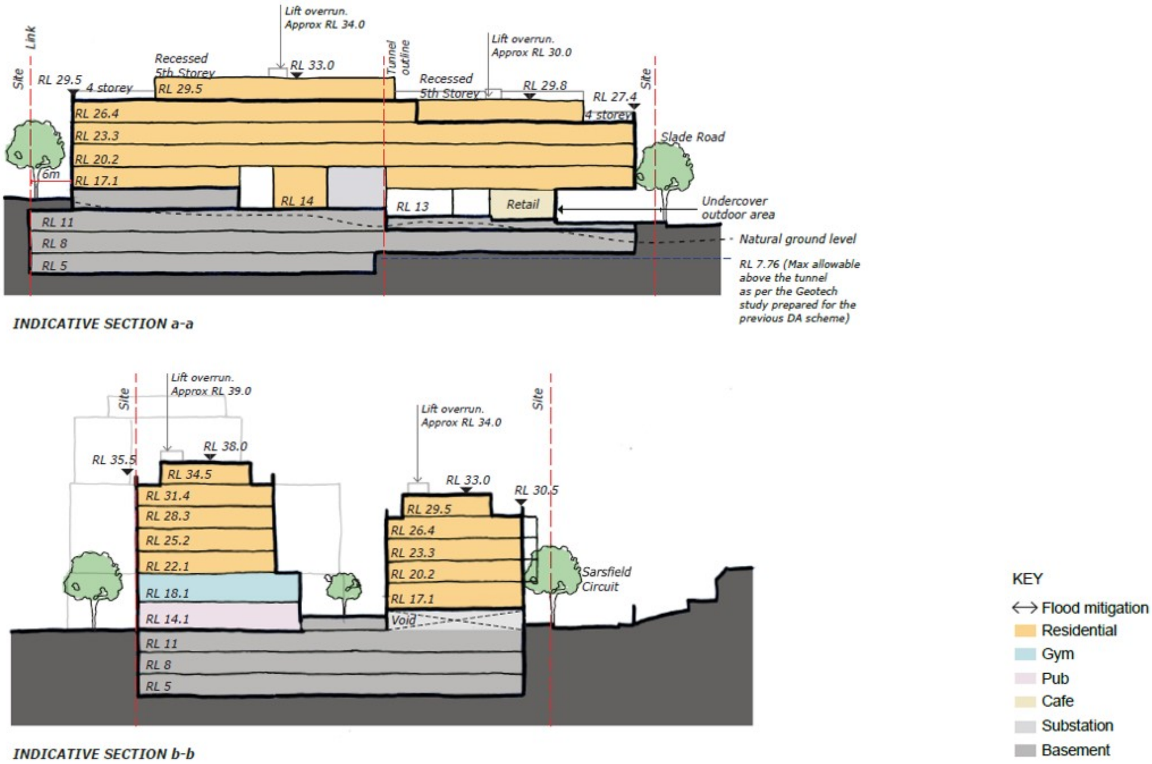


Figure 3 Proposed Site Layout – Elevations



The assumed population data for the various land uses is given in Appendix A.2 (Assumption No. 7 and Assumption No. 8).

2.3 Ethane Pipeline

The Moomba Sydney Ethane pipeline (MSE) runs parallel to the T8 South Line railway. The location of the MSE in relation to the BNH is shown in Figure 2. The pipeline is owned by APA Group, which has been contacted by Arriscar for details of the MSE close to the BNH. Information obtained from APA is presented in Table 1.

Figure 4 Location of the MSE in Relation to the BNH

Table 1 Data for the MSE Pipeline in Proximity to the BNH

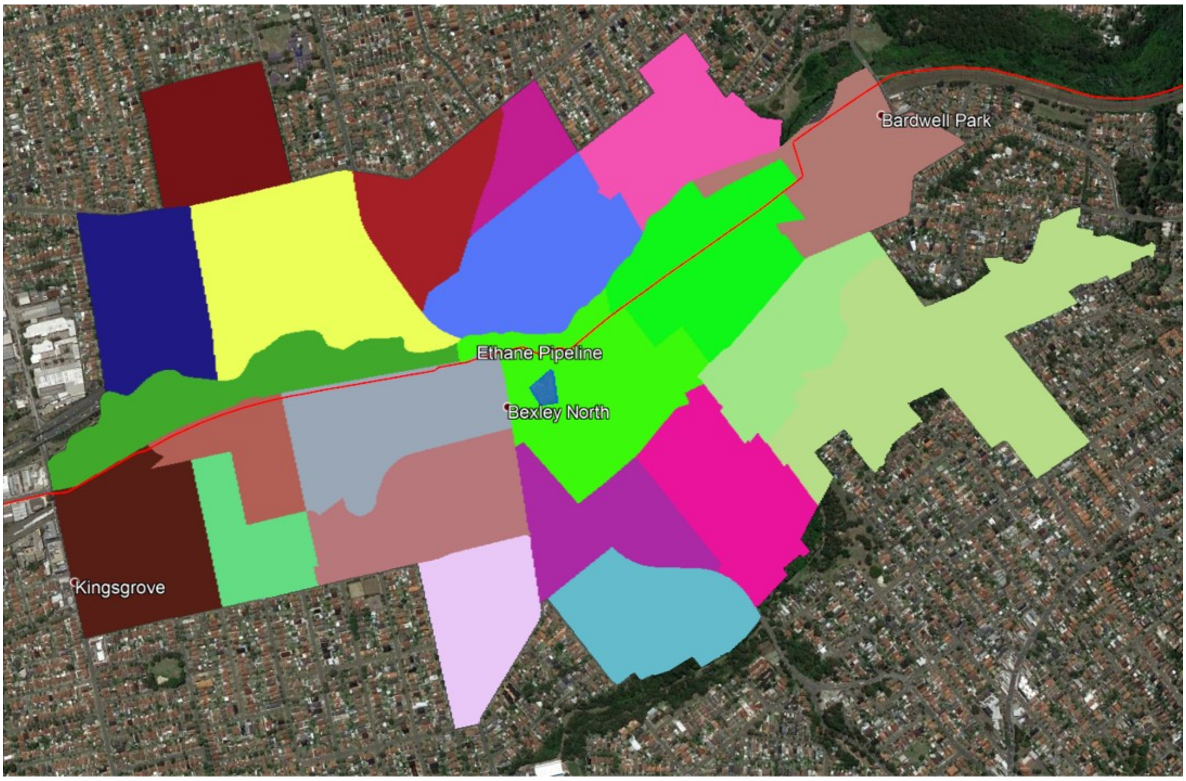
Description	MSE Pipeline
Pipeline Owner	Gorodok Pty Ltd (part of APA Group)
Pipeline Name	Moomba to Sydney Ethane Pipeline
Product in pipeline	Ethane
Pipeline Licence (NSW)	New South Wales Licence No 15
MAOP (Maximum allowable operating pressure)	10,000kPa
Actual Operating Pressure	8,200kPa
Operating Temperature	Typical 20°C
Material flow rate (pumping rate)	Typical 30 Tonne per hour
Pipeline Material	API -5L grade X60
Pipeline Diameter	200mm NB
Pipeline Wall Thickness	11.9mm in area of concern
Critical defect length	332mm
Minimum depth of cover	>1200mm – Varies between 1200 and 2500mm
Cathodic Protection for pipeline	Impressed Current Cathodic Protection applied.
External Coating on pipeline	HDPE (Yellowjacket) Joint Coating is 2 layer Tape Wrap system
Location of ALBVs from first ALBV upstream of BNH to first ALBV downstream of BNH	Upstream LV - Moorebank Ave kp1344 Downstream LV - Marsh Street kp1368
Pressure set points for ALBVs and approximate closure time	4500kPa

Description	MSE Pipeline
Frequency of inspections and patrols undertaken	Ground Patrol Daily (Monday to Friday) Aerial Patrol Fortnightly
Control measures for third party activity near pipeline	11.9mm pipe wall thickness >1.2m depth of cover 25mm Concrete Coating of pipeline (Rockjacket) Either Top slabbing or top and side slabbing in all areas of concern apart from Rail Easements Marker Posts DBYD Patrols Aerial patrol fortnightly Daily ground patrol Liaison with Councils, telecommunications companies, Electricity companies
Pigging done for pipeline? If so, how often?	Metal Loss intelligent pigging carried out on a risk basis program but is undertaken at 5 yearly presently
Was intelligent pigging carried out to determine rate of loss of wall thickness?	Yes – no wall thickness loss has been found in this section of pipeline
Location of nearest upstream pump / compressor station and pressure at this point	Bulla Park
Are there non-return valves located in the pipeline downstream of and where?	Bexley Rd kp1363 just off Bexley Rd approximately 110m from Bexley North Hotel. No further NRV's downstream

2.4 Surrounding Suburbs and Populations

The Statistical Area 1 locations for suburbs surrounding the BNH within the notification length of the MSE pipeline are shown in Figure 5 for which the populations as at the 2016 census were compiled.

Figure 5 Surrounding Suburbs and Population Statistical Areas



3 RISK ASSESSMENT METHODOLOGY

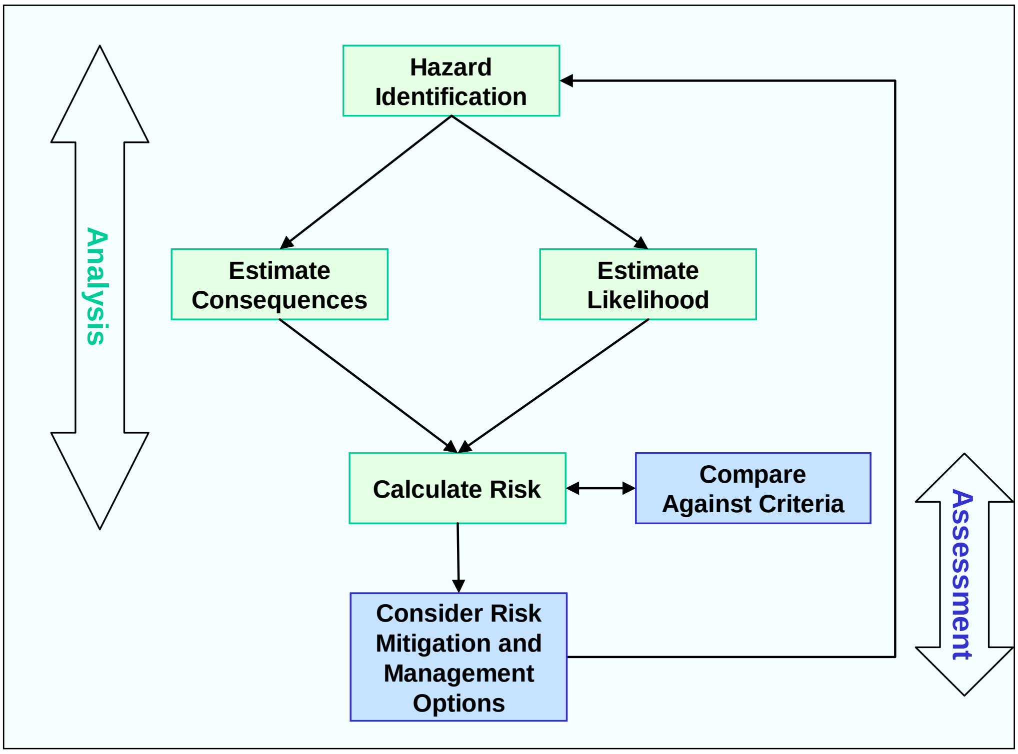
3.1 Introduction

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 [3].

Diagrammatically, the QRA process is as follows:

Figure 6 Overview of QRA Process [3]



3.2 Methodology Overview

3.2.1 Hazard Identification and Register of Major Accident Events

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

For example, the Hazard identification (or HAZID) step for a QRA of a potentially hazardous pipeline would identify representative events that could result in a release of the material from the pipeline with the potential to cause harm (e.g. due to a subsequent ignition and fire/explosion). The representative potentially hazard events are commonly described as 'Major Accident Events' (or MAEs). In the context of the QRA, an MAE is an event with the potential to cause: off-site fatality or injury; off-site property damage; or, long-term damage to the biophysical environment (i.e. any outcome for which DPI&E has defined an acceptable risk criterion – Refer to Section 3.4).

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 MAEs 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.

3.2.2 Hazard Consequence Analysis

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

- the quantity released;
- the rate of release; and,
- for fire and explosion events 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 Pasquill 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 Pasquill stability classes is site-specific, it is generally observed that Class F conditions are more likely to occur during the night-time while Class D (neutral) conditions occur during the daytime (sunny conditions).

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

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

3.2.3 Impairment Criteria

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

Explosion

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

The impact of explosion overpressure on humans takes two forms:

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

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

Table 2 Effects of Explosion Overpressure

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

Fire

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

The effects of exposure to thermal radiation are summarised in Table 4 [3]. The vulnerability criteria used in the risk analysis are included in Appendix A.6.

Table 3 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.

3.2.4 Frequency and Likelihood Analysis

Once the consequences of the various accident scenarios have been estimated, it is necessary to estimate the likelihood of each scenario. In a QRA, the likelihood must be estimated in quantitative terms (i.e. occurrences per year). Exponential notation (e.g. 5.0×10^{-6} per year or 5E-06 per year) is normally used because the likelihood of a MAE 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 4.3 and Appendix C.

3.2.5 Risk Analysis and Assessment

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

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

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

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

The latest SAFETI 8.23 software package was used to generate the iso-risk contours / transects and societal risk results (Refer to Section 6).

3.3 Study Assumptions

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

To comply with the general principles outlined in Section 2.2 of HIPAP No. 6 [3], all steps taken in the risk analysis should be: "*traceable and the information gathered as part of the analysis should be well documented to permit an adequate technical review of the work to ensure reproducibility, understanding of the assumptions made and valid interpretation of the results*". Therefore, details of the key assumptions adopted for the risk analysis are provided in Appendix A.

3.4 Quantitative Risk Criteria

3.4.1 Individual Fatality Risk

The individual fatality risk imposed by a proposed (or existing) industrial activity should be low relative to the background risk. This forms the basis for the following individual fatality risk criteria adopted by the NSW DPIE [1] and [5].

Table 4 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 DPIE has adopted a fatality risk criterion of 1 x 10^{-6} per year (or 1 chance of fatality per million per year) for residential area exposure because this risk is very low in relation to typical background risks for individuals in NSW. For sensitive land uses such as schools, the criterion is one-half that for residential area, viz. 0.5 x 10^{-6} pe year.

3.4.2 Injury Risk

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

The DPIE'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/m² at a frequency of more than 50 chances in a million per year.*

The DPIE'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 DPIE'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.*

3.4.3 Risk of Property Damage and Accident Propagation

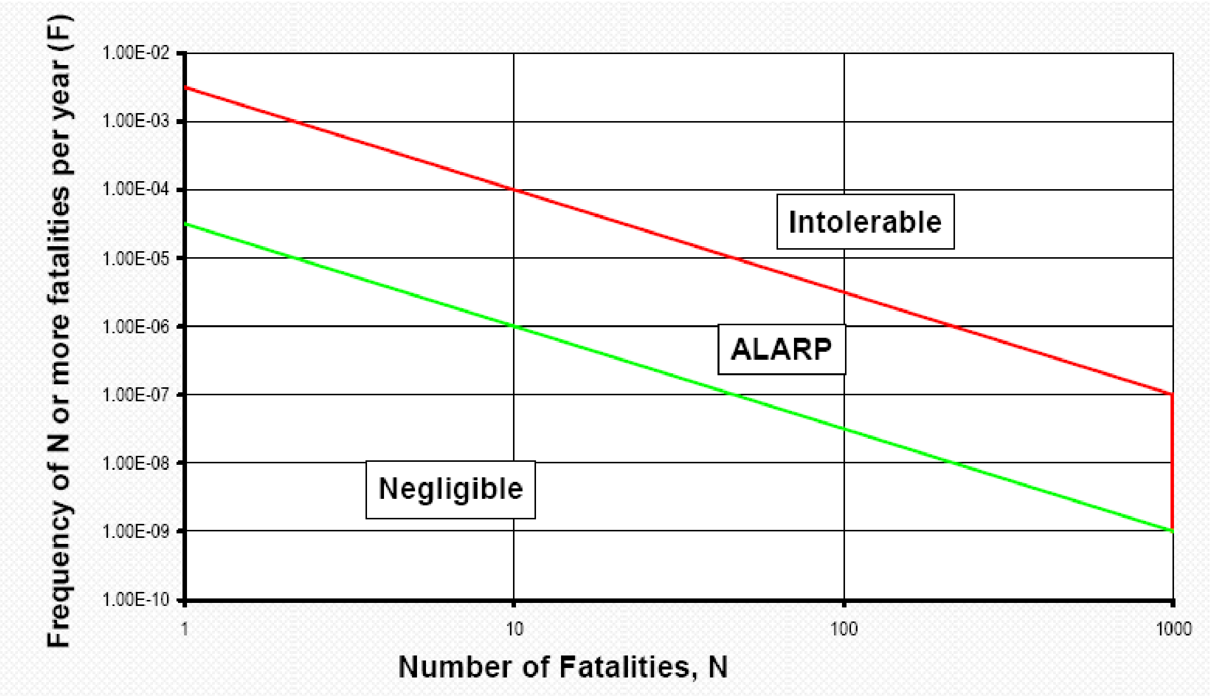
Heat radiation exceeding 23 kW/m^2 may cause unprotected steel to suffer thermal stress that may cause structural damage and an explosion overpressure of 14 kPa can cause damage to piping and low-pressure equipment. The DPIE's criteria for risk of damage to property and accident propagation are as follows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

- *Incident heat flux radiation at neighbouring potentially hazardous installations or at land zoned to accommodate such installations should not exceed a risk of 50 in a million per year for the 23 kW/m² heat flux level.*
- *Incident explosion overpressure at neighbouring potentially hazardous installations, at land zoned to accommodate such installations or at nearest public buildings should not exceed a risk of 50 in a million per year for the 14 kPa explosion overpressure level.*

3.4.4 Societal Risk

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

Figure 7 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 [5] also states that the criteria in Figure 5 are an indicative criteria and provisional only and do not represent a firm requirement in NSW.

3.5 Qualitative Risk Criteria

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

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

4 HAZARD IDENTIFICATION

4.1 Introduction

The hazard identification was based on a review of the: information on the MSE pipeline; properties of Ethane; 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 Ethane.

Section 4.3 - Pipeline Failure Modes.

Section 4.4 - Consequences.

Section 4.5 - Control Measures.

The representative MAEs carried forward to the consequence analysis are listed in Section 4.6.

4.2 Properties of Ethane

Ethane is principally used as a raw material for the manufacture of ethylene. It is modelled as 100% Ethane in the QRA.

Physical properties are listed in Table 6.

Table 5 Physical Properties of Ethane

Boiling Point	-88.6 °C
Autoignition Temperature	515 °C
Relative Density (Air =1)	1.05
Lower Flammability Limit in air (vol. %)	2.4%
Upper Flammability Limit in air (vol. %)	14.3%

Ethane is:

- A gas at ambient conditions;
- Flammable;
- A similar density to air at ambient temperatures; and
- Colourless and non-toxic.

Ethane is transported by pipeline as a liquefied gas under pressure.

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 [8]:

- **Mechanical failures**, including material defects or design and construction faults;
- **Corrosion**, including both internal and external corrosion;
- **Ground movement and other failure modes**, including ground movement due to earthquakes, heavy rains/floods or operator error, and other natural hazards such as lightning, etc.; and

- **Third Party Activity (TPA)**, including damage from heavy plant and machinery, damage from drills/boring machines and hot tapping, etc.

The relative likelihood of each failure mode is shown in Appendix C 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 MSE pipeline; however, historical incident data for other pipelines (Refer to Appendix C) indicates this is generally a low likelihood failure mode, particularly for more recently manufactured pipelines (i.e. post 1980).

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 MSE pipeline; however, historical incident data for other pipelines (Refer to Appendix C) indicates this is a low likelihood failure mode, particularly for pipelines with a higher wall thickness (i.e. > 10 mm) 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 the MSE pipeline.

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 the MSE pipeline.

4.4 Consequences of Gas Release

4.4.1 Asphyxiation

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

thane 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 [9]) 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 641,000 mg/m^3 for Ethane).

Oxygen deficiency from exposure to Ethane should not be a major issue because the fire hazards are usually the dominant effects in most locations (the LFL for Ethane is approximately one-twentieth, or 5%, 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

A release of Ethane at 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.).

4.4.5 Gas Ingress into Buildings

The gas jet 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. Ethane 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.

4.5 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 [10] 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 [11] 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.

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.

The MSE pipeline is inspected using ‘intelligent pigging’ (Refer to Section 2.2) and has a significant wall thickness (11.9 mm). It is equipped with a cathodic protection system and a double layered HDPE coating (Refer to Section 2.2).

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 [12], 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).

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.

Two key control measures are typically implemented by pipeline operators to minimise the likelihood of impact from TPA: the 'Dial Before You Dig' (DBYD) 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 DBYD before any excavation work [13].

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 MSE pipeline can be isolated by closing automated and/or manual valves (Refer to Section 2.3 for locations of upstream and downstream isolation valves).

4.6 MAEs for Risk Analysis

The list of MAEs included in the risk analysis is provided in Table 7.

Table 6 List of MAEs

MAE	Potential Consequences
Release of High Pressure Ethane from APA Moomba-Sydney Ethane Pipeline	Jet Fire, Flash Fire or Explosion

5 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), 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.
- There is insufficient historical incident data for Ethane to determine the representative hole diameter/s in each hole size category. Therefore, the representative hole diameters were assumed to be the same as proposed by the UK HSE for LPG.

Table 7 Representative Hole Diameters Selected for Consequence Analysis

Pipeline/s	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)
APA Ethane Pipeline	202.9	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 estimated release rates are tabulated below for each representative hole size.

Table 8 Representative Hole Diameters Selected for Consequence Analysis

MAE	Hole Diameter (mm)	Release Rate [kg/s]
Release of High Pressure Ethane from APA Moomba-Sydney Ethane Pipeline	10	3.5
	25	21.7
	75	195.4
	110	420.2
	FBR	317.8 *

* Average release rate from 'Long Pipeline' model for t = 0 to 20 seconds.

5.1.3 Height and Orientation of Release

All releases were modelled as vertical releases at ground level. The SAFETI GASPIPE module determines a crater size and air entrainment for a release from a buried pipeline.

The release of high pressure gas or liquefied gas from a buried pipeline would result a crater and gas would be released vertically from the crater [14].

5.1.4 Duration of Release

Ethane 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 pipeline (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 latest SAFETI software package (Version 8.23) 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.1.2 for representative jet fire events included in the risk analysis.

5.2.2 Flash Fire

Example distances to the lower flammability limit (LFL) concentration are tabulated in Appendix B.1.2 for representative flash fire events included in the risk analysis.

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 Multi-Energy model in SAFETI was used to estimate the overpressure for a VCE. Results are provided in Appendix B.2.4.

6 RISK ANALYSIS

6.1 Individual Risk of Fatality

The risk contours for individual risk of fatality at 1.0 and 0.5 x 10^{-6} per annum (p.a.) for the MSE pipeline are shown in Figure 8. These are the risk criteria in HIPAP No.10 [1] for: (i) residential uses and places of continuous occupancy, such as hotels; and (ii) sensitive land uses.

Figure 8 Location Specific Individual Fatality Risk Contours

The 1.0 x 10^{-6}p.a. risk contour is not reached at the BNH site. The 0.5 x 10^{-6} risk contour crosses the northern corner of the site. This location on the site is proposed to be for outdoor decking and retail, Figure 2, and not for sensitive use.

6.2 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 the proposed BNH development complies with the relevant DPIE risk criteria (Refer to Section 3.4.2).

6.3 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. This criterion does not apply to the proposed BNH development (Refer to Section 3.4.3).

6.4 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. This criterion does not apply to the proposed BNH development (Refer to Section 3.4.3).

6.5 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, the proposed BNH development complies with the relevant DPIE risk criterion (Refer to Section 3.4.2).

6.6 Risk of Injury (Exceeding 4.7 kW/m²)

The cumulative risk of injury (Heat radiation exceeding 4.7 kW/m^2) does not reach 50 x 10^{-6} per annum; therefore, the proposed BNH development complies with the relevant DPIE risk criteria (Refer to Section 3.4.2).

6.7 Qualitative Risk Criteria

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

- Avoidance of all 'avoidable' risks – The MSE pipeline is an existing facility and cannot be relocated to avoid risk exposure.
- Reduction, wherever practicable, of the risk from a major hazard, even where the likelihood of exposure is low.
- Containment, wherever possible, within the site boundary of the effects (consequences) of the more likely hazardous events – The effects (consequences) of the more likely hazardous events (i.e. the smaller representative hole sizes) do not reach the proposed BNH development (Refer to Appendix B.1.2).
- Recognition that if the risk from an existing installation is already high, further development should not be permitted if it significantly increases that existing risk – The risk to the proposed development meets the individual risk criteria.

6.8 Societal Risk

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

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

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

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

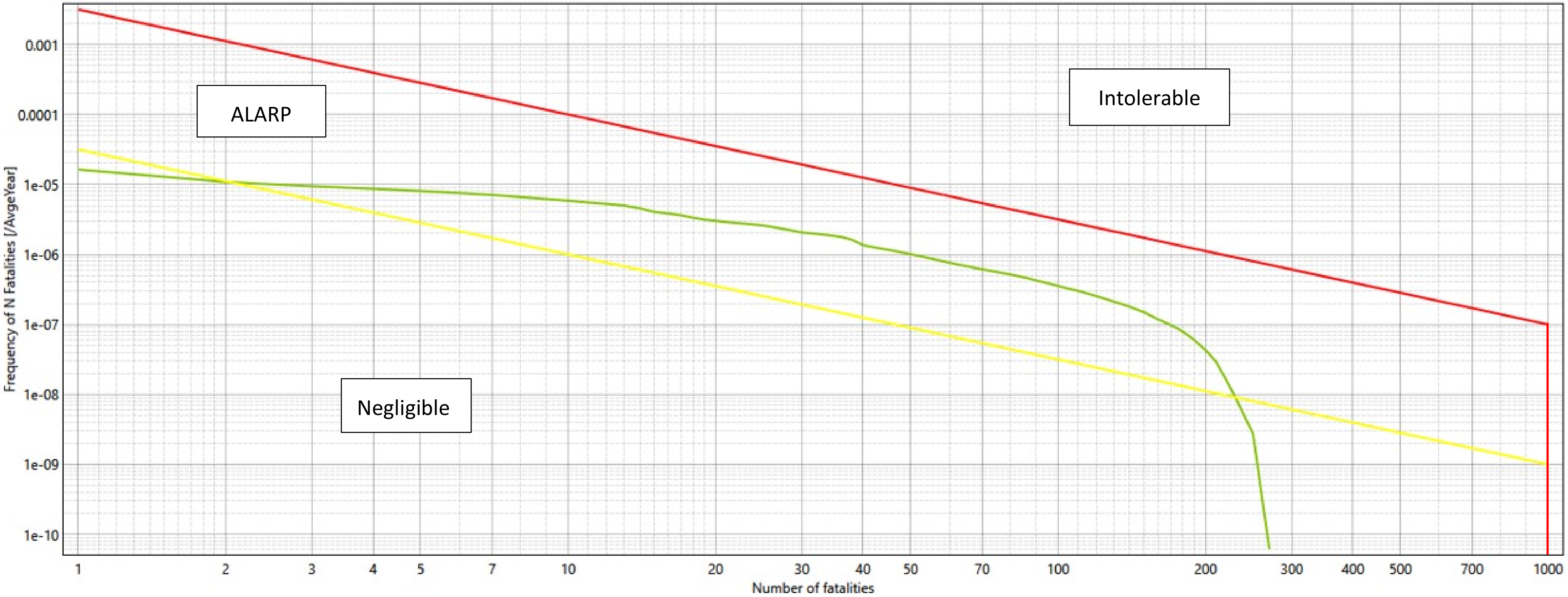
The F-N plot is cumulative in the sense that, for each frequency on the plot, N is the number of fatalities that could be equalled ***or exceeded***, and F is the frequency of exceedance of the specified number of fatalities.

In HIPAP 10 [1], the following is reported in regard to the F-N criteria:

If a development proposal involves an intensification of population in the vicinity of a potential source of risk, then the incremental change in societal risk needs to be taken into account, even if individual risk criteria are met [Ref.2, Section 5.5.4]. The incremental societal risk should be compared against the indicative societal risk criteria in Section 5.4.2 of HIPAP No. 10 [Figure 4 below]. If the incremental societal risk lies within the 'Negligible' region, then the development should not be precluded and if it lies within the 'Tolerable if ALARP' region, then options should be considered to relocate people away from the affected areas [Ref.2, Section 5.5.4]. If, after taking this step, there is still a significant portion of the societal risk plot within the 'Tolerable if ALARP' region, the proposed development should only be approved if benefits clearly outweigh the risks [Ref.2, Section 5.5.4].

An FN curve depicting the societal risk from the MSE pipeline in the area is shown in Figure 9. The entirety of this curve is in the 'Negligible' or 'ALARP' regions and complies with the DPIE's indicative societal risk criteria.

Figure 9 Societal Risk



7 FINDINGS AND RECOMMENDATIONS

7.1 Findings

The following findings were made from the risk assessment:

- The individual risk of fatality at the BNH is less than 1.0×10^{-6} p.a. and does not exceed the risk criterion for residential uses and places of continuous occupancy, such as hotels in HIPAP No.10 [1].
- The individual risk of fatality at the BNH is 0.5×10^{-6} p.a. and exceeds the risk criterion for sensitive use in HIPAP No.10 [1]. The current planning proposal does not include sensitive land uses.
- All other individual risk levels comply with the corresponding quantitative risk criteria in HIPAP No.10 [1] (Refer to Sections 6.2 to 6.7)
- The entirety of the F-N curve is in the 'Negligible' or 'ALARP' regions and complies with the DPIE's indicative societal risk criteria (Refer Section 6.8)
- Recommendations have been made to ensure ongoing compliance with HIPAP 10.

7.2 Recommendations

The following recommendations are mode to ensure compliance with the HIPAP 10 land use criteria:

1. If further population intensification is considered, i.e. a significantly larger number of apartments, or increased commercial populations, then an additional risk analysis should be undertaken to ensure the societal risk criteria are still met.
2. As the 0.5×10^{-6} p.a. risk contour is exceeded at the site, sensitive land uses should not considered for this site.

8 REFERENCES

[1] NSW Department of Planning, “Hazardous Industry Planning Advisory Paper No.10 - Land Use Safety Planning,” Sydney, 2011.

[2] Planning Ingenuity , “Planning Proposal Report - 187 Slade Rd Bexley North,” Sydney, 2020.

[3] NSW Department of Planning, “Hazardous Industry Planning Advisory Paper No.6 - Hazard Analysis,” Sydney, 2011.

[4] Standards Australia, “AS/NZS 2885.0:2018 - Pipelines - Gas and Liquid Petroleum - General Requirements,” 2018.

[5] NSW Department of Planning, “Hazardous Industry Planning Advisory Paper No.4 - Risk Criteria for Land Use Safety Planning,” Sydney, 2011.

[6] “NSW Land Use Maps,” New South Wales Government, [Online]. Available: https://www.planningportal.nsw.gov.au/spatialviewer/#/find-a-property/lga. [Accessed 20 December 2020].

[7] GMU Urban Design and Architecture, “Revised Concept Plans 18054-PP-Bexley North 187 Slade Rd,” Sydney, 2020.

[8] Health and safety Laboratory, “Research Report RR 1035 - Update of pipeline failure rates for land use planning assessments,” HSE Books, London, 2015.

[9] Occupational Safety and Health Administration, “Precautions and the order of testing before entering confined and enclosed spaces and other dangerous atmospheres.,” US Department of Labour, Washington, D.C., 1995.

[10] Standards Australia, “AS 2885.0 - Pipelines - Gas and Liquid Petroleum. Part 0 - General Requirements,” 2008.

[11] Standards Australia, “Pipelines - Gas and Liquid Petroleum Operations and Maintenance,” 2012.

[12] Standards Australia, “Pipelines - Gas and liquid petroleum Design and construction,” 2018.

[13] NSW Planning & Environment, “New South Wales 2017-18 Gas Networks Performance Report,” 2018.

[14] DNVGL, “SAFETI 8.2.3 Technical reference manual,” 2019.

[15] E. N. F. e. M. P. a. K. Silva, “Underground parallel pipelines domino effect: An analysis based on pipeline crater models and historical accidents,” vol. 43, no. June, 2016.

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 MAEs potentially affected. Key references are also listed for each assumption, where relevant.

It is important that the assumptions be supported by:

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

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

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 Section 2.2.
Justification and Impact/s of Assumption/s: • All operational data for the pipelines was provided by the pipeline owner (APA Group). • Operating conditions (particularly operating pressure) are required to undertake the release and dispersion modelling.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group.

Assumption No. 2 Pipeline Utilisation
Subject: Operational Data
Assumption/s: • The MSE pipeline is 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.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group.

A.2 Locational Data

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

Subject: Locational Data

Assumption/s:

- The probabilistic distribution of wind speed and wind direction for the representative stability classes is provided in Table 11 and Table 12.
- The data was split into daytime and night time conditions.
- 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.

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 Bankstown Airport weather station. This raw data was rationalised into a set of wind speed/weather stability classes for dispersion calculations. The Bankstown Airport weather station was selected as being the closest to the BNH 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).
- The day/night split of the weather data is required to allow for the fact that residential, commercial and industrial occupancies change over a 24 hour period.

MAE/s Affected:

- All.

Reference/s:

- BoM meteorological data for Bankstown AWS.

Table 9 Probability of Representative Stability Classes and Wind Speeds (Day)

Stab. Class	Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
B	3.0	0.025	0.012	0.011	0.011	0.014	0.009	0.008	0.006	0.010	0.008	0.011	0.013	0.023	0.022	0.020	0.020	0.222
D	7.4	0.006	0.001	0.008	0.020	0.018	0.029	0.038	0.036	0.027	0.005	0.007	0.015	0.022	0.015	0.006	0.006	0.259
D	4.4	0.026	0.011	0.020	0.031	0.038	0.031	0.028	0.022	0.030	0.014	0.027	0.028	0.032	0.025	0.027	0.022	0.414
D	1.8	0.008	0.003	0.002	0.002	0.003	0.002	0.003	0.003	0.006	0.006	0.008	0.009	0.014	0.015	0.014	0.008	0.105
Total		0.064	0.026	0.042	0.064	0.073	0.072	0.076	0.067	0.073	0.033	0.053	0.065	0.092	0.076	0.068	0.056	1.000

Table 10 Probability of Representative Stability Classes and Wind Speeds (Night)

Stab. Class	Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
D	7.4	0.001	0.000	0.001	0.000	0.001	0.003	0.007	0.010	0.007	0.002	0.002	0.004	0.006	0.003	0.002	0.001	0.050
D	4.1	0.016	0.008	0.022	0.015	0.016	0.018	0.021	0.020	0.027	0.014	0.021	0.020	0.021	0.012	0.013	0.018	0.283
D	1.2	0.008	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.006	0.006	0.007	0.007	0.009	0.006	0.007	0.009	0.082
E	2.6	0.005	0.003	0.005	0.003	0.004	0.004	0.003	0.003	0.006	0.005	0.007	0.007	0.006	0.005	0.005	0.006	0.076
F	1.1	0.043	0.018	0.023	0.022	0.024	0.018	0.015	0.015	0.035	0.029	0.039	0.042	0.056	0.037	0.043	0.049	0.508
Total		0.074	0.032	0.053	0.043	0.048	0.044	0.048	0.050	0.081	0.055	0.077	0.081	0.098	0.063	0.070	0.083	1.000

Assumption No. 4: Ambient Conditions

Subject: Locational Data

Assumption/s:

- The typical ambient conditions (temperature, atmospheric pressure, solar radiation and relative humidity) are listed in Table 13 and Table 14.

Table 11 Average Temperature, Relative Humidity and Solar Radiation (Day)

Stability Class	Wind Speed (m/s)	Average Temp (°C)	Average Solar Radiation (kW/m^2)	Average Relative Humidity (fraction)
B	3.0	23.7	0.8	0.42
D	7.4	22.7	0.5	0.47
D	4.4	20.6	0.4	0.52
D	1.8	16.8	0.3	0.69

Table 12 Average Temperature, Relative Humidity and Solar Radiation (Night)

Stability Class	Wind Speed (m/s)	Average Temp (°C)	Average Solar Radiation (kW/m^2)	Average Relative Humidity (%)
D	7.4	18.0	0.0	0.61
D	4.1	16.7	0.0	0.68
D	1.2	11.8	0.1	0.89
E	2.6	13.9	0.0	0.81
F	1.1	10.9	0.0	0.90

Justification and Impact/s of Assumption/s:

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

MAE/s Affected:

- All.

Reference/s:

- BoM meteorological data for Bankstown Airport.

Assumption No. 5: Surface Roughness Length

Subject: Locational Data

Assumption/s:

- The roughness length for different surface types, as listed in the SAFETI user manual, is shown below in Table 15.

Table 13 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 Bexley North.

Justification and Impact/s of Assumption/s:

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

MAE/s Affected:

- Dispersion modelling for all relevant MAEs.

Reference/s:

- SAFETI software documentation.

Assumption No. 6: Location of High Pressure Gas Pipelines
Subject: Locational Data
Assumption/s: • The location of the MSE pipeline is sourced from the Australian Pipeline and Gas Association's (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. Dial Before You Dig 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.

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

Assumption No. 7: Total Population (Day and Night)

Subject: Locational Data

Assumption/s:

- The risk analysis includes the estimated population within the Development. Surrounding residential populations located outside the Development (within the maximum estimated hazard range) are also included in the risk analysis.
- Populations are evenly distributed across each relevant area.
- **Proposed Residential Apartment and Hotel** – The population in the apartments and hotel of the Development is conservatively based on an occupancy rate of 2.2 persons per room, with 83 apartments and 66 hotel rooms. 40% of this population is assumed to be present during the day and 100% is present during the night.
- **Retail and Commercial Population** – The retail and commercial populations associated with the BNH was estimated as per the Table D1.13 of the National Construction Code on Area per person according to use.
- **Existing Residential Areas** – The population in the surrounding residential area has been based on occupancy rates from the 2016 Census (within the maximum estimated hazard range) is given in Table 14. The majority of these dwellings are residential houses.

Table 14 Surrounding Residential Population

Statistical Area 1 7-digit identifier	Population		Statistical Area 1 7-digit identifier	Population	
	Night	Day		Night	Day
1136409	257	129	1137721	456	246
1136412	446	271	1137722	530	291
1136425	262	151	1137723	363	211
1136433	572	325	1137724	444	225
1136437	451	237	1137725	350	196
1136442	436	241	1137726	273	148
1136443	353	180	1137727	670	313
1137704	438	247	1137728	399	201
1137709	279	135	1137729	557	254
1137710	281	126	1137730	397	181
1137711	207	89	1137521	0	0

Assumption No. 7: Total Population (Day and Night)

Justification and Impact/s of Assumption/s:

- The occupancy rate and % of the total population present during the day and night was estimated from 2016 census data.
- As the data given in Table D1.13 of the National Construction Code apply to the specific use of an area as a maximum occupancy and the areas given in the planning proposal for each use include bathrooms, hallways, kitchens, etc., and occupancy may change given time of day factors were applied as in Table 15.

Table 15 Retail and Commercial Use Population

Use	Area (m2)	No people per m2	Occupancy Factor		Population	
			Night	Day	Night	Day
Pub	2060	1	0.5	0.25	1030	515
Retail	287	5	0.25	1	14	57
Gym	297	3	0.5	0.5	50	50
Café	160	1	0.5	0.5	80	80

- The total population and the % of the total population present during the day and night is required for estimation of the societal risk.

MAE/s Affected:

- All societal risk calculations. Population density, along with the area of consequence distances, determines the fn points of societal risk.
- Locational specific risk is not impacted by these assumptions.

Reference/s:

- Australian Bureau of Statistics, 2016 census data.
- National Construction Code, Building Code of Australia 2019, Volume 1.

Assumption No. 8: Indoor / Outdoor distribution of people

Subject: Locational Data

Assumption/s:

- 99% of the night time population will be located indoors.
- 90% of the daytime population will be located indoors.
- All population is located at ground level.

Justification and Impact/s of Assumption/s:

- The default values recommended by the TNO ['Purple Book'] for residential and industrial areas are tabulated below.

Table 16 Proportion of Population Indoor and Outdoor During Day and Night [TNO]

Location	Day Time (8am to 6:00pm)	Night Time (6:00pm to 8am)
Indoor	93%	99%
Outdoor	7%	1%

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

MAE/s Affected:

- All societal risk calculations

Reference/s:

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

A.3 Risk Analysis Methodology

Assumption No. 9: Location and Segmentation of Pipelines
Subject: Risk Analysis Methodology
Assumption/s: • Representative release events are modelled using the 'Long Pipeline' model in SAFETI, which distributes these events along the pipeline at set intervals.
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 pipeline is selected automatically by the 'Long Pipeline' model based on the incident consequence.
MAE/s Affected: • All.
Reference/s: • SAFETI software documentation.

A.4 Consequence Analysis

Assumption No. 10: Representative Materials
Subject: Consequence Analysis
Assumption/s: • Ethane is modelled as 100% Ethane.
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 MSE pipeline carries ethane which has been processed to serve as a petrochemical feed stock.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group.

Assumption No. 11: Pressure and Flow for Release Modelling
Subject: Consequence Analysis
Assumption/s: • A release of Ethane from the Moomba to Sydney Ethane Pipeline is modelled at 8.2 MPag (Operating pressure), compared to an MAOP of 10 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). • 30 tonnes per hour flow is assumed.
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. • Specifying a flow rate will increase the residual pressure that the long pipeline model calculates; however, this is not relevant as it will take much longer than 30 seconds to reach this residual pressure.
MAE/s Affected: • All.
Reference/s: • Data provided by APA Group.

Assumption No. 12: Representative Hole Diameters for Release Modelling

Subject: Consequence Analysis

Assumption/s:

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

Table 17 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)
APA Ethane Pipeline	Ethane	202.9	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.
  - There is insufficient historical incident data for Ethane to determine the representative hole diameter/s in each hole size category. Therefore, the representative hole diameters were assumed to be the same as proposed by the UK HSE for LPG (Refer to C.1). Ethane is transported as a liquefied flammable gas.

MAE/s Affected:

- All.

Reference/s:

- Refer to Appendix B.1.

Assumption No. 13: 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.
MAE/s Affected: • All.
Reference/s: • SAFETI software documentation. • UK HSE, 2015, *Review of the Event Tree Structure and Ignition Probabilities used in HSE's Pipeline Risk Assessment Code MISHAP*, Research Report (RR) 1034.

Assumption No. 14: Maximum Extent of Flash Fire
Subject: Consequence Analysis
Assumption/s: • The maximum extent of a flash fire is defined by the downwind and crosswind distances from the release location to a concentration equal to 100% of the lower flammability limit (LFL) concentration calculated using a 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 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 either buoyant, or have a neutral buoyancy, and should ignition occur, effects from jet fires are expected to dominate.
MAE/s Affected: • All MAEs 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. 15: Isolation Time and Duration of Release
Subject: Consequence Analysis
Assumption/s: • Isolation time and duration of release is not specified as these will be 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: • Ethane 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).
MAE/s Affected: • All.
Reference/s: • SAFETI software documentation.

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

Assumption No. 17: 3D Explosion Model Parameters
Subject: Consequence Analysis
Assumption/s: • The maximum explosive mass in a flammable gas or vapour cloud is the maximum mass between the LFL and UFL concentration for that section of the cloud that overlaps a congested area. • The peak side-on overpressure resulting from an explosion is estimated using the Extended Explosion Modelling option in the SAFETI software. • The 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 open space between the buildings in the study area is not strictly a congested area; however, the presence of vehicles, trees etc. at ground level may contribute to flame acceleration and the formation of an overpressure if ignition occurs. Therefore, TNO Model curve number 2 was assumed to apply, which is the default value in the SAFETI software. • The 3D Obstructed Region Explosion Modelling option considers the interactions between the flammable cloud and obstructed regions that have been defined for the study area. This is more valid than simple models (e.g. TNT equivalence) which do not consider these interactions.
MAE/s Affected: • All MAEs with a VCE as a potential outcome.
Reference/s: • Centre for Chemical Process Safety, Estimating the flammable mass of vapour clouds", American Institute of Chemical Engineers, 1999. • TNO, VROM, 'Yellow Book'. • SAFETI software documentation.

A.5 Likelihood Analysis

Assumption No. 18: Likelihood of Release (Loss of Containment)
Subject: Likelihood Analysis
Assumption/s: • The likelihood of each representative release is provided in Appendix C.3. • The UK HSE pipeline failure rate data is the primary data used for the risk assessment. • 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.
MAE/s Affected: • All.
Reference/s: • Refer to Appendix C.1.

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

Assumption No. 20: Probability of VCE or Flash Fire
Subject: Likelihood Analysis
Assumption/s: • Ignition of a free gas or vapour cloud is modelled as 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.
MAE/s Affected: • All MAEs with clouds in an obstructed region.
Reference/s: • SAFETI software documentation. • TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition.

A.6 Vulnerability Parameters

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

Subject: Vulnerability Parameters

Assumption/s:

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

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

  Where Y is the probit value, *I* is the heat radiation intensity (W/m^2) and t is the exposure duration (seconds).
- A maximum exposure duration of 30 seconds is applicable for individuals located outdoors 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 18 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.

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

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

Justification and Impact/s of Assumption/s:

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

Table 19 Effects of Thermal Radiation

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

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

MAE/s Affected:

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

Reference/s:

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

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

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

Subject: Vulnerability Parameters

Assumption/s:

- The probability of fatality from exposure to the peak side-on overpressure from an explosion is as shown in Table 20 (Person located outdoors) and Table 21 (Person located indoors).

Table 20 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 21 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 DPI&E'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 DPIE's injury/damage risk criterion for explosion overpressure is as follows: "Incident explosion overpressure at residential and sensitive use areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year".

Incidents Affected:

- All incidents with a VCE as a potential outcome.

Reference/s:

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

Appendix B Consequence Analysis – 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, 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.1.1 Leak 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.

The failure reports in the UKOPA database include the length and width of the failures. The failure area is also recorded for some events. The equivalent diameter of a circular opening with the same cross-sectional area was calculated.

The following table includes the recorded incidents where the hole size was reported [Cited by HSE in RR1035]. This data is almost exclusively for Natural Gas (NG) leaks, with only one leak from another material (Propylene).

Table 22 Dimensions of Leaks for Above Ground or Underground Cross-Country Natural Gas or Propylene Pipelines (UKOPA - Reported Values Only)

Fault ID	Discovery Date	Product	Wall Thickness (mm)	Diameter (in)	Diameter (mm)	Equivalent Hole Diameter (mm)	Cause
1950	1998	NG	4.4	3.9	100	1.1	Corrosion
1948	1997	NG	4.4	3.9	100	11.3	Corrosion
400	1998	NG	Not Recorded	4	102	2.8	Corrosion
3112	2010	NG	4.4	4.5	114	1.1	Corrosion
1424	1990	NG	4.5	4.5	114	3.6	Corrosion
1998	2001	NG	4.8	5.9	150	24.5	Corrosion
2569	2005	NG	4.7	6.4	163	1.1	Corrosion
2979	2009	NG	4.3	6.4	163	17.8	Corrosion
728	1990	NG	6	6.6	168	1.1	Corrosion
425	2000	NG	6.6	8.6	218	1.1	Corrosion
417	1998	NG	5.2	8.6	218	3.2	Corrosion
402	1999	NG	5.2	8.6	218	3.6	Corrosion
422	1999	NG	6.6	8.6	218	3.6	Corrosion
1934	1993	NG	6.4	14	356	1.1	Corrosion
730	1994	NG	6.4	18	457	1.1	Corrosion
1460	2001	NG	6.35	12.7	323	3.6	Ground movement/Other
1490	1989	NG	6.4	12.8	325	1.1	Ground movement/Other
1489	1989	NG	6.4	12.8	325	3.6	Ground movement/Other
1388	1998	NG	8	18	457	2.3	Ground movement/Other

Fault ID	Discovery Date	Product	Wall Thickness (mm)	Diameter (in)	Diameter (mm)	Equivalent Hole Diameter (mm)	Cause
2923	2008	NG	9.52	18	457	3.4	Ground movement/Other
2872	2000	NG	9.52	18	457	27.8	Ground movement/Other
1972	1990	NG	4.5	3.5	89	3.6	Mechanical
1949	1997	NG	4.4	3.9	100	3.6	Mechanical
1947	1990	NG	4.4	4	102	3.6	Mechanical
1909	1989	NG	4.4	4	102	11.3	Mechanical
1913	1990	NG	4.4	4	102	11.3	Mechanical
1914	1990	NG	4.4	4	102	11.3	Mechanical
1916	1990	NG	4.4	4	102	11.3	Mechanical
1917	1990	NG	4.4	4	102	11.3	Mechanical
1919	1990	NG	4.4	4	102	11.3	Mechanical
363	1997	NG	Not recorded	5.9	150	1.1	Mechanical
1928	1990	NG	4.5	5.9	150	11.3	Mechanical
1973	1990	NG	4.5	5.9	150	11.3	Mechanical
2028	1990	NG	4.8	5.9	150	11.3	Mechanical
2078	1989	NG	5.6	5.9	150	11.3	Mechanical
1996	1993	NG	4.8	6.6	168	1.1	Mechanical
1875	1989	NG	5.2	6.6	168	11.3	Mechanical
1886	1990	NG	4.4	6.6	168	11.3	Mechanical
1887	1990	NG	4.4	6.6	168	11.3	Mechanical
1925	1989	NG	4.4	6.6	168	11.3	Mechanical
1926	1989	NG	4.4	6.6	168	11.3	Mechanical
1940	1990	NG	4.4	6.6	168	11.3	Mechanical
2069	1990	NG	6.4	8.6	218	3.6	Mechanical
1876	1989	NG	6.4	8.6	218	11.3	Mechanical
2055	1989	NG	6.4	8.6	218	11.3	Mechanical
1710	1989	NG	7.9	14	356	3.6	Mechanical
1842	1992	NG	9.5	17.7	450	1.1	Mechanical
1361	1994	NG	9.5	24	610	1.1	Mechanical
1117	1993	NG	12.7	36	914	160.1	Mechanical
1918	1990	NG	4.4	4	102	22.6	TPA
1987	1990	NG	4.8	6.6	168	23.9	TPA
2980	2009	NG	5.56	6.6	168	25	TPA
1645	1992	NG	7.1	8.6	218	5.5	TPA
366	1991	NG	4.8	8.6	218	24	TPA
2783	2006	NG	4.5	8.6	219	25	TPA
1560	1989	NG	6.4	12.8	325	56.2	TPA
1185	1998	NG	10.4	15.7	400	20	TPA
1193	1990	NG	9.5	16	406	25	TPA
3109	2009	Propylene	7.1	6.6	168	6.8	TPA

B.1.2 Leak Data for Underground Cross-Country Pipelines – Natural Gas

US Department of Transportation (DoT), Pipeline and Hazardous Materials Safety Administration (PHMSA), Accident Reports - Reported Data for Underground Natural Gas Steel Pipelines (January 2010 to September 2017)

The dimensions of a leak are not always included in the US DoT database. The following tables include all recorded incidents where the hole size was reported.

The length and width of the hole is reported in the US DoT database; therefore, the equivalent diameter of a circular opening with the same cross-sectional area was calculated.

Table 23 Dimensions of Rupture Events for Underground Natural Gas Steel Pipelines (US DoT - Reported Values Only)

MAOP		Pipe Diameter (in)	Rupture Length (in)	Rupture Width (in)	Approx. Rupture Area (sq.in)	% of Cross-Section Area	Equiv. Hole Diameter (mm)	Cause
(psig)	(kPag)							
15	205	1.66	1.5	1.5	1.8	81.7	38.1	Natural Force - High Winds
95	756	20	16	1	12.6	4.0	101.6	Corrosion - External
15	205	1	3.3	1	2.6	330.0	46.1	Excavation Damage
60	515	1.25	2	0.1	0.2	12.8	11.4	Excavation Damage
60	515	2	7.5	0.5	2.9	93.8	49.2	Material Failure of Pipe or Weld - Butt Weld
60	515	2.375	6.5	2.1	10.7	242.0	93.8	Material Failure of Pipe or Weld - Butt Weld
60	515	2.375	2	2	3.1	70.9	50.8	Excavation Damage
433	3087	4	10	0.2	1.6	12.5	35.9	Excavation Damage
60	515	6.625	12.5	0.5	4.9	14.2	63.5	Material Failure of Pipe or Weld - Pipe
78	639	16	16	16	201.1	100.0	406.4	Other Cause - Unknown

Table 24 Dimensions of Puncture Events for Underground Natural Gas Steel Pipelines (US DoT - Reported Values Only)

MAOP		Pipe Diameter (in)	Puncture Axial Length (in)	Puncture Circumferential Length (in)	Approx. Puncture Area (sq.in)	% of Cross-Section Area	Equiv. Hole Diameter (mm)	Cause
(psig)	(kPag)							
60	515	0.75	0.5	0.5	0.2	44.4	12.7	Other Outside Force - Electrical arcing
260	1894	0.75	0.8	0.8	0.5	113.8	20.3	Excavation Damage
60	515	1.25	1.5	0.7	0.8	67.2	26.0	Excavation Damage
4	129	2	2	1	1.6	50.0	35.9	Excavation Damage
9.5	167	2	1	3	2.4	75.0	44.0	Excavation Damage
25	274	2	3.5	0.7	1.9	61.3	39.8	Incorrect Operation
52	460	2	0.5	0.5	0.2	6.3	12.7	Other Outside Force - Electrical arcing
60	515	2	1	0.5	0.4	12.5	18.0	Excavation Damage
60	515	2	0.5	0.5	0.2	6.3	12.7	Excavation Damage
60	515	2	1.5	0.7	0.8	26.3	26.0	Other Outside Force - Not Specified
35	343	2.375	1	1	0.8	17.7	25.4	Excavation Damage
440	3135	2.375	2.5	0.5	1.0	22.2	28.4	Excavation Damage
60	515	3	3	9.4	22.1	313.3	134.9	Excavation Damage
17	219	4	1.3	1.3	1.3	10.6	33.0	Excavation Damage
30	308	4	6	3	14.1	112.5	107.8	Excavation Damage
35	343	4	2	2	3.1	25.0	50.8	Excavation Damage
35	343	4	3	3	7.1	56.3	76.2	Excavation Damage
57	494	4	5	2	7.9	62.5	80.3	Excavation Damage

MAOP (psig)	MAOP (kPag)	Pipe Diameter (in)	Puncture Axial Length (in)	Puncture Circumferential Length (in)	Approx. Puncture Area (sq.in)	% of Cross-Section Area	Equiv. Hole Diameter (mm)	Cause
60	515	4	24	2	37.7	300.0	176.0	Excavation Damage
60	515	4	9	3	21.2	168.8	132.0	Excavation Damage
60	515	4	0.8	0.8	0.5	4.0	20.3	Excavation Damage
250	1825	4	5	3	11.8	93.8	98.4	Excavation Damage
285	2066	4	0.6	1.3	0.6	4.9	22.4	Excavation Damage
300	2170	4.5	1	12.6	9.9	62.2	90.2	Excavation Damage
10	170	6	6	6	28.3	100.0	152.4	Excavation Damage
35	343	6	3	3	7.1	25.0	76.2	Excavation Damage
60	515	6	6	6	28.3	100.0	152.4	Excavation Damage
60	515	6	6	6	28.3	100.0	152.4	Excavation Damage
60	515	6	6	6	28.3	100.0	152.4	Excavation Damage
60	515	6	0.5	0.5	0.2	0.7	12.7	Other Outside Force - Electrical arcing
150	1136	6	1.5	0.5	0.6	2.1	22.0	Excavation Damage
200	1480	6	1.2	1	0.9	3.3	27.8	Excavation Damage
200	1480	6	2	2	3.1	11.1	50.8	Excavation Damage
300	2170	6	0.5	0.5	0.2	0.7	12.7	Excavation Damage
400	2859	6	4	1	3.1	11.1	50.8	Excavation Damage
500	3549	6	1	0.5	0.4	1.4	18.0	Other Outside Force - Other Vehicle
60	515	6.58	1	1	0.8	2.3	25.4	Other Outside Force - Other Vehicle
300	2170	6.625	3	4	9.4	27.3	88.0	Excavation Damage
50	446	8	2.1	2.1	3.5	6.9	53.3	Excavation Damage
50	446	8	11	4	34.6	68.8	168.5	Excavation Damage
60	515	8	0.1	0.1	0.0	0.0	2.5	Excavation Damage
80	653	8	12	8	75.4	150.0	248.9	Excavation Damage
120	929	8	6.5	2.5	12.8	25.4	102.4	Excavation Damage
157	1184	8	3.9	3.2	9.8	19.5	89.7	Excavation Damage
300	2170	8	4	2	6.3	12.5	71.8	Excavation Damage
400	2859	8	2	6	9.4	18.8	88.0	Excavation Damage
870	6100	8	25.1	25.1	494.8	984.4	637.5	Excavation Damage
0.43	104	8.625	6	6	28.3	48.4	152.4	Excavation Damage
60	515	8.625	1	1	0.8	1.3	25.4	Other Outside Force - Not Specified
250	1825	8.625	1	5	3.9	6.7	56.8	Excavation Damage
15	205	10	5	5	19.6	25.0	127.0	Excavation Damage
50	446	10	1.5	0.5	0.6	0.8	22.0	Excavation Damage
60	515	10	0.3	13	3.1	3.9	50.2	Excavation Damage
60	515	10	1	3	2.4	3.0	44.0	Excavation Damage
150	1136	10	7.5	1.1	6.5	8.3	73.0	Excavation Damage
240	1756	10	2	2	3.1	4.0	50.8	Excavation Damage
82	667	10.75	3	2	4.7	5.2	62.2	Excavation Damage
33	329	12	11	4	34.6	30.6	168.5	Excavation Damage
60	515	12	3	3	7.1	6.3	76.2	Excavation Damage
100	791	12	2.3	2.5	4.5	4.0	60.9	Excavation Damage
100	791	12	3	3	7.1	6.3	76.2	Excavation Damage
225	1653	12	7	6.3	34.6	30.6	168.7	Excavation Damage

MAOP (psig)	MAOP (kPag)	Pipe Diameter (in)	Puncture Axial Length (in)	Puncture Circumferential Length (in)	Approx. Puncture Area (sq.in)	% of Cross-Section Area	Equiv. Hole Diameter (mm)	Cause
0.64	106	12.75	2.5	2.5	4.9	3.8	63.5	Other Outside Force - Not Specified
15	205	12.75	6	6	28.3	22.1	152.4	Excavation Damage
170	1273	14	6	3	14.1	9.2	107.8	Other Outside Force - Other Vehicle
58	501	16	2.5	5	9.8	4.9	89.8	Excavation Damage
188	1398	16	4	4	12.6	6.3	101.6	Excavation Damage
300	2170	16	1.1	3.5	3.0	1.5	49.8	Excavation Damage
150	1136	20	5	1	3.9	1.3	56.8	Excavation Damage
400	2859	26	0.2	0.2	0.0	0.0	5.1	Excavation Damage

B.2 Consequence Analysis Results for Representative Release Scenarios

Hazard ranges for the modelled release cases are tabulated in Sections B.2.1 to B.2.4

B.2.1 Discharge Results

Table 25 Discharge Results

Hole Size	Release rate [kg/s]	Release duration [s]	Release velocity [m/s]	Droplet diameter [um]	Release temperature [°C]	Liquid fraction	Release phase
10mm MID	3.36283	3600	27.8388	12.2374	-88.572	0.526525	Two phase
25mm MID	21.0177	3600	27.896	12.2374	-88.572	0.526525	Two phase
75mm MID	189.159	3600	77.104	12.2374	-88.572	0.526525	Two phase
75mm TOP	189.159	3600	223.95	12.2374	-88.572	0.526525	Two phase
110mm MID	406.902	2191.2	108.958	12.2374	-88.572	0.526525	Two phase
110mm TOP	406.902	2191.2	242.953	12.2374	-88.572	0.526525	Two phase
FBR	262.322	833.6	18.3191	170.88	-88.572	0.431467	Two phase

B.2.2 Flash Fire Consequence Analysis Results

Flash fire consequences are summarised in Table 26 and Table 27.

Table 26 Night Conditions Flash Fire Consequence Results @ 1.5m

Scenario	Weather	Distance to UFL [m]	Distance to LFL [m]
10mm MID	Night 7.4D	0.30	0.494
	Night 4.1D	0.26	0.42
	Night 1.2D	0.24	0.37
	Night 2.6E	0.25	0.37
	Night 1.1F	0.24	0.36
25mm MID	Night 7.4D	0.61	0.94
	Night 4.1D	0.57	0.93
	Night 1.2D	n/a	n/a
	Night 2.6E	0.56	0.85
	Night 1.1F	0.74	1.25
75mm MID	Night 7.4D	0.97	1.41
	Night 4.1D	0.90	1.36
	Night 1.2D	n/a	n/a
	Night 2.6E	0.99	1.46
	Night 1.1F	1.13	1.65
75mm TOP	Night 7.4D	0.45	0.67
	Night 4.1D	0.48	0.64
	Night 1.2D	0.44	0.57
	Night 2.6E	0.40	0.68
	Night 1.1F	0.52	0.68
110mm MID	Night 7.4D	1.10	1.64
	Night 4.1D	1.13	1.60
	Night 1.2D	n/a	n/a

Scenario	Weather	Distance to UFL [m]	Distance to LFL [m]
	Night 2.6E	1.11	1.66
	Night 1.1F	1.18	2.15
110mm TOP	Night 7.4D	0.58	0.88
	Night 4.1D	0.64	0.89
	Night 1.2D	0.55	0.74
	Night 2.6E	0.65	0.73
	Night 1.1F	2.13	2.40
FBR	Night 7.4D	2.52	4.01
	Night 4.1D	2.48	63.92
	Night 1.2D	n/a	563.38
	Night 2.6E	5.45	240.70
	Night 1.1F	n/a	760.34

Table 27 Day Conditions Flash Fire Consequence Results @ 1.5m

Scenario	Weather	Distance to UFL [m]	Distance to LFL [m]
10mm MID	Day 3.0B	0.26	0.41
	Day 7.4D	0.30	0.50
	Day 4.4D	0.27	0.42
	Day 1.8D	0.24	0.38
25mm MID	Day 3.0B	0.58	0.91
	Day 7.4D	0.61	0.94
	Day 4.4D	0.59	0.90
	Day 1.8D	0.57	0.88
75mm MID	Day 3.0B	0.95	1.39

Scenario	Weather	Distance to UFL [m]	Distance to LFL [m]
	Day 7.4D	0.97	1.42
	Day 4.4D	0.98	1.41
	Day 1.8D	0.96	1.42
75mm TOP	Day 3.0B	0.44	0.61
	Day 7.4D	0.45	0.67
	Day 4.4D	0.47	0.58
	Day 1.8D	0.46	0.58
110mm MID	Day 3.0B	1.10	1.59
	Day 7.4D	1.09	1.64
	Day 4.4D	1.05	1.64
	Day 1.8D	1.16	1.46
110mm TOP	Day 3.0B	0.61	0.73
	Day 7.4D	0.57	0.89
	Day 4.4D	0.61	0.76
	Day 1.8D	0.61	0.82
FBR	Day 3.0B	2.63	72.23
	Day 7.4D	2.53	4.00
	Day 4.4D	2.54	3.98
	Day 1.8D	n/a	369.77

B.2.3 Jet Fire Consequence Results

Table 28 Night Conditions Downwind Distance (m) to Varying Heat Radiation Levels @1.5m Height

Scenario	Weather	Flame length [m]	4.7 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2
10mm MID	Night 7.4D	15.41	36.23	25.73	20.72	17.31
	Night 4.1D	17.58	35.20	22.91	18.38	14.95
	Night 1.2D	24.04	31.47	15.22	5.16	2.65
	Night 2.6E	20.01	33.06	22.13	15.27	8.73
	Night 1.1F	24.43	30.99	13.94	4.52	2.38
25mm MID	Night 7.4D	33.01	82.83	56.41	43.29	37.15
	Night 4.1D	37.64	80.38	51.97	40.77	32.55
	Night 1.2D	51.49	74.13	38.52	15.18	7.18
	Night 2.6E	42.84	76.98	50.55	35.14	21.98
	Night 1.1F	52.31	73.34	36.39	7.81	6.39
75mm MID	Night 7.4D	75.75	178.05	114.44	90.34	75.09
	Night 4.1D	86.39	179.55	118.08	86.41	62.55
	Night 1.2D	118.17	188.86	95.50	36.47	10.38
	Night 2.6E	98.32	188.00	114.78	72.16	39.31
	Night 1.1F	120.05	187.67	92.35	31.79	11.12
75mm TOP	Night 7.4D	67.38	134.77	88.21	63.25	43.15
	Night 4.1D	76.84	137.00	79.18	42.62	16.32
	Night 1.2D	105.10	148.44	62.16	9.33	3.09
	Night 2.6E	87.45	141.50	72.67	26.48	7.74
	Night 1.1F	106.78	149.42	60.24	8.49	n/a

Scenario	Weather	Flame length [m]	4.7 kW/m²	12.5 kW/m²	23 kW/m²	35 kW/m²
110mm MID	Night 7.4D	100.74	222.99	144.57	112.38	89.27
	Night 4.1D	114.88	223.13	141.19	94.24	58.09
	Night 1.2D	157.14	235.82	110.14	31.67	10.33
	Night 2.6E	130.74	231.47	132.26	72.30	30.33
	Night 1.1F	159.65	236.37	107.93	21.45	9.24
110mm TOP	Night 7.4D	92.08	178.50	114.71	78.51	48.39
	Night 4.1D	105.01	180.59	101.06	49.32	17.48
	Night 1.2D	143.63	195.57	75.88	10.01	n/a
	Night 2.6E	119.51	186.13	91.78	28.40	8.28
	Night 1.1F	145.93	196.98	74.66	8.96	3.56
FBR	Night 7.4D	95.03	216.79	141.10	111.62	93.96
	Night 4.1D	108.37	244.58	158.81	122.43	97.00
	Night 1.2D	148.23	243.25	140.58	77.67	42.14
	Night 2.6E	123.33	246.72	161.30	115.69	82.08
	Night 1.1F	150.60	242.68	137.61	73.24	39.08

Table 29 Day Conditions Downwind Distance (m) to Varying Heat Radiation Levels @1.5m Height

Scenario	Weather	Flame length [m]	4.7 kW/m²	12.5 kW/m²	23 kW/m²	35 kW/m²
10mm MID	Day 3.0B	19.21	33.88	22.57	16.77	11.07
	Day 7.4D	15.41	36.23	25.73	20.72	17.31
	Day 4.4D	17.24	35.47	23.00	18.58	15.52
	Day 1.8D	22.03	32.73	19.97	10.10	4.68
25mm MID	Day 3.0B	41.13	77.65	51.47	37.66	26.13
	Day 7.4D	33.01	82.80	56.39	43.28	37.14

Scenario	Weather	Flame length [m]	4.7 kW/m²	12.5 kW/m²	23 kW/m²	35 kW/m²
	Day 4.4D	36.92	81.03	52.26	41.24	33.62
	Day 1.8D	47.18	76.38	46.64	26.38	12.86
75mm MID	Day 3.0B	94.41	185.95	117.04	77.91	48.31
	Day 7.4D	75.75	177.96	114.40	90.31	75.05
	Day 4.4D	84.74	179.16	117.82	87.53	64.91
	Day 1.8D	108.29	191.60	107.96	56.32	23.58
75mm TOP	Day 3.0B	83.97	140.63	75.19	31.46	9.71
	Day 7.4D	67.38	134.71	88.17	63.21	43.11
	Day 4.4D	75.38	136.63	80.38	45.39	18.63
	Day 1.8D	96.32	144.92	67.04	16.01	4.20
110mm MID	Day 3.0B	125.54	230.34	136.20	79.41	37.82
	Day 7.4D	100.74	222.86	144.50	112.33	89.21
	Day 4.4D	112.70	222.56	142.47	97.65	62.33
	Day 1.8D	144.00	234.49	122.19	49.89	17.89
110mm TOP	Day 3.0B	114.76	185.10	95.37	34.97	10.64
	Day 7.4D	92.08	178.40	114.65	78.45	48.31
	Day 4.4D	103.01	180.27	102.80	54.63	19.82
	Day 1.8D	131.63	190.61	83.92	17.07	5.06
FBR	Day 3.0B	118.43	247.66	163.52	120.89	90.12
	Day 7.4D	95.03	216.69	141.03	111.58	93.92
	Day 4.4D	106.31	241.12	156.03	121.05	96.62
	Day 1.8D	135.84	245.53	153.52	99.41	60.97

B.2.4 Explosion Consequence Analysis Results

Table 30 Night conditions distance (m) to varying overpressures

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
25mm MID	Night 4.1D	0.07 0.1379 0.2068	22.33 Not reachable Not reachable	36.88 0 0
	Night 1.2D	0.07 0.1379 0.2068	29.89 Not reachable Not reachable	49.94 0 0
	Night 2.6E	0.07 0.1379 0.2068	23.88 Not reachable Not reachable	39.70 0 0
	Night 1.1F	0.07 0.1379 0.2068	29.49 Not reachable Not reachable	49.08 0 0
75mm MID	Night 7.4D	0.07 0.1379 0.2068	45.36 Not reachable Not reachable	74.06 0 0
	Night 4.1D	0.07 0.1379 0.2068	47.41 Not reachable Not reachable	78.51 0 0
	Night 1.2D	0.07 0.1379 0.2068	52.33 Not reachable Not reachable	88.81 0 0
	Night 2.6E	0.07 0.1379 0.2068	50.05 Not reachable Not reachable	82.83 0 0
	Night 1.1F	0.07 0.1379 0.2068	54.04 Not reachable Not reachable	89.93 0 0

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
75mm TOP	Night 7.4D	0.07 0.1379 0.2068	34.63 Not reachable Not reachable	56.83 0 0
	Night 4.1D	0.07 0.1379 0.2068	32.95 Not reachable Not reachable	55.61 0 0
	Night 1.2D	0.07 0.1379 0.2068	25.17 Not reachable Not reachable	45.16 0 0
	Night 2.6E	0.07 0.1379 0.2068	29.80 Not reachable Not reachable	51.53 0 0
	Night 1.1F	0.07 0.1379 0.2068	30.14 Not reachable Not reachable	52.61 0 0
110mm MID	Night 7.4D	0.07 0.1379 0.2068	63.27 Not reachable Not reachable	102.07 0 0
	Night 4.1D	0.07 0.1379 0.2068	52.85 Not reachable Not reachable	90.40 0 0
	Night 1.2D	0.07 0.1379 0.2068	76.44 Not reachable Not reachable	126.99 0 0
	Night 2.6E	0.07 0.1379 0.2068	56.53 Not reachable Not reachable	96.48 0 0
	Night 1.1F	0.07 0.1379 0.2068	73.00 Not reachable Not reachable	120.38 0 0

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
110mm TOP	Night 7.4D	0.07 0.1379 0.2068	50.11 Not reachable Not reachable	82.17 0 0
	Night 4.1D	0.07 0.1379 0.2068	49.22 Not reachable Not reachable	82.32 0 0
	Night 1.2D	0.07 0.1379 0.2068	24.02 Not reachable Not reachable	44.67 0 0
	Night 2.6E	0.07 0.1379 0.2068	36.23 Not reachable Not reachable	64.08 0 0
	Night 1.1F	0.07 0.1379 0.2068	83.33 Not reachable Not reachable	121.52 0 0
FBR	Night 7.4D	0.07 0.1379 0.2068	85.77 Not reachable Not reachable	135.30 0 0
	Night 4.1D	0.07 0.1379 0.2068	107.35 Not reachable Not reachable	170.76 0 0
	Night 1.2D	0.07 0.1379 0.2068	489.24 Not reachable Not reachable	452.41 0 0
	Night 2.6E	0.07 0.1379 0.2068	208.58 Not reachable Not reachable	249.83 0 0
	Night 1.1F	0.07 0.1379 0.2068	742.75 Not reachable Not reachable	488.28 0 0

Table 31 Night Conditions Distance (m) to Varying Overpressures

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
25mm MID	Day 4.4D	0.07 0.1379 0.2068	22.13 Not reachable Not reachable	36.51 0 0
	Day 1.8D	0.07 0.1379 0.2068	25.99 Not reachable Not reachable	43.33 0 0
75mm MID	Day 3.0B	0.07 0.1379 0.2068	31.50 Not reachable Not reachable	56.19 0 0
	Day 7.4D	0.07 0.1379 0.2068	45.53 Not reachable Not reachable	74.27 0 0
	Day 4.4D	0.07 0.1379 0.2068	47.18 Not reachable Not reachable	78.05 0 0
	Day 1.8D	0.07 0.1379 0.2068	53.48 Not reachable Not reachable	89.04 0 0
75mm TOP	Day 3.0B	0.07 0.1379 0.2068	27.00 Not reachable Not reachable	47.30 0 0
	Day 7.4D	0.07 0.1379 0.2068	34.82 Not reachable Not reachable	57.08 0 0
	Day 4.4D	0.07 0.1379 0.2068	33.83 Not reachable Not reachable	56.67 0 0
	Day 1.8D	0.07 0.1379 0.2068	24.26 Not reachable Not reachable	43.48 0 0

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
110mm MID	Day 3.0B	0.07 0.1379 0.2068	55.97 Not reachable Not reachable	95.42 0 0
	Day 7.4D	0.07 0.1379 0.2068	63.38 Not reachable Not reachable	102.21 0 0
	Day 4.4D	0.07 0.1379 0.2068	67.17 Not reachable Not reachable	109.36 0 0
	Day 1.8D	0.07 0.1379 0.2068	72.51 Not reachable Not reachable	119.85 0 0
110mm TOP	Day 3.0B	0.07 0.1379 0.2068	32.41 Not reachable Not reachable	58.01 0 0
	Day 7.4D	0.07 0.1379 0.2068	50.26 Not reachable Not reachable	82.37 0 0
	Day 4.4D	0.07 0.1379 0.2068	49.014 Not reachable Not reachable	81.92 0 0
	Day 1.8D	0.07 0.1379 0.2068	28.15 Not reachable Not reachable	51.47 0 0
FBR	Day 3.0B	0.07 0.1379 0.2068	96.61 Not reachable Not reachable	162.78 0 0
	Day 7.4D	0.07 0.1379 0.2068	86.23 Not reachable Not reachable	135.93 0 0

Scenario	Weather	Overpressure level [bar]	Maximum distance [m]	Diameter [m]
	Day 4.4D	0.07 0.1379 0.2068	105.4 Not reachable Not reachable	167.14 0 0
	Day 1.8D	0.07 0.1379 0.2068	324.74 Not reachable Not reachable	335.91 0 0

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

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

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 is no leak frequency data specifically for Ethane in RR1035. The data for natural gas (methane), ethylene and LPG (propane and butane) was reviewed. The data for LPG was selected as it is slightly more conservative for the larger leak diameters and is more applicable for a liquefied gas.

The total leak frequency data reported in Section 7.6 of RR1035 for underground LPG pipelines is slightly more conservative (e.g. 2.1E-04 per km per year for a pipeline with wall thickness ≥ 5 mm to < 10 mm) and was adopted in the QRA for the underground HP Ethane pipeline (Refer to Table 32).

Table 32 Leak Frequencies for Underground LPG Pipelines

Failure Mode	Pipeline Diameter (mm)	Wall Thickness (mm)	Leak Frequency (per km per yr)				
			Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)	Total Leak Frequency
Mechanical Failure	All	All	5.7E-05	1.3E-05	6.7E-06	8.3E-06	8.5E-05
Corrosion	All	< 5	1.6E-04	8.9E-07	4.5E-07	1.3E-06	1.6E-04
		5 to < 10	8.4E-05	2.4E-07	4.8E-07	7.3E-07	8.6E-05
		10 to < 15	4.5E-06	1.3E-08	2.6E-08	3.9E-08	4.6E-06
		≥ 15	4.3E-07	1.2E-09	2.5E-09	3.7E-09	4.4E-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 Freq. =	All	5 to < 10	1.7E-04	1.8E-05	7.4E-06	1.2E-05	**2.1E-04**
% =			82.4	8.7	3.5	5.5	

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 Moomba to Sydney Ethane Pipeline (Refer to Table 33). The data applicable for a pipeline with a wall thickness of 8.1 mm, manufactured after 1980, was used.

Leak frequency data is not reported for internal corrosion; therefore, the total leak frequencies reported in Table 33 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 B.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 Moomba to Sydney Ethane Pipeline (i.e. location, design factor, wall thickness and depth of cover). As this pipeline has concrete slab protection and marker tapes, the base rupture frequency was reduced by a factor of 0.125 (Table A.0, p.31).

Table 33 Approx. Leak Frequencies for Underground Ethane 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	8.0E-06	3.2E-06	0.0E+00	0.0E+00	1.1E-05
Corrosion	3.2E-05	1.1E-05	3.0E-06	0.0E+00	4.6E-05
Ground Movement / Other	4.9E-07	4.9E-07	4.9E-07	6.6E-08	1.5E-06
TPA	6.1E-06	4.0E-06	2.0E-06	8.1E-06	2.0E-05
Total Leak Freq. =	4.7E-05	1.9E-05	5.5E-06	8.1E-06	**7.9E-05**
% =	59.0	23.7	7.0	10.3	

US Department of Transportation (DoT)

The US Department of Transportation (DoT), Pipeline and Hazardous Materials Safety Administration (PHMSA), Accident Reports - Hazardous Liquid Pipeline Systems (January 2010 to September 2018) include incidents for Ethane pipelines; however, the total length of the Ethane pipelines is not available (i.e. it is not possible to determine the leak rate per km.year).

To enable a comparison with the UK data, the data for all Highly Volatile Liquids (Except Ammonia) 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 34.

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Period of Recorded Incident Data =	8.75	years	(Jan 2010 to Sept 2018)
Total Length of All HVL Pipelines =	102663	km	Note: Average for 2010 to 2017 for ALL HVLs

Table 34 Leak Frequencies for Underground HVL Pipelines (Excluding Ammonia)

Failure Mode	Approx. Leak Frequency (per km per yr)					Comments
	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	3.9E-05	0.0E+00	0.0E+00	0.0E+00	3.9E-05	Excludes pipelines manufactured prior to 1980.
Corrosion	5.6E-06	0.0E+00	0.0E+00	1.1E-06	6.7E-06	Excludes external corrosion (other than SCC).
Ground Movement / Other	5.6E-06	2.2E-06	1.1E-06	5.6E-06	1.4E-05	
TPA	8.9E-06	6.7E-06	2.2E-06	8.9E-06	2.7E-05	
Total Leak Freq. =	5.9E-05	8.9E-06	3.3E-06	1.6E-05	**8.7E-05**	
% =	67.9	10.3	3.8	17.9		

C.2 Ignition Probability

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

Ethane

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

   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.

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

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

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

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

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

Table 35 Ignition Probability - UKOPA

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

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

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

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

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

Table 36 Ignition Probability – OGP Scenario 3

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

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

US Department of Transportation (DoT), Pipeline and Hazardous Materials Safety Administration (PHMSA), Accident Reports - Hazardous Liquid Pipeline Systems (January 2010 to September 2018)

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

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

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

(1) Not otherwise reportable under this section;

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

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

(4) Cleaned up promptly;

(c) Death of any person;

(d) Personal injury necessitating hospitalisation;

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

Table 37 Ignition Probability – US DoT

Liquid	Leak			Mechanical Puncture			Other			Rupture			Total		
	# with Ignition	# with no ignition	Prob. of Ignition	# with Ignition	# with no ignition	Prob. of Ignition	# with Ignition	# with no ignition	Prob. of Ignition	# with Ignition	# with no ignition	Prob. of Ignition	# with Ignition	# with no ignition	Prob. of Ignition
HVLs *	0	46	0.0	0	7	0.0	4	2	0.7	5	5	0.5	9	60	0.13

* Highly Volatile Liquids (Includes Ethane).

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

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

The following data is proposed in RR 1034 for the HSE's computer program MISHAP 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 and appear to be only applicable for larger release events.

For MISHAP, 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 by VCE. It is acknowledged in RR 1034 that this may require further review.

Table 38 Ignition Probability – UK HSE (RR 1034)

Outcome	Probability of Outcome		
	R12 Materials with a MIE < 0.2 mJ (1)	R12 Materials with a MIE ≥ 0.2 mJ (2)	R11 and Low Reactive Materials (3)
Immediate ignition, fireball and jet fire	0.350	0.300	0.250
Delayed ignition and jet fire	0.325	0.210	0.188
Delayed ignition, flash fire and jet fire	0.096	0.145	0.167
No ignition	0.229	0.345	0.396

(1) For example: ethylene

(2) For example: butane, ethane and propane

(3) For example: ammonia, carbon monoxide

C.3 Likelihood of Representative Release Scenarios

The estimated likelihood of each representative release scenario is listed in Table 43.

Table 39 Release Frequency – Ethane Pipeline (MSE)

Leak Scenario	Release Frequency (per km per year)			Probability of scenario compared to total
	TPA	All Other Failure Modes	Total Release Frequency	
10mm MID		1.53E-04	1.53E-04	0.7200
10mm TOP		0.00E+00	0.00E+00	0.0000
25mm MID	2.20E-05		2.20E-05	0.1036
25mm TOP	0.00E+00		0.00E+00	0.0000
75mm MID	2.40E-06	5.94E-06	8.34E-06	0.0393
75mm TOP	0.00E+00	1.01E-05	1.01E-05	0.0476
110mm MID	1.00E-07	2.70E-06	2.80E-06	0.0132
110mm TOP	0.00E+00	4.60E-06	4.60E-06	0.0217
FBR	1.00E-07	1.15E-05	1.16E-05	0.0547
Total	2.46E-05	1.88E-04	**2.124E-04**	1.0000