# HAZARDS AND RISK ASSESSMENT

## Light Horse Interchange Business Hub (SSD 9667)

For Western Sydney Parklands Trust

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| | | | | | |

# Summary

**Overview**

Arriscar Pty Ltd (Arriscar) was engaged by Western Sydney Parklands Trust (WSPT) to undertake a risk assessment for the development of a proposed industrial business hub adjacent to the Light Horse Interchange at Eastern Creek.

The Development Application (SSD 9667, Light Horse Interchange Business Hub, Eastern Creek) is for a concept layout and the first stage of development of the site including demolition, bulk earthworks, infrastructure (roads, etc.) and subdivision. Additional approvals will be sought later for the construction of individual buildings, ancillary facilities and their associated site works. The specific use at each lot is not known at this stage but to the proposal is for industrial and light industrial uses.

Jemena operate a high-pressure natural gas pipeline ('JGN Trunk Pipeline – Licence 3'), which is in an easement adjacent to the proposed industrial business hub.

**Secretary's Environmental Assessment Requirements**

The Secretary's Environmental Assessment Requirements (SEARs) for SSD 9667 included the following requirements with respect to Hazards and Risks:

| Requirement | Comments |
|---|---|
| *a preliminary risk screening completed in accordance with State Environmental Planning Policy No. 33 - Hazardous and Offensive Development and Applying SEPP 33 (DoP, 2011), with a clear indication of class, quantity and location of all dangerous goods and hazardous materials associated with the development. Should the preliminary risk screening indicate that the development is "potentially hazardous", a Preliminary Hazard Analysis (PHA) must be prepared in accordance with Hazardous Industry Planning Advisory Paper No. 6 - Guidelines for Hazard Analysis (DoP, 2011) and Multi-Level Risk Assessment (DoP, 2011)* | As noted above, the specific use at each lot is anticipated to include warehousing facilities and ancillary offices; however, the specific details (including types and quantities of Dangerous Goods, if present) are not known at this stage and will be addressed separately in later Development Applications. Consequently, it was not possible to undertake a preliminary risk screening in accordance with *Applying SEPP 33* for the industrial business hub facilities or to undertake a PHA for these facilities in accordance with HIPAP No. 6.<br>*Note: The risk exposure to potential populations within the development from the nearby high-pressure natural gas pipeline was assessed in accordance with HIPAP No. 6 (See below).* |
| *ongoing consultation with Jemena on the high-pressure gas pipeline adjacent to the development area with regards to requirements of Australian Standard AS 2885 Pipelines - Gas and liquid petroleum* | Consultation with Jemena was undertaken during preparation of the risk assessment.<br>Jemena provided the relevant data for the JGN Trunk Pipeline (Refer to Section 4.2). |

| Requirement | Comments |
|---|---|
| *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). It must include, and not be limited to, an assessment on risk exposures to potential populations within the development from the high-pressure gas pipeline located within or near the development area. The risks established in the hazard analysis must be compared against 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'. If a Safety Management Study (SMS) required under AS 2885 Pipelines - Gas and liquid petroleum is available, the SMS must be included in the hazard analysis.* | The JGN Trunk Pipeline was the only identified credible external source of risk to potential populations within the development. The risk at the proposed development from this pipeline was assessed against the risk criteria in HIPAP No. 10.<br>It was determined that the risks at the proposed development from the JGN Trunk Pipeline are extremely low and well below the relevant DP&E risk criteria from HIPAP No. 10 (Refer to Section 8).<br>*Note: The SMS for the JGN Trunk Pipeline was not available at the time of preparation of this risk assessment. WSPT advised that this will be undertaken at a later date as agreed with Jemena* |

**Findings**

The specific use at each lot (including types and quantities of Dangerous Goods, if present) are not known at this stage and will be addressed separately in later Development Applications. If significant quantities of Dangerous Goods are to be stored at, and/or transported to/from, any facilities at the proposed industrial business hub, then this will require a PHA in accordance with HIPAP No. 6.

The risks at the proposed development from the JGN Trunk Pipeline are low and comply with the relevant DP&E risk criteria from HIPAP No. 10 (Refer to Section 8). In this case, compliance with the relevant societal risk criteria is based on an assumption that the population at the proposed industrial business hub will be less than c. 1000 persons (equivalent to 61 persons per hectare, distributed evenly across all lots and assuming 90% are located indoors and 10% are located outdoors). The total parking provided for the development is 782 spaces . With the average occupancy per trip to work of 1.1 persons, assuming approximately 1,000 persons on the development appears reasonable. Whilst the population estimate used in this risk assessment is expected to be conservative for the types of use envisaged for the proposed industrial business hub, it may be necessary to review the societal risk exposure from the JGN Trunk Pipeline as part of the subsequent DAs.

The design of the concept development application is appropriate, subject to the following recommendations being incorporated into later detailed development applications.

**Recommendations**

1. Future DAs relating to the specific use of each lot (including construction of structures or buildings) in the proposed industrial business hub should consider the risks imposed from the JGN Trunk Pipeline (Particularly societal risk). If the development will result in significant

changes to any key parameters used in this risk assessment (e.g. population estimates, etc.) then this should be addressed accordingly in the future DA.

2. Future occupied buildings in the proposed industrial business hub should be constructed with due regard of the fire and explosion hazards posed by the JGN Trunk Pipeline. This should be commensurate with the risk exposure and is therefore primarily relevant for Lot 7 (Refer to Figure 5) as the risk exposure at the other lots is low (Refer to Section 8).

   In future detailed DAs, the proponent should demonstrate how reasonably practicable measures to protect the building occupants has been incorporated into the building design (e.g. through use of appropriate non-combustible materials (cladding etc.), fire-rated walls or other barriers, sizing and location of windows and balconies, measures to minimise smoke ingress, measures to prevent ingress of gas into underground basements / car parks / utilities, etc.).

3. Emergency refuge and/or egress arrangements should be provided for all future occupied areas in the proposed industrial business hub. This is to ensure the safety of the occupants in the event of an incident involving the JGN Trunk Pipeline. The proponent should demonstrate how this has been incorporated into the design (e.g. emergency egress stairwells, egress to a safe location on the far side of the building away from the pipeline, shelter-in-place facilities, etc.) and the occupier should prepare appropriate emergency response plan/s.

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# Notation

| Abbreviation | Description |
|---|---|
| Arriscar | Arriscar Pty Ltd |
| DA | Development Application |
| DP&E | NSW Department of Planning and Environment |
| HAZID | Hazard Identification |
| HIPAP | Hazardous Industry Planning Advisory Paper |
| LEP | Local Environmental Plan |
| LSIR | Location-Specific Individual Risk |
| MAE | Major Accident Event |
| NSW | New South Wales |
| PHA | Preliminary Hazard Analysis |
| QRA | Quantitative Risk Assessment |
| RA | Risk Analysis |
| SEAR | Secretary's Environmental Assessment Requirements |
| SEPP | State Environmental Planning Policy |
| SSD | State Significant Development |
| VCE | Vapour Cloud Explosion |
| WSPT | Western Sydney Parklands Trust |

# 1 INTRODUCTION

## 1.1 Background

Arriscar Pty Ltd (Arriscar) was engaged by Western Sydney Parklands Trust (WSPT) to undertake a risk assessment for the development of a proposed industrial business hub adjacent to the Light Horse Interchange at Eastern Creek. The development is categorised as State Significant Development (SSD).

The Development Application (SSD 9667, Light Horse Interchange Business Hub, Eastern Creek) is for a concept layout and the first stage of development of the site including demolition, bulk earthworks, infrastructure (roads, etc.) and subdivision. Additional approvals will be sought later for the construction of individual buildings, ancillary facilities and their associated site works. The specific use at each lot is not known at this stage but to the proposal is for industrial and light industrial uses.

Jemena operate a high-pressure natural gas pipeline ('JGN Trunk Pipeline – Licence 3'), which is in an easement adjacent to the proposed industrial business hub.

The Secretary's Environmental Assessment Requirements (SEARs) for this development (SSD 9667) include the following requirements for the assessment of hazards and risks [Ref. 4]:

> *The EIS must address the following specific matters:*
>
> *…*
>
> ***Hazards and Risk***
>
> - *a preliminary risk screening completed in accordance with State Environmental Planning Policy No. 33 - Hazardous and Offensive Development and Applying SEPP 33 (DoP, 2011), with a clear indication of class, quantity and location of all dangerous goods and hazardous materials associated with the development. Should the preliminary risk screening indicate that the development is "potentially hazardous", a Preliminary Hazard Analysis (PHA) must be prepared in accordance with Hazardous Industry Planning Advisory Paper No. 6 - Guidelines for Hazard Analysis (DoP, 2011) and Multi-Level Risk Assessment (DoP, 2011)*
> - *ongoing consultation with Jemena on the high-pressure gas pipeline adjacent to the development area with regards to requirements of Australian Standard AS 2885 Pipelines - Gas and liquid petroleum*
> - *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). It must include, and not be limited to, an assessment on risk exposures to potential populations within the development from the high-pressure gas pipeline located within or near the development area. The risks established in the hazard analysis must be compared against 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'. If a Safety Management Study (SMS) required under AS 2885 Pipelines - Gas and liquid petroleum is available, the SMS must be included in the hazard analysis.*

## 1.2 Scope

The scope of the study included undertaking a risk assessment for the proposed development in accordance with HIPAP No. 6. It also included an assessment of the risks from existing potentially hazardous facilities and operations near the proposed development in accordance with HIPAP No. 10.

## 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. This included:

- Identification of any potential hazards near the development (particularly from any dangerous goods pipelines);
- Identification of all 'Major Accident Events' (MAEs) that might impact upon the proposed development, and the appropriate and relevant representative scenarios for each MAE;
- Quantification of the consequences of potential harmful effects for each representative scenario, including the potential for impact on the proposed development;
- Quantification of the likelihood of occurrence of each representative scenario;
- Using assumptions that are appropriate and justified, with a focus on minimising uncertainty and obtaining the 'cautious best estimate';
- Generation of Location-Specific Individual Risk (LSIR) contours for comparison with the DP&E's risk criteria for land use safety planning (viz. as per HIPAP No. 4 and HIPAP No. 10); and
- Estimation of societal risk for comparison with the DP&E's indicative risk criteria for land use safety planning (viz. as per HIPAP No. 4 and HIPAP No. 10).

# 2 DESCRIPTION OF PROPOSED DEVELOPMENT AND SURROUNDING LAND USES

## 2.1 Site Location

The proposed industrial business hub is located adjacent to the existing Light Horse Interchange at Eastern Creek and includes:

- Part of Lot 10 DP 1061237 (165 Wallgrove Road, Eastern Creek); and
- Part of Lot 5 DP 804051 (475 Ferrers Road, Eastern Creek).

The lots affected by the proposal are shown in Figure 1 and Figure 2, while the area affected is shown in Figure 3.

**Figure 1 Site Location [Ref. 3]**

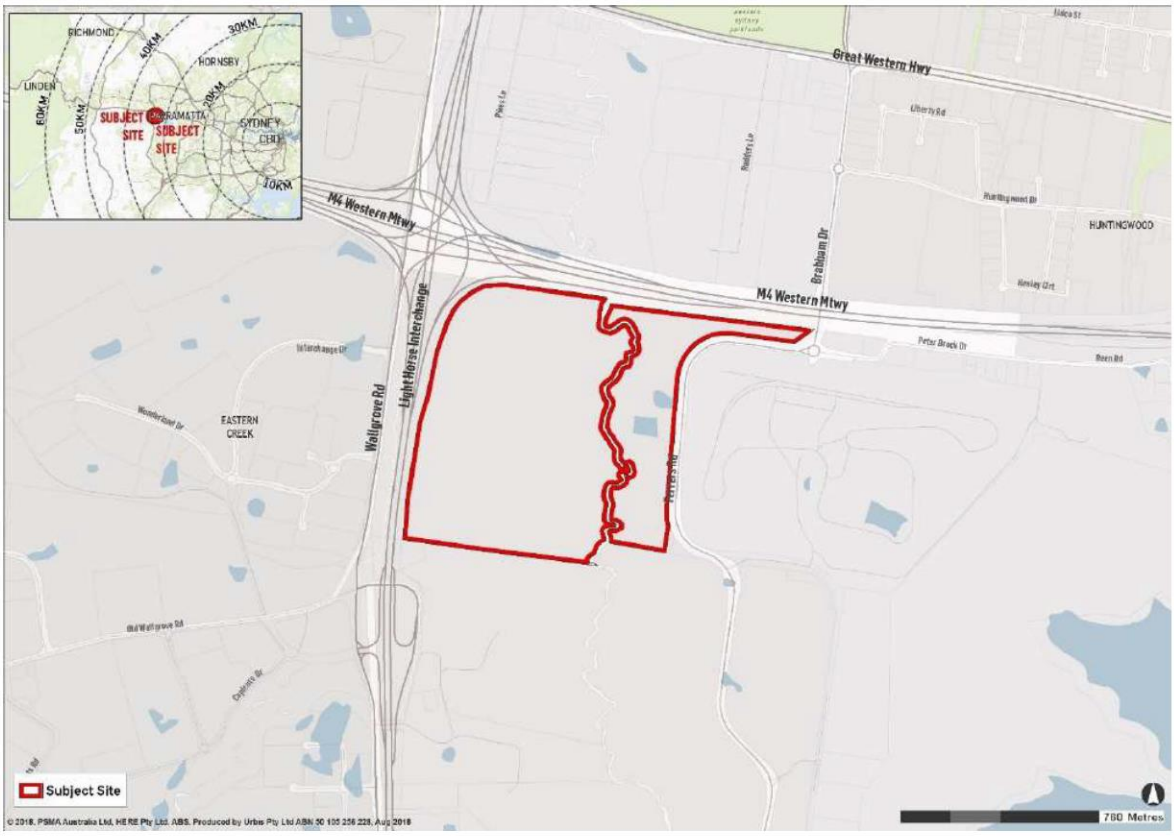


**Figure 2 Lot Boundaries [Ref. 3]**

**Figure 3 Affected area [Ref. 3]**

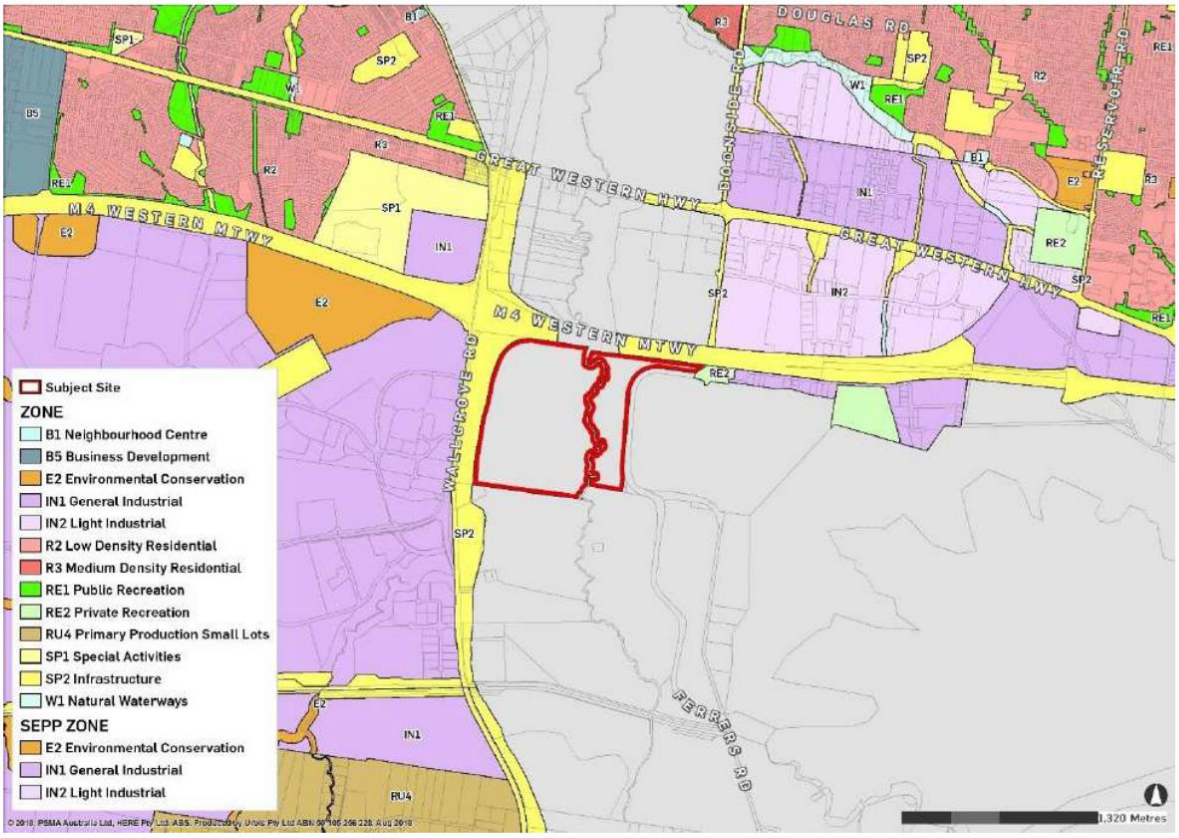

## 2.2 Zoning

The environmental planning instruments and statutory planning documents relevant to the site are *State Environmental Planning Policy (Western Sydney Parklands) 2009* and the *Western Sydney Parklands Plan of Management 2030*. Under the provisions of the Western Sydney Parklands SEPP the entire area of the Western Sydney Parklands is not zoned.

The subject site is within the southern part of the Blacktown local government area (LGA), approximately 1.3 kilometres north of the Fairfield LGA boundary. The surrounding land use zones from the *Blacktown Local Environmental Plan 2015* are shown in Figure 4 for reference only.

The subject site is within the Western Sydney Parklands corridor and has been identified as a Business Hub in the Western Sydney Parklands Trust Plan of Management 2030 Supplement.

**Figure 4 Zoning [Ref. 3]**




## 2.3 Existing Facilities and Surrounding Land Uses

The site is predominantly undeveloped with large areas of cleared land and scattered vegetation, with more densely vegetated areas in the south-western corner and along Eastern Creek. Derelict buildings and structures associated with the former Wallgrove Army Base are located within the central part of the development site.

A 24 metre wide high-pressure gas main easement runs north-south to the east of the development site (and within the Lot 10 boundary). A 6 metre wide trunk sewer main easement is located within the central part of the development site and also runs in a north-south direction.

As per the Western Sydney Parklands SEPP, the land subject to the SSD is currently not zoned. For reference, the development site is surrounded by a variety of land use activities and significant transport and utilities infrastructure as summarised below:

- **North**: the undeveloped land immediately north of the M4 Western Motorway also forms part of the Western Sydney Parklands. Adjoining developments include the Bungarribee industrial estate to the east and the Calibre industrial business park to the west.
- **East**: the Sydney Motorsport Park and Sydney Dragway are immediately east of Ferrers Road, comprising a permanent race track and other motor-related activities. Prospect Reservoir is located further east. The reservoir and adjoining nature reserve form part of the Western Sydney Parklands.

- **South**: the SUEZ Eastern Creek Resource Recovery Park is located to the south of the development site, including separation, recycling and re-use of waste materials and landfill operations. Austral Bricks is located further south of the Sydney Water pipeline within the Fairfield LGA.
- **West**: the land to the west of the Westlink M7 Motorway and Wallgrove Road has been developed as the Eastern Creek Business Park including large-scale warehouses, freight and logistics and light industrial activities with ancillary offices.

## 2.4 Proposed Development

The key features of the concept proposal are summarised below [Ref. 3]:

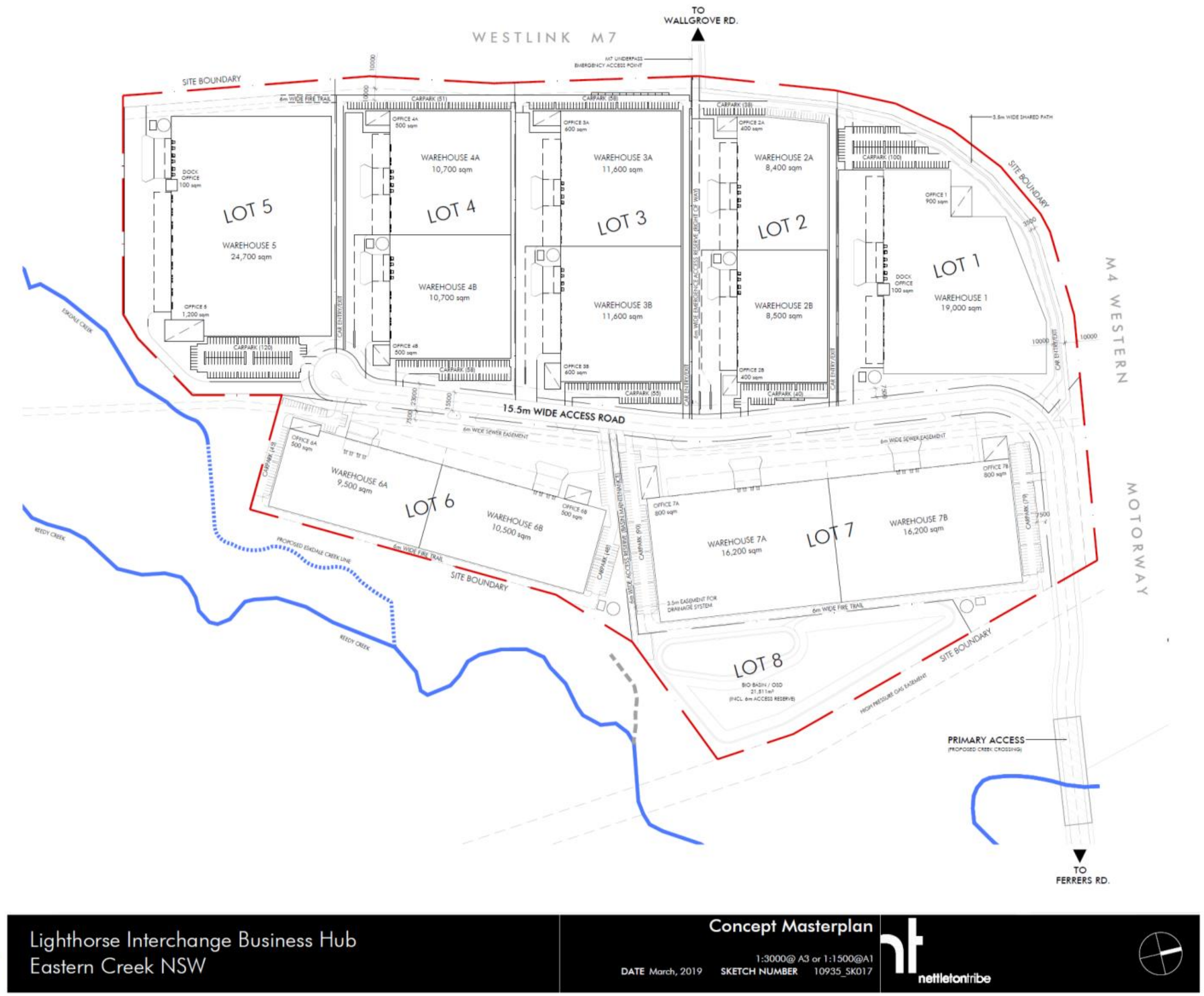
- Approximately 157,000 sqm of industrial and light industrial floorspace with approximately 8,000 sqm of ancillary offices to accommodate a range of land use activities, including advanced manufacturing, freight and logistics and warehouse and distribution facilities.
- Site landscaping to provide visual screening of the proposed buildings from the surrounding road network.
- Primary access will be from Ferrers Road with new roads and road improvement works. A second access point for emergencies only via the existing Wallgrove Road entry/exit driveway.
- Stormwater management and flood mitigation works will as necessary to manage the quality and quantity of water flows across the site and avoid adverse impacts to the environment.
- Vegetation management to avoid, minimise and/or manage potential ecological impacts, including implementation of bushfire protection recommendations.
- Delivery of utility services required to service the proposed development, including any necessary upgrades and siting and design of the proposed industrial subdivision to incorporate the existing easements for high-pressure gas and sewer.

The conceptual layout of the facilities is shown in Figure 5.

**Figure 5 Concept Masterplan [Ref.13]**

| DEVELOPMENT DATA | | | |
|---|---|---|---|
| OVERALL SITE AREA | | | $336,287 m^2$ |
| LOT 8 (RESIDUAL) - ESTATE BIO-BASIN/OSD | | | $21,511 m^2$ |
| ACCESS ROAD RESERVE | | | $21,137 m^2$ |
| TOTAL DEVELOPABLE AREA (LOT 1 TO 7) | | | $293,639 m^2$ |
| TOTAL BUILDING AREA | | | $165,500 m^2$ |
| FLOOR SPACE RATIO | | | 56.4% |
| DEVELOPABLE LOT | W/H AREA | OFFICE AREA | TOTAL |
| LOT 1 SITE AREA ($41,270 m^2$) | 19,000 | 1,000 | 20,000 |
| LOT 2 SITE AREA ($34,141 m^2$) | 16,900 | 800 | 17,700 |
| LOT 3 SITE AREA ($41,112 m^2$) | 23,200 | 1,200 | 24,400 |
| LOT 4 SITE AREA ($38,686 m^2$) | 21,400 | 1,000 | 22,400 |
| LOT 5 SITE AREA ($44,193 m^2$) | 24,700 | 1,300 | 26,000 |
| LOT 6 SITE AREA ($38,406 m^2$) | 20,000 | 1,000 | 21,000 |
| LOT 7 SITE AREA ($55,831 m^2$) | 32,400 | 1,600 | 34,000 |
| TOTAL | 157,600 | 7,900 | 165,500 |

| CARPARK PROVISIONS | |
|---|---|
| TOTAL CARPARK REQUIRED<br>RMS - Warehouse: 1 space/300sqm<br>Office: 1 space/40sqm | 723 spaces |
| TOTAL CARPARK PROVIDED | 782 spaces |



# 3 METHODOLOGY

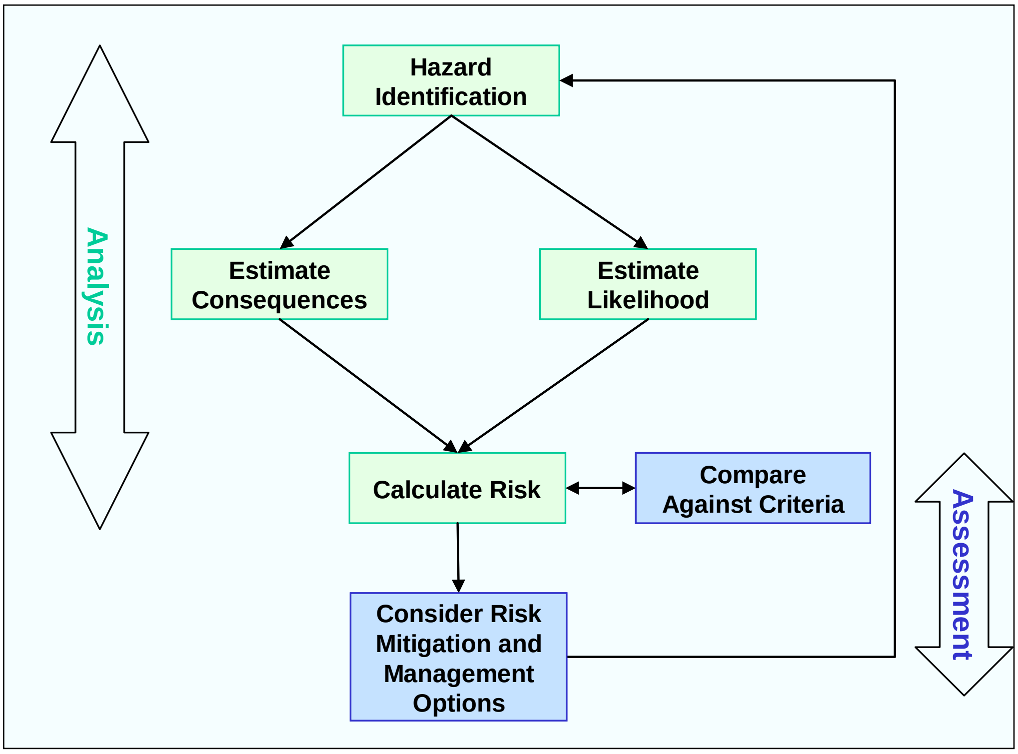
## 3.1 Introduction

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 DP&E's guidelines for undertaking this type of assessment [6].

Diagrammatically, the QRA process is as follows:

**Figure 6 Overview of QRA Process [6]**




## 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 a material with the potential to cause harm (e.g. due to a subsequent fire). 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 DP&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 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 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 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 local meteorological department.

In addition to wind speed, the Pasquill stability class has a significant impact on the vertical and crosswind dispersion of a released gas. There are six wind stability classes (A to F). 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.

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 (v.8.11) was used for all consequence modelling and the generation of the risk contours / transects 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 1 [Ref. 6].

**Table 1 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.<br>Minor injury from window breakage in building. |
| 7.0 | Glass fragments fly with enough force to cause injury.<br>Probability of injury is 10%. No fatality.<br>Damage to internal partitions and joinery of conventional buildings but can be repaired. |
| 14.0 | 1% chance of ear drum rupture.<br>House uninhabitable and badly cracked. |
| 21.0 | 10% chance of ear drum rupture.<br>20% chance of fatality for a person within a conventional building.<br>Reinforced structures distort.<br>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.<br>House uninhabitable.<br>Heavy machinery damaged.<br>Significant damage to plant. |
| 70.0 | 100% chance of fatality for a person within a building or in the open.<br>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 2 [Ref. 6]. The vulnerability criteria used in the risk analysis are included in Appendix A.6.

**Table 2 Effects of Thermal Radiation**

| Heat Radiation [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.<br>Injury (second degree burns) to person who cannot escape or seek shelter after 30s exposure. |
| 12.6 | High chance of injury.<br>30% chance of fatality for extended exposure.<br>Melting of plastics (cable insulation).<br>Causes the temperature of wood to rise to a point where it can be ignited by a naked flame after long exposure.<br>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.<br>10% chance of fatality on instantaneous exposure.<br>Spontaneous ignition of wood after long exposure.<br>Unprotected steel will reach thermal stress temperatures, which can cause failure.<br>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. $5.0 \times 10^{-6}$ per year or 5E-06 per year) is normally used because the likelihood of a MAE is usually a low number (i.e. much less than 1 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 many 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 considered. 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. In this case, historical data was available and the frequency analysis data and results are summarised in Section 7 and Appendix C.

### 3.2.5 Risk Analysis and Assessment

Risk analysis and assessment are separate tasks although they are often undertaken at the same time. 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: $1 \times 10^{-6}$ per year, $10 \times 10^{-6}$ per year and $50 \times 10^{-6}$ 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 software package (v.8.11) was used to generate the iso-risk contours / transects and societal risk results (Refer to Section 8).

## 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, 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 DP&E [Ref. 5].

**Table 3 Individual Fatality Risk Criteria**

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

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

The DP&E has adopted a fatality risk criterion of 1 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.

### 3.4.2 Injury Risk

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

The DP&E's suggested injury risk criterion for heat radiation is as follows:

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

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

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

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

- *Toxic concentrations in residential and sensitive use areas should not exceed a level which would be seriously injurious to sensitive members of the community following a relatively short period of exposure at a maximum frequency of 10 in a million per year.*
- *Toxic concentrations in residential and sensitive use areas should not cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community over a maximum frequency of 50 in a million per year.*

### 3.4.3 Risk of Property Damage and Accident Propagation

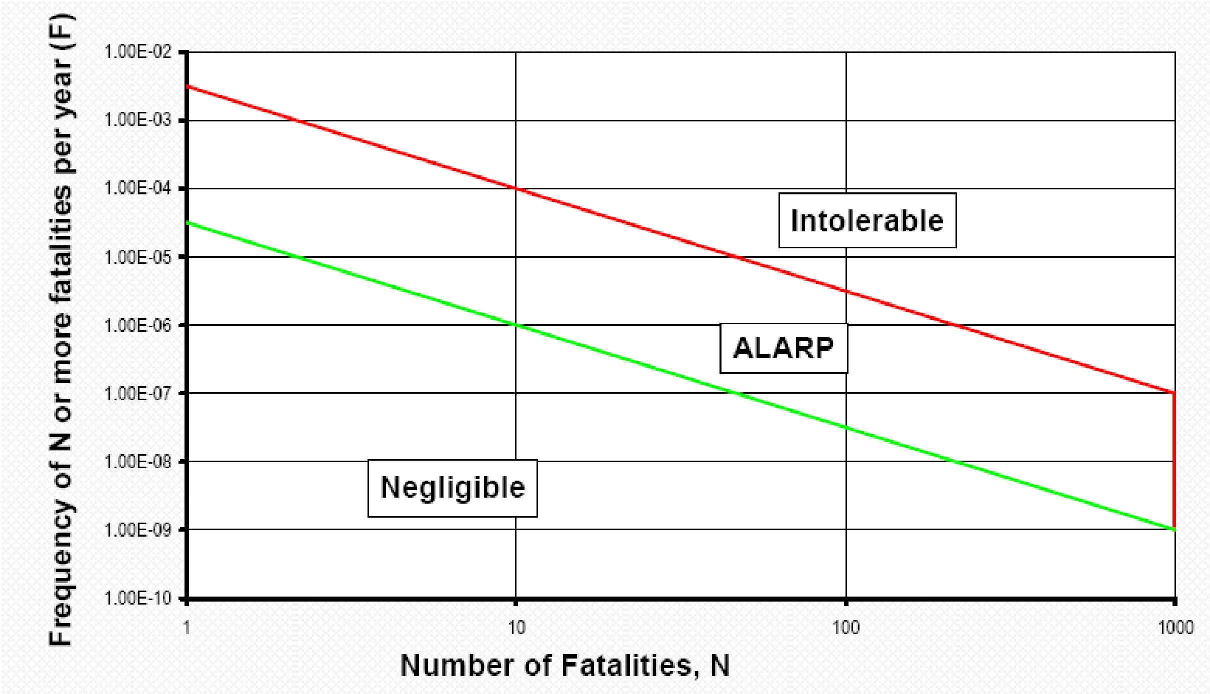
Heat radiation exceeding 23 kW/m$^2$ may cause unprotected steel to suffer thermal stress that may cause structural damage and an explosion overpressure of 14 kPa can cause damage to piping and low-pressure equipment. The DP&E's criteria for risk of damage to property and accident propagation are as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

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

### 3.4.4 Societal Risk

The DP&E's suggested societal risk criteria (Refer to Figure 7), 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 are met, the risks from the activity would be considered tolerable in the ALARP region.

**Figure 7 Indicative Societal Risk Criteria**



## 3.5 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 qualitative risk criteria outlined in HIPAP No. 4 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 IDENTIFICATION OF POTENTIALLY HAZARDOUS FACILITIES & OPERATIONS

## 4.1 Introduction

The specific use at each lot is anticipated to include warehousing facilities and ancillary offices; however, the specific details (including types and quantities of Dangerous Goods, if present) are not known at this stage and will be addressed separately in later Development Applications. Consequently, it was not possible to undertake a preliminary risk screening in accordance with *Applying SEPP 33* for the industrial business hub facilities or to undertake a PHA for these facilities in accordance with HIPAP No. 6.

It is noted in the SEARs that an existing high pressure pipeline is near the proposed industrial business hub. This pipeline is the JGN Trunk Main (Refer to Section 4.2) and its location was identified by the 'Dial Before You Dig' (DBYD) process and direct surveying of the pipeline (Refer to Section 5.5.4).

At this stage, the JGN Trunk Pipeline was the only identified credible external source of risk to occupants of the proposed industrial business hub. Consultation with Jemena was undertaken during preparation of the risk assessment and Jemena provided the relevant data for the JGN Trunk Pipeline (Refer to Section 4.2). The risk at the proposed development from this pipeline was assessed against the risk criteria in HIPAP No. 10 (Refer to Section 8).

## 4.2 JGN Trunk Pipeline

The approximate location of the JGN Trunk Pipeline is shown in Figure 8 (Blue line marked in the high pressure gas easement), which is based on the pipeline survey data (Refer to Section 5.5.4).

**Figure 8 Approximate Location of JGN Trunk Pipeline [Ref. 1]**

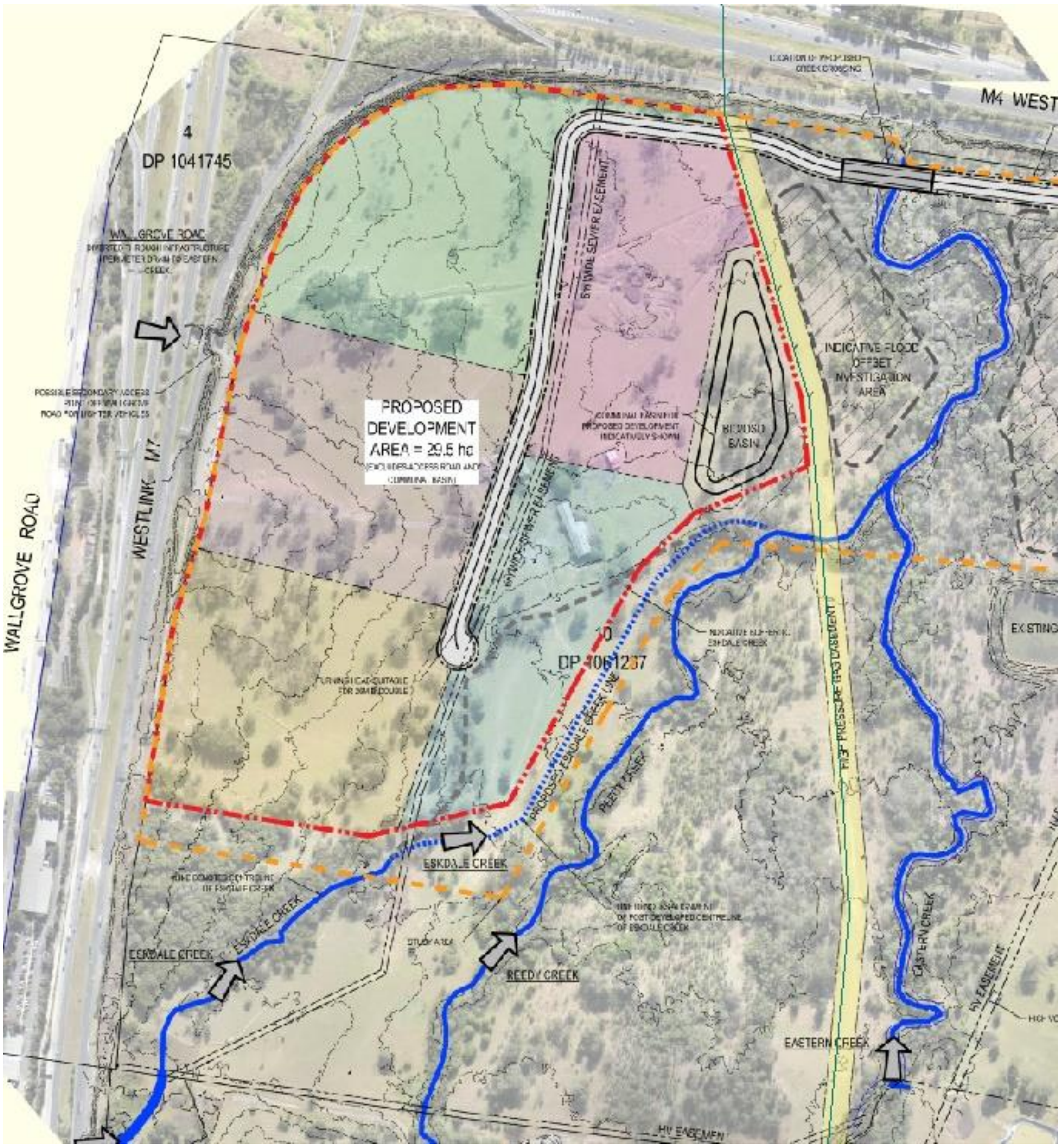


**Figure 9 Approximate Location of JGN Trunk Pipeline**

Information provided by Jemena for the JGN Trunk Pipeline is listed in Table 4.

**Table 4 JGN Trunk Pipeline**

| | |
|---|---|
| **Pipeline Owner** | Jemena |
| **Pipeline Name** | JGN Trunk Pipeline - Licence 3 |
| **Pipeline Origin and Destination** | Horsley Park to Plumpton |
| **Material/Product Transferred** | Natural Gas |
| **Licence No.** | 3 |
| **Utilisation (%)** | |
| **MAOP (MPag)** | 6.895 |
| **Normal Operating Pressure (MPag)** | 4.2 |
| **Operating Temperature (oC)** | Ambient |
| **Average and Maximum Flowrate (kg/hr)** | ~8432GJ/Hr or 202TJ/day |
| **Pipeline Material** | API5L X60 |
| **Pipeline Diameter (mm)** | 508 |
| **Wall Thickness (mm)** | 8.5 |
| **Design Factor** | 0.72 |
| **Depth of Cover (m)** | >900mm (as per as built drawings) |
| **Cathodic Protection** | Yes, Impressed current system |
| **External Coating** | High Density Polyethylene (HDPE) |
| **Leak Detection** | NA |
| **Locations of Nearest Isolation Valves** | Horsley Park TRS and Plumpton ALBV station |
| **Location of Nearest Booster Station** | APA Moomba-Sydney Pipeline (MSP) at Young and<br>Jemena Eastern Gas Pipeline (EGP) at Michelago |
| **Inspections** | Inline Inspection (ILI), Cathodic Protection Survey, Coating Survey (DCVG) as required, Right of Way inspections |
| **Control Measures for 3rd Party Interference** | Physical measures - Wall thickness, Depth of cover and Concrete slabs (at all major road crossings)<br>Procedural Measures - Marker Posts, Dial Before You Dig, Jemena Encroachment Management System, Aerial Patrol (weekly), Ground Patrol (weekly), Land owner liaison |
| **Pigging** | Last pigging carried out in Nov 2018, Awaiting pigging Data |
| **Current Condition of Pipeline** | Fit to operate at MAOP |
| **Projected changes (if any)** | None |

# 5 HAZARD IDENTIFICATION

## 5.1 Introduction

The hazard identification was based on a review of the: information on the JGN Trunk Pipeline (Refer to Section 4.2); properties of Natural Gas; and, potential failure modes and consequences if a leak were to occur from the JGN Trunk Pipeline. These findings are presented as follows:

Section 5.2 – Properties of Natural Gas.

Section 5.3 - Pipeline Failure Modes.

Section 5.4 - Potential Consequences.

Section 5.5 - Control Measures.

The representative MAE/s carried forward to the consequence analysis are listed in Section 5.6.

## 5.2 Properties of Natural Gas

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

Physical properties of Methane are listed in Table 5.

**Table 5 Physical Properties of Methane**

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

Methane is:

- A gas at ambient conditions;
- Flammable;
- Lighter than air at ambient temperatures; and
- Colourless, odourless and non-toxic.

### 5.3 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:

- **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.

#### 5.3.1 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 JGN Trunk Pipeline.

#### 5.3.2 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 JGN Trunk Pipeline.

#### 5.3.3 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.

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

This failure mode is credible for the JGN Trunk Pipeline.

## 5.4 Potential Consequences

### 5.4.1 Asphyxiation

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

Natural Gas 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) there is a rapid onset of impairment of mental activity.

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

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

Oxygen deficiency from exposure to Natural Gas should not be a major issue because the fire hazards are usually the dominant effects in most locations (the LFL for Methane is approximately one-tenth, or 10%, 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.

### 5.4.2 Jet Fire

Combustion of Natural Gas released from a hole in a pipeline may create a jet fire.

The SAFETI software uses a different correlation depending on the release conditions. The Chamberlain model is used for non-horizontal gas releases and the Johnstone model is used for horizontal gas releases.

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.

### 5.4.3 Flash Fire

Combustion of an unconfined gas cloud will usually progress at low velocities and will not generate a significant explosion overpressure. Ignition of the gas cloud will result in 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.

### 5.4.4 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. This may occur inside buildings and around obstacles (e.g. vehicles, trees, etc.).

In this case, an explosion is less likely than a flash fire due to the relatively open area surrounding the JGN Trunk Pipeline easement (Refer to Figure 8) and the buoyancy of Natural Gas. This may change once the future structures / buildings are constructed. Since the configuration of the future structures / buildings is not known at this stage, all delayed ignition events were modelled as flash fires (See above) and conservative assumptions were adopted in the risk assessment for the flash fire modelling (e.g. flash fire extent based on distance to 50% of the Lower Flammable Limit concentration, release pressure based on MAOP rather than lower normal operating pressure, etc.).

### 5.4.5 Toxic Smoke

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

### 5.4.6 Explosion in a Confined Space

If a leak of flammable gas or vapour enters a confined space (e.g. a building), then a confined explosion may occur if it is ignited. The type and configuration of the buildings at the proposed industrial business hub has not been defined at this stage; therefore, an explosion in a confined space was not carried forward to the consequence, likelihood and risk estimation steps of the QRA.

A leak of flammable gas or liquid from an underground pipeline also has the potential to enter underground services (e.g. sewer pipes) if there is inadequate segregation. This was the cause of major explosions in Mexico and Taiwan; however, these incidents occurred due to very specific circumstances (e.g. For the incident in Taiwan, a gas pipeline had been routed through a sewer and subsequently leaked inside the sewer due to corrosion. For the incident in Mexico, a fuel pipeline was in direct contact with a water pipe and a leak occurred between the two due to corrosion). This does not appear to be applicable for the JGN Trunk Pipeline, which is in a separate easement to the sewer pipes (Refer to Figure 8).

## 5.5 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 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.

The JGN Trunk Pipeline is a licensed pipeline (Licence No. 3 – Refer to Section 4.2).

### 5.5.1 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 (as per Section 6 of AS 2885.3:2012) 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 (e.g. not operated above the MAOP). Anomalies should be assessed, and defects repaired.

The JGN Trunk Pipeline is inspected via ‘intelligent pigging’ (Refer to Section 4.2) and has a wall thickness of 8.5 mm (Design factor = 0.72).

### 5.5.2 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 JGN Trunk Pipeline is inspected via inline inspections, cathodic protection surveys, coating surveys and 'intelligent pigging' (Refer to Section 4.2). It is equipped with a cathodic protection system and a High Density Polyethylene (HDPE) coating (Refer to Section 4.2).

### 5.5.3 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 AS2885.1:2018). To comply with AS2885.1:2018, 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).

The JGN Trunk Pipeline has a wall thickness of 8.5 mm (Design factor = 0.72) and is mostly located on flat land; however, there are some waterways nearby (Refer to Figure 8). Jemena advised that concrete slabs are provided at all major road crossings (Refer to Section 4.2).

### 5.5.4 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.

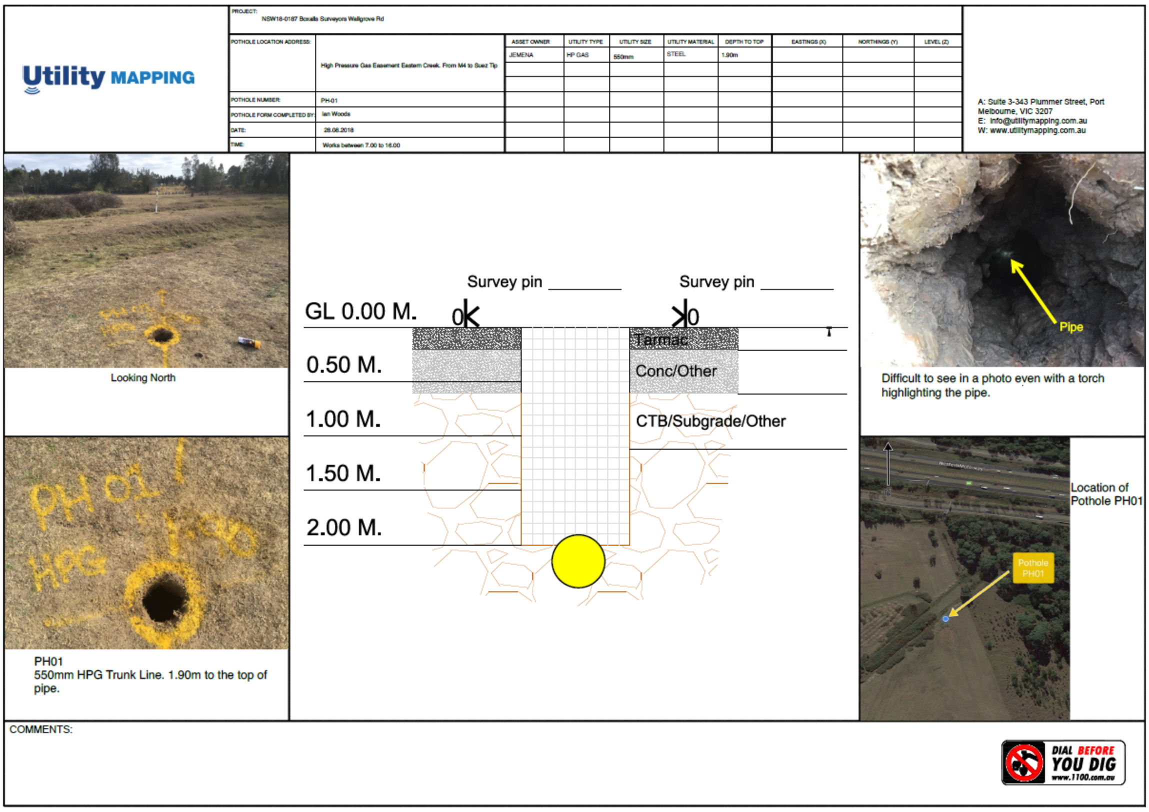
The pipeline wall thickness affects the probability of a leak if impact occurs. For example, the average frequency of TPA contact (with NO leak) in NSW is 0.206 per 1000 km per year (Average frequency from NSW Performance Report (2016) for 5-year period 2011/12 to 2015/16), which is c. 2.5 times higher than the average leak frequency in NSW from all causes (viz. 0.085 per 1000 km per year) and c. 10 times higher than the average leak frequencies reported by the UK HSE for TPA (Refer to Appendix C).

The depth of cover may also reduce the likelihood of impact.

The JGN Trunk Pipeline has a wall thickness of 8.5 mm (Design factor = 0.72). The JGN Trunk Pipeline may be located using the installed marker posts and the DBYD process. There are right of way inspections, weekly ground patrols and weekly aerial patrols (Refer to Section 4.2).

The depth of cover for the JGN Trunk Pipeline near the proposed development ranges from 1.77 to 2.05 m (Average = 1.8 m) and has been surveyed at multiple locations in the easement (An example survey drawing is included below).

**Figure 10 Example Pipeline Survey Drawing**




### 5.5.5 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 JGN Trunk Pipeline can be isolated by shutting down compressors and closing isolation valves (Refer to Section 4.2 for locations of upstream and downstream isolation valves).

## 5.6 MAEs for Risk Analysis

Only one MAE was identified for the risk analysis: a release of Natural Gas from the JGN Trunk Pipeline. The potential outcomes from such a release include a jet fire or flash fire.

# 6 Consequence Analysis

## 6.1 Release of Flammable Gas

### 6.1.1 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 C).

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). This is also consistent with the predicted hole sizes in this size category reported in Table E3 of AS 2885.1 – 2018, which are based on excavator weight and tooth dimensions (i.e. 15 mm for a 5 tonne excavator, 20 mm for 10-15 tonne excavators and 25 mm for 20-25 tonne excavators). Therefore, two representative hole diameters were selected in this category: 25 mm for TPA and 10 mm for all other failure modes.

**Table 6 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) |
| JGN Trunk Pipeline | 491 | 10 or 25* | 75 | 110 | 491 |

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

### 6.1.2 Rate of Release

The rate of release from a pipeline leak is dependent on the pressure. A release of Natural Gas from the JGN Trunk Pipeline was modelled at 6.895 MPag, which is the MAOP for the pipeline. This is greater than the typical operating pressure at the location of interest (viz. 4.2 MPag - Refer to Section 4.2).

Release events were modelled using the ‘long pipeline’ model in Safeti (v.8.11). The estimated release rates are tabulated below for each representative hole size.

**Table 7 Representative Hole Diameters Selected for Consequence Analysis**

| Representative Hole Diameter (mm) | Release Rate [kg/s] |
|---|---|
| 10 | 0.89 |
| 25 | 5.55 |
| 75 | 49.9 |
| 110 | 107.4 |
| 491 (FBR) | 3436.3 * |

* Peak release rate for Long Pipeline Model

### 6.1.3 Height and Orientation of Release

The SAFETI software does not permit entry of a release height below 0 m; therefore, all releases from the underground pipeline were modelled at a release height of 0 m (i.e. ground level). This is not a significant factor for the typical burial depth (Refer to Section 4.2).

The direction of release from a pipeline is dependent on the failure mode and representative hole size. The following representative release directions were adopted for the QRA (Refer to Appendix A, Assumption No. 14).

- **Third Party Activity (TPA)** – All hole sizes are modelled as 25% at 45 degrees (Not impinged – e.g. fully excavated), 25% at vertical (Not impinged – e.g. fully excavated) and 50% at horizontal (Impinged – by ground and/or the machinery that caused damage).
- **All other failure modes** – All hole sizes (expect 'pinhole') are modelled as 25% at 45 degrees (Not impinged), 25% at vertical (Not impinged) and 50% at horizontal (Impinged). All 'Pinhole' leaks are modelled as horizontal (Impinged).

### 6.1.4 Duration of Release

Natural Gas is flammable and any adverse impact will occur quickly; 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.

## 6.2 Fire

The latest SAFETI software package (v.8.11) 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.

### 6.2.1 Jet Fire

Example distances to heat radiation levels of 4, 12.5 and 35 $kW/m^2$ are tabulated in Appendix B.2 for representative jet fire events included in the risk analysis.

### 6.2.2 Flash Fire

Example distances to the lower flammability limit (LFL) concentration and ½ LFL concentration are tabulated in Appendix B.2 for representative flash fire events included in the risk analysis.

# 7 FREQUENCY AND LIKELIHOOD ANALYSIS

## 7.1 Likelihood of Release

The likelihood of a release (i.e. leak) from the JGN Trunk Pipeline is tabulated in Table 8 (Also refer to Appendix C.1) and was estimated based on a review of relevant data sources. The primary data sources included:

- Department of Industry, Resources and Energy, New South Wales, *2015-16 Licensed Pipelines Performance Report*. This includes data for all licensed pipelines in NSW for the 5-year period: 2011/12 to 2015/16; 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 - Reported Data for Underground Natural Gas Steel Pipelines (January 2010 to September 2017).

**Table 8 Leak Frequencies for JGN Trunk Pipeline**

| 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 |
| 7.6E-05 | 4.9E-06 | 2.7E-07 | 2.6E-06 | **8.35E-05** |

## 7.2 Probability of Ignition

The ignition probabilities adopted in the risk analysis are listed in Table 9 and were based on a review of relevant ignition probability data and ignition probability correlations (Refer to Appendix C.1.3).

**Table 9 Ignition Probabilities**

| Representative Hole Diameter (mm) | Release Rate [kg/s] | Total Ignition Probability | Immediate Ignition Probability | Delayed Ignition Probability |
|---|---|---|---|---|
| 10 | 0.89 | 0.005 | 0.0025 | 0.0025 |
| 25 | 5.55 | 0.020 | 0.010 | 0.010 |
| 75 | 49.9 | 0.106 | 0.053 | 0.053 |
| 110 | 107.4 | 0.187 | 0.093 | 0.093 |
| 491 (FBR) | 3436.3 * | 1.0 | 0.5 | 0.5 |

* Peak release rate for Long Pipeline Model

## 7.3 Likelihood of Representative MAEs

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

# 8 Risk Analysis and Assessment

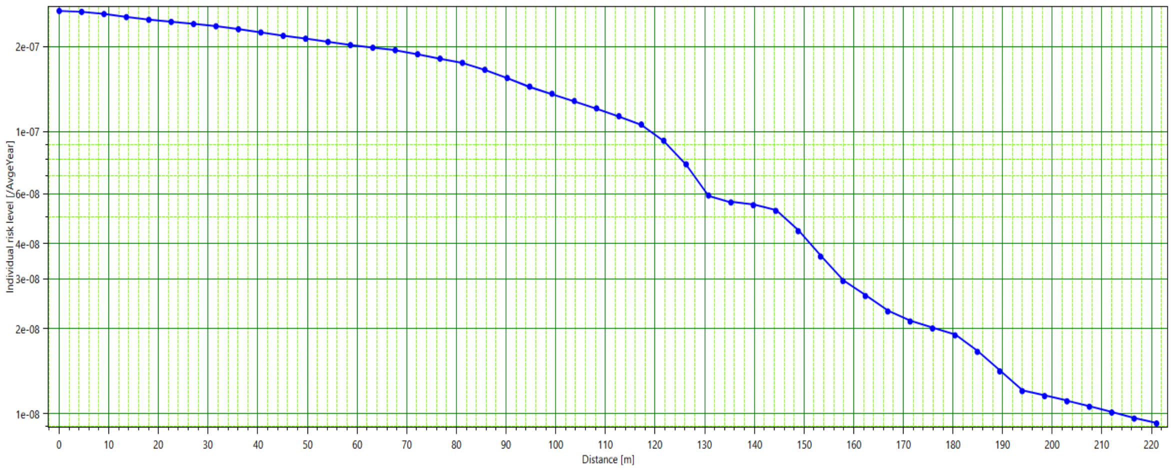
## 8.1 Individual Fatality Risk

The maximum cumulative individual fatality risk for the JGN Trunk Pipeline is 0.27 x $10^{-6}$ per annum (Refer to Figure 11 – Note: This is a representative risk transect showing the risk perpendicular to the JGN Trunk Pipeline through the centre of Lot 7).

The maximum cumulative individual fatality risk at the proposed industrial business hub is significantly lower than the relevant DP&E risk criterion of 50 x $10^{-6}$ per annum.

The cumulative individual fatality risk is less than 1 x $10^{-8}$ per annum for most of Lots 1-5.

**Figure 11 Individual Fatality Risk**




## 8.2 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 5.4.5). Furthermore, the relevant DP&E risk criteria are only applicable for residential or sensitive use developments and are not applicable for the proposed industrial business hub.

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

The cumulative risk of property damage and accident propagation (Overpressure exceeding 14 kPa) for the JGN Trunk Pipeline was not evaluated since all delayed ignition events are modelled as flash fires (Refer to Section 5.4.4).

## 8.4 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$^2$) for the JGN Trunk Pipeline does not reach 50 x $10^{-6}$ per annum. The proposed industrial business hub complies with this DP&E risk criterion (Refer to Section 3.4.3).

## 8.5 Risk of Injury (Exceeding 7 kPa)

The cumulative risk of injury (Overpressure exceeding 7 kPa) for the JGN Trunk Pipeline was not evaluated since all delayed ignition events are modelled as flash fires (Refer to Section 5.4.4).

The DP&E injury risk criterion (Overpressure exceeding 7 kPa) is only applicable for residential or sensitive use developments; therefore, it is not applicable for the proposed industrial business hub.

## 8.6 Risk of Injury (Exceeding 4.7 kW/m$^2$)

The cumulative risk of injury (Heat radiation exceeding 4.7 kW/m$^2$) for the JGN Trunk Pipeline does not reach 50 x $10^{-6}$ per annum.

The DP&E injury risk criterion (Heat radiation exceeding 4.7 kW/m$^2$) is only applicable for residential or sensitive use developments; therefore, it is not applicable for the proposed industrial business hub.

## 8.7 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 industrial business hub is considered to generally comply with the qualitative risk criteria outlined in HIPAP No. 4, as follows:

- Avoidance of all 'avoidable' risks – The JGN Trunk Pipeline is an existing facility (i.e. it cannot be relocated to avoid the risk exposure). The proposed industrial business hub is not existing; however, it is a use that is more appropriate from a land use safety perspective than residential, sensitive or commercial uses (i.e. it avoids a potentially more significant land use safety conflict). The proposal is an important component of the Western Sydney Parklands Plan of Management.
- Reduction, wherever practicable, of the risk from a major hazard, even where the likelihood of exposure is low – In this case, the risk exposure at the proposed industrial business hub (particularly Lots 1-6) is lower than the relevant quantitative individual and societal risk criteria. The pipeline owner will also review the existing control measures in accordance with AS 2885 (Refer to Section 5.5).
- Containment, wherever possible, within the site boundary of the effects (consequences) of the more likely hazardous events – The effects (consequences) of the more likely effects may extend into part of Lot 7 (Refer to Figure 5 and Appendix 0); however, these may be mitigated through appropriate building design, barriers, etc. The proposed development also includes a water storage basin (Lot 8 – Refer to Figure 5), which provides additional segregation between the potentially occupied areas and the JGN Trunk Pipeline.
- 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 – In this case, the risk exposure at the proposed industrial business hub is lower than the relevant quantitative individual and societal risk criteria.

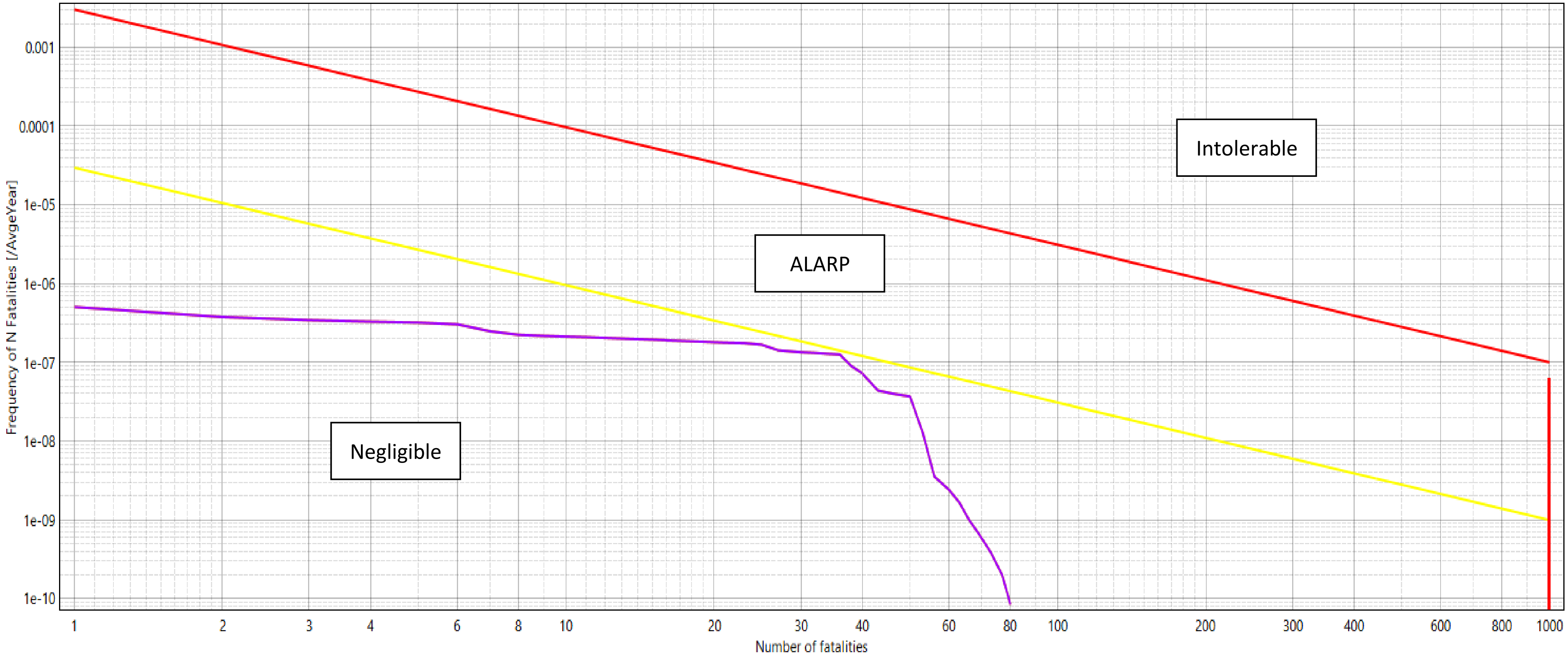
## 8.8 Societal Risk

The FN Curve for the proposed industrial business hub is wholly within the 'negligible' risk zone (Refer to Figure 12) and therefore complies the relevant DP&E risk criteria (Refer to Section 3.4.4).

The FN Curve is based on a total population of 1,000 persons (equivalent to 61 persons per hectare, distributed evenly across all lots and assuming 90% are located indoors and 10% are located outdoors). The total parking provided for the development is 782 spaces [Ref: 13]. With the average occupancy per trip to work of 1.1 persons [Ref 14], assuming approximately 1,000 persons on the development appears reasonable. Whilst the population estimate used in this risk assessment is expected to be conservative for the types of use envisaged for the proposed industrial business hub, it may be necessary to review the societal risk exposure from the JGN Trunk Pipeline as part of the subsequent DAs.

Due to its proximity to the JGN Trunk Pipeline, Lot 7 accounts for approximately 82% of the risk (PLL). Lots 1-5 only account for approximately 13% of the risk (PLL).

**Figure 12 Societal Risk FN Curve**



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# Appendices

# Appendix A Assumptions

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

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

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

It is important that the assumptions be supported by:

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

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

**Table 10 List of Assumptions by Subject**

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

## A.1 Operational Data

| Assumption No. 1: Operating Conditions |
|---|
| **Subject:** Operational Data |
| **Assumption/s:**<br>• All pipeline operating conditions (pressure, temperature, etc.) are as reported in Section 4.2. |
| **Justification and Impact/s of Assumption/s:**<br>• All operational data for the JGN Trunk Pipeline was provided by the pipeline owner (Jemena).<br>• Operating conditions (particularly operating pressure) are required to undertake the release and dispersion modelling. |
| **MAE/s Affected:**<br>• All. |
| **Reference/s:**<br>• Data provided by Jemena (9 January 2019). |

| Assumption No. 2: Utilisation of Pipelines |
|---|
| **Subject:** Operational Data |
| **Assumption/s:**<br>• The JGN Trunk Pipeline is utilised 100% of the time. |
| **Justification and Impact/s of Assumption/s:**<br>• Utilisation data is required to undertake the release and dispersion modelling and to estimate the release frequency.<br>• Utilisation data was not provided by Jemena (Refer to Section 4.2); therefore, it was conservatively assumed to be 100% for the QRA. |
| **MAE/s Affected:**<br>• All. |
| **Reference/s:**<br>• Data provided by Jemena (9 January 2019). |

## A.2 Locational Data

| Assumption No. 3: Representative Wind Speeds, Wind Directions and Stability Classes |
|---|
| **Subject:** Locational Data |
| **Assumption/s:**<br>• The probabilistic distribution of wind speed and wind direction for the representative stability classes is provided in Table 11. |
| **Justification and Impact/s of Assumption/s:**<br>• Meteorological data (mean cloud cover, temperature, wind speeds) is collected by the Bureau of Meteorology (BoM) at the Parramatta weather station. This raw data was rationalised in a form appropriate for dispersion calculations. The Parramatta weather station was selected as being closest to the proposed development.<br>• Wind speed typically has minimal impact on jet fires as the jet velocity is much higher than the wind speed.<br>• The downwind concentrations, and hence the hazard ranges for dispersion of flammable gas, vary with wind speed and stability class. Therefore, multiple representative wind speed and stability class categories are included in accordance with standard practice for undertaking a quantified risk analysis (QRA). |
| **MAE/s Affected:**<br>• All. |
| **Reference/s:**<br>• BoM meteorological data for Parramatta weather station. |

**Table 11 Probability (%) of Representative Stability Classes and Wind Speeds**

| Stab. Class | Wind Speed (m/s) | N | NNE | NE | ENE | E | ESE | SE | SSE | S | SSW | SW | WSW | W | WNW | NW | NNW | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | 1.8 | 1.03 | 0.52 | 0.49 | 0.45 | 0.56 | 0.35 | 0.31 | 0.25 | 0.40 | 0.35 | 0.50 | 0.58 | 0.98 | 0.97 | 0.95 | 0.84 | 9.52 |
| D | 7.5 | 0.30 | 0.06 | 0.41 | 0.87 | 0.79 | 1.40 | 1.96 | 2.02 | 1.54 | 0.33 | 0.43 | 0.86 | 1.27 | 0.84 | 0.39 | 0.33 | 13.81 |
| D | 3.9 | 2.16 | 1.05 | 2.29 | 2.36 | 2.70 | 2.59 | 2.56 | 2.24 | 3.07 | 1.60 | 2.68 | 2.67 | 2.84 | 2.03 | 2.17 | 2.16 | 37.17 |
| D | 1.0 | 2.52 | 1.11 | 1.31 | 1.14 | 1.28 | 1.00 | 1.04 | 0.92 | 2.07 | 1.85 | 2.57 | 2.63 | 3.49 | 2.81 | 3.19 | 2.78 | 31.70 |
| E | 2.6 | 0.06 | 0.04 | 0.09 | 0.08 | 0.08 | 0.07 | 0.05 | 0.03 | 0.06 | 0.06 | 0.08 | 0.08 | 0.08 | 0.06 | 0.08 | 0.10 | 1.13 |
| F | 1.0 | 0.57 | 0.20 | 0.29 | 0.27 | 0.30 | 0.26 | 0.20 | 0.19 | 0.41 | 0.32 | 0.49 | 0.50 | 0.76 | 0.48 | 0.67 | 0.76 | 6.67 |
| **Total** | | **6.64** | **2.98** | **4.88** | **5.17** | **5.71** | **5.67** | **6.12** | **5.65** | **7.55** | **4.51** | **6.75** | **7.32** | **9.42** | **7.19** | **7.45** | **6.97** | **100.00** |

## 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 12.

**Table 12 Average Temperature, Atmospheric Pressure and Solar Radiation**

| Average Temp (°C) | Average Pressure (kPa) | Average Solar Radiation ($W/m^2$) | Average Relative Humidity (%) |
|---|---|---|---|
| 20.9 | 101.3 | 0 (Night)<br>500 (Day) | 61 |

**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 atmospheric pressure is a required input for the SAFETI model. The pipeline operating pressures are relatively high relative to the average atmospheric pressure. Therefore, the average atmospheric pressure does not have a significant impact on the consequence calculations.
- The average solar radiation is a required input for the SAFETI model.
- The average relative humidity is a required input for the SAFETI model.

**MAE/s Affected:**

- All.

**Reference/s:**

- BoM meteorological data for Parramatta weather station.

## 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 13.

**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 roughness length of 1 m is applicable for the area surrounding the pipeline.

**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 study area.

**MAE/s Affected:**

- Dispersion modelling for all relevant MAEs.

**Reference/s:**

- SAFETI software documentation.
- Aerial photographs of study area.

| Assumption No. 6: Total Population (Day and Night) |
|---|
| **Subject:** Locational Data |
| **Assumption/s:**<br>• The total population at the proposed industrial business hub is 1,000.<br>• The total population is evenly distributed across the proposed development area (excluding roads), which equates to a population density of c. 1 person per 164.8 $m^2$ (or 61 per hectare).<br>• The % of the total population that is present at the proposed industrial business hub during the day and night is:<br>  • **Day**: 100%.<br>  • **Night**: 100%. |
| **Justification and Impact/s of Assumption/s:**<br>• The Development Application (SSD 9667) is for the first ('concept') stage development of the site and only includes demolition, bulk earthworks, infrastructure (roads, etc.) and subdivision. Additional approvals will be sought at a later date for the construction of individual buildings, ancillary facilities and associated site works. The specific use at each lot is not known at this stage but is anticipated to include warehousing facilities and ancillary offices.<br>• The assumed population density is marginally less that a typical residential population density of 1 person per 182 $m^2$ (or 55 per hectare) and is therefore considered to be conservative for an industrial business hub.<br>• 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:**<br>• All (Note: This assumption is only applicable to the calculation of societal risk). |
| **Reference/s:**<br>• Information provided by WSPT (January 2019). |

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

**Subject:** Locational Data

**Assumption/s:**

- The % of people located indoors and outdoors at the proposed development during the day and night is as follows:
  - **Day**: 90% indoors.
    10% outdoors.
  - **Night**: 90% indoors.
    10% outdoors.

**Justification and Impact/s of Assumption/s:**

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

**Table 14 Proportion of Population Indoor and Outdoor During Day and Night [TNO]**

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

- The population distribution is not known at this stage. Assuming 90% are indoors (day or night) is conservative.

**MAE/s Affected:**

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

**Reference/s:**

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

| Assumption No. 8: Distribution of Population |
|---|
| **Subject:** Locational Data |
| **Assumption/s:**<br>• The total population is located at ground level. |
| **Justification and Impact/s of Assumption/s:**<br>• The height of the future structures / buildings is not known at this stage. Locating the entire population at ground level is conservative. |
| **MAE/s Affected:**<br>• All (Note: This assumption is only applicable to the calculation of societal risk). |
| **Reference/s:**<br>• SAFETI software documentation. |

## A.3 Risk Analysis Methodology

| Assumption No. 9: Location and Segmentation of Pipelines |
|---|
| **Subject:** Risk Analysis Methodology |
| **Assumption/s:**<br>• Incidents are distributed along the pipeline at set intervals. |
| **Justification and Impact/s of Assumption/s:**<br>• Distribution of the incidents along the pipeline at set intervals is the standard approach for linear sources. The interval is selected based on a review of the estimated hazard ranges so as to ensure a contiguous risk profile. |
| **MAE/s Affected:**<br>• All. |
| **Reference/s:**<br>• SAFETI software documentation. |

## A.4 Consequence Analysis

| Assumption No. 10: Representative Materials |
|---|
| **Subject:** Consequence Analysis |
| **Assumption/s:**<br>• Natural Gas is modelled as 100% Methane. |
| **Justification and Impact/s of Assumption/s:**<br>• 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. |
| **MAE/s Affected:**<br>• All. |
| **Reference/s:**<br>• Data provided by Jemena (9 January 2019). |

| Assumption No. 11: Pressure for Release Modelling |
|---|
| **Subject:** Consequence Analysis |
| **Assumption/s:**<br>• A release of Natural Gas from the JGN Trunk Pipeline is modelled at 6.895 MPag.<br>• Release events are modelled using the 'long pipeline' model in Safeti (v.8.11) and may be based on a time varying release rate (depending on hole size). |
| **Justification and Impact/s of Assumption/s:**<br>• The release rate is dependent on the pressure and the MAOP (6.895 MPag) is the maximum pressure permitted under an existing licence.<br>• The pressure used to model the release rates was based on the pipeline pressure near the proposed development, as advised by the pipeline owner (Refer to Section 4.2). |
| **MAE/s Affected:**<br>• All. |
| **Reference/s:**<br>• Data provided by Jemena (9 January 2019). |

## 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 15 Representative Hole Diameters Selected for Consequence Analysis**

| Pipeline/s | 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) |
| JGN Trunk Pipeline | 491 | 10 or 25* | 75 | 110 | 491 |

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

**Justification and Impact/s of Assumption/s:**

- The representative hole diameters were selected to align with the leak frequency data (Refer to Appendix C), which includes four hole size categories: Pinhole (≤ 25 mm); Small Hole (> 25 mm to ≤ 75 mm), Large Hole (> 75 mm to ≤ 110 mm); and, Rupture (> 110 mm). The representative hole diameter/s in each hole size category were selected based on a review of the available historical data (Refer to Appendix D).
- 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). This is also consistent with the predicted hole sizes in this size category reported in Table E5 of AS 2885.1 – 2018, which are based on excavator weight and tooth dimensions (i.e. 15 mm for a 5 tonne excavator, 20 mm for 10-15 tonne excavators and 25 mm for 20-25 tonne excavators). Therefore, two representative hole diameters were selected in this category: 25 mm for TPA and 10 mm for all other failure modes.

**MAE/s Affected:**

- All.

**Reference/s:**

- Refer to Appendix C.

| Assumption No. 13: Height of Release |
|---|
| **Subject:** Consequence Analysis |
| **Assumption/s:**<br>• All releases are modelled at a release height of 0 m above ground level. |
| **Justification and Impact/s of Assumption/s:**<br>• Modelling releases from underground pipelines at a release height of 0 m above ground level is generally conservative as the resultant point of release will be closer to the potential receptors. However, this is not a significant factor for typical burial depths.<br>• The default release height in the SAFETI software is 1 m. |
| **MAE/s Affected:**<br>• All. |
| **Reference/s:**<br>• SAFETI software documentation. |

| Assumption No. 14: Direction of Release |
|---|
| **Subject:** Consequence Analysis |
| **Assumption/s:**<br>• The direction of release for underground pipelines is dependent on the failure mode and representative hole size, as follows:<br>  ◦ **Third Party Activity (TPA)** – All hole sizes are modelled as 25% at 45 degrees (Not impinged – e.g. fully excavated), 25% at vertical (Not impinged – e.g. fully excavated) and 50% at horizontal (Impinged – by ground and/or the machinery that caused damage).<br>  ◦ **All other failure modes** – All hole sizes (expect 'pinhole') are modelled as 25% at 45 degrees (Not impinged), 25% at vertical (Not impinged) and 50% at horizontal (Impinged). All 'Pinhole' leaks are modelled as horizontal (Impinged). |
| **Justification and Impact/s of Assumption/s:**<br>• Impingement reduces the momentum of the release and the dispersion modelling is dominated by the representative wind conditions.<br>• During TPA, an underground pipeline may be exposed (uncovered); therefore, a non-impinged release may occur. In this case, the TPA is more likely to damage the upper surface of the pipe so a vertical or 45 degree angle of release is assumed to be representative. A non-impinged release might also occur for other failure modes if the release momentum is sufficient to displace the soil.<br>• Some releases may occur on the side or underside of an underground pipe or the machinery involved in the TPA may be close to or above the point of failure. In this case, the release may impinge on the ground and/or machinery so a horizontal impinged release is also included.<br>• 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. $19^{o}$ from horizontal) 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:**<br>• All. |
| **Reference/s:**<br>• 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. 15: Maximum Extent of Flash Fire |
|---|
| **Subject:** Consequence Analysis |
| **Assumption/s:**<br>• The maximum extent of a flash fire is defined by the downwind and crosswind distances from the release location to a concentration equal to half the lower flammability limit (LFL) concentration. |
| **Justification and Impact/s of Assumption/s:**<br>• The peak to mean concentration within the gas cloud is approximately 2:1, and hence, while the average concentration is ½ LFL, there may be gas pockets within the cloud where the concentration can be LFL, and hence ignition is possible.<br>• The formation of higher concentration pockets of gas is more applicable when the cloud passes around obstacles such as large structures and buildings (e.g. warehouses). |
| **MAE/s Affected:**<br>• All MAEs with a flash fire as a potential outcome. |
| **Reference/s:**<br>• SAFETI software documentation. |

| Assumption No. 16: Isolation Time and Duration of Release |
|---|
| **Subject:** Consequence Analysis |
| **Assumption/s:**<br>• 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:**<br>• Natural Gas is flammable and any adverse impact will occur quickly (fire or explosion); therefore, the duration of exposure is not as critical as it would be if there were toxic materials in the pipeline (i.e. where the adverse impact can significantly increase for longer exposure durations). |
| **MAE/s Affected:**<br>• All. |
| **Reference/s:**<br>• SAFETI software documentation. |

| Assumption No. 17: Shielding by Intervening Structures |
|---|
| **Subject:** Consequence Analysis |
| **Assumption/s:**<br>• The presence of intervening structures (e.g. buildings) does not shield other receptors from the heat radiation from a fire. |
| **Justification and Impact/s of Assumption/s:**<br>• In the SAFETI software, it is not possible to take account of the potential protection provided by intervening structures. |
| **MAE/s Affected:**<br>• All MAEs with a jet fire as a potential outcome. |
| **Reference/s:**<br>• SAFETI software documentation. |

## A.5 Likelihood Analysis

| Assumption No. 18: Likelihood of Release (Loss of Containment) |
|---|
| **Subject:** Likelihood Analysis |
| **Assumption/s:**<br>• The likelihood of each representative release is provided in Appendix C. |
| **Justification and Impact/s of Assumption/s:**<br>• 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.<br>• The justification for the data used in this risk analysis is provided in Appendix C. |
| **MAE/s Affected:**<br>• All. |
| **Reference/s:**<br>• Refer to Appendix C. |

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

| Assumption No. 20: Probability of VCE or Flash Fire |
|---|
| **Subject:** Likelihood Analysis |
| **Assumption/s:**<br>• Ignition of a free gas or vapour cloud is modelled a flash fire (Probability = 1.0). |
| **Justification and Impact/s of Assumption/s:**<br>• Ignition of a free gas cloud may demonstrate characteristics of a flash fire and/or an explosion. This is typically modelled as two separate events: a flash fire or an explosion.<br>• The assumed probabilities differ from the default values in the SAFETI software (viz. explosion probability = 0.4 and flash fire probability = 0.6).<br>• Since the configuration of the future structures / buildings is not known at this stage, all delayed ignition events were modelled as flash fires and conservative assumptions were adopted in the risk assessment for the flash fire modelling (e.g. flash fire extent based on distance to 50% of the LFL concentration, release pressure based on MAOP rather than lower normal operating pressure, etc.). |
| **MAE/s Affected:**<br>• All MAEs with a VCE or flash fire as potential outcomes. |
| **Reference/s:**<br>• SAFETI software documentation.<br>• TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition. |

## A.6 Vulnerability Parameters

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

**Subject:** Vulnerability Parameters

**Assumption/s:**

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

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

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

**Table 16 Probability of Fatality for Exposure to Heat Radiation (Outdoor)**

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

- 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 Jet Fire (Indoor or Outdoor)**

**Justification and Impact/s of Assumption/s:**

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

**Table 17 Effects of Thermal Radiation**

| Heat Radiation Intensity [kW/m$^2$] | Effect/s |
|---|---|
| 1.2 | • Received from sun in summer at noon. |
| 1.6 | • Minimum necessary to be felt as pain. |
| 4.7 | • Pain in 15 to 20 seconds, 1st degree burns in 30 seconds. Injury (second degree burns) to person who cannot escape or seek shelter after 30s exposure. |
| 12.6 | • High chance of injury.<br>• 30% chance of fatality for extended exposure.<br>• Melting of plastics (cable insulation).<br>• Causes the temperature of wood to rise to a point where it can be ignited by a naked flame after long exposure.<br>• 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.<br>• 10% chance of fatality on instantaneous exposure.<br>• Spontaneous ignition of wood after long exposure.<br>• Unprotected steel will reach thermal stress temperatures, which can cause failure.<br>• 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:**<br>• For calculation of location-specific individual risk, the probability for fatality = 1 for any individual located within the flammable cloud (Distance to LFL concentration).<br>• 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:**<br>• 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:**<br>• All MAEs with a flash fire as a potential outcome. |
| **Reference/s:**<br>• SAFETI software documentation.<br>• TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition. |

# Appendix B Consequence Analysis – Example Data and Results

## B.1 Representative Hole Diameters

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

### B.1.1 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 18 Dimensions of Rupture Events for Underground Natural Gas Steel Pipelines (US DoT - Reported Values Only)**

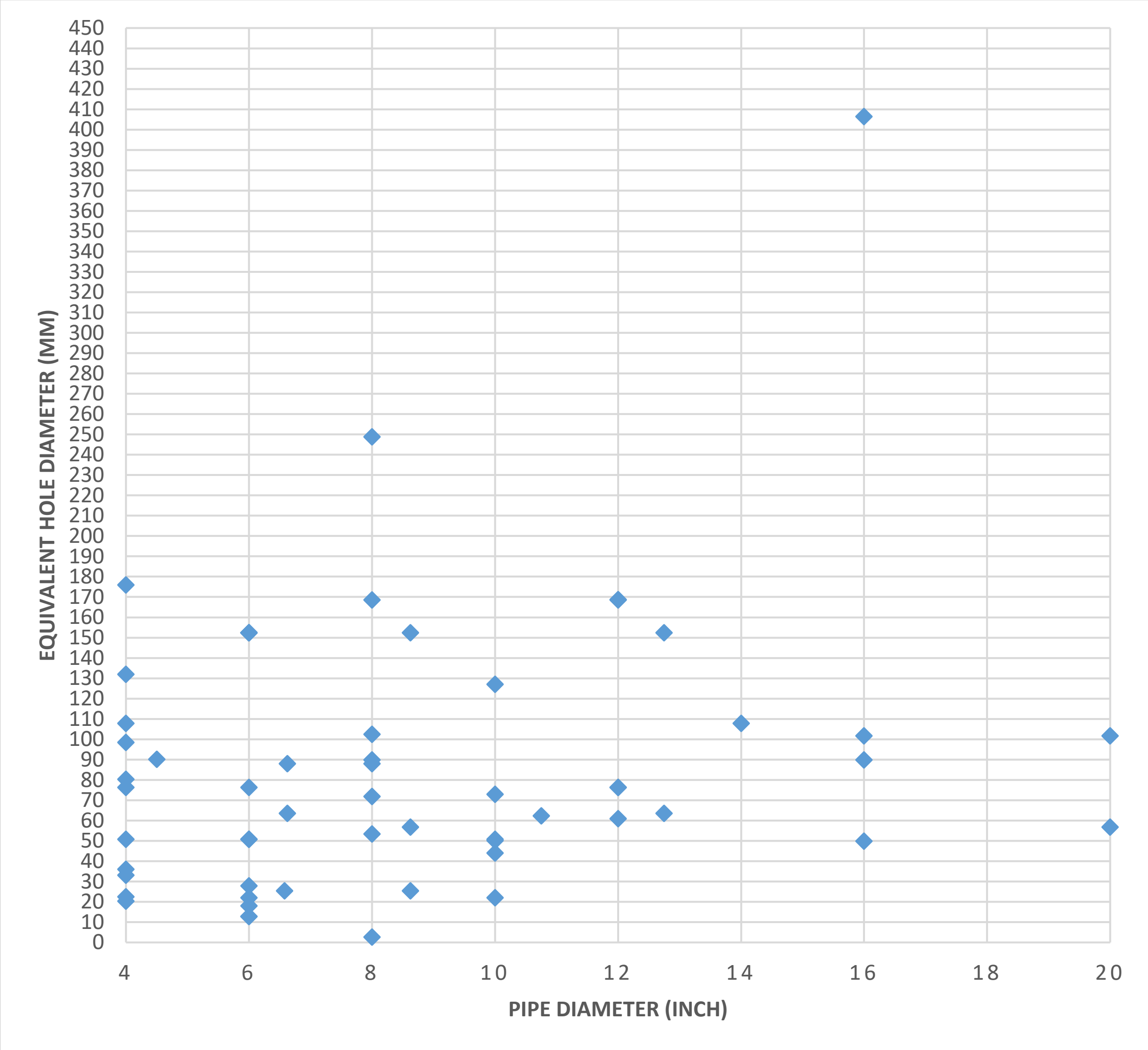
| MAOP | | Pipe Diameter (in) | Rupture Length (in) | Rupture Width (in) | Approx. Rupture Area (sq.in) | % of Cross-Section Area | Equiv. Hole Diameter (mm) | Cause |
|---|---|---|---|---|---|---|---|---|
| (psig) | (kPag) | | | | | | | |
| 15 | 205 | 1.66 | 1.5 | 1.5 | 1.8 | 81.7 | 38.1 | Natural Force - 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 19 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 |
| 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 |

| 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 | 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 |
| 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 |

**Figure 13 Equivalent Hole Diameter for Leaks from Underground Natural Gas Steel Pipelines (US DoT - Reported Values Only)**




### B.1.2 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.

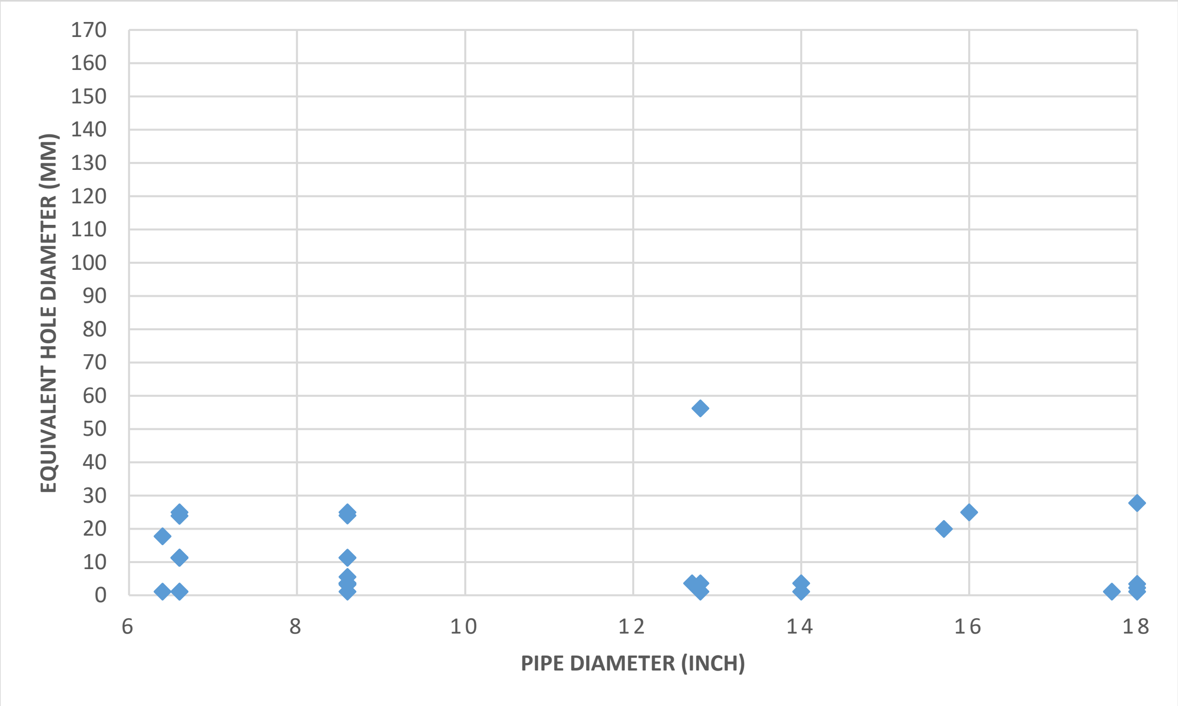
The following table includes the recorded incidents where the hole size was reported [Cited by HSE in RR1035]. This data is almost exclusively for Natural Gas (NG) leaks, with only one leak from another material (Propylene).

**Table 20 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 |
| 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 |

| Fault ID | Discovery Date | Product | Wall Thickness (mm) | Diameter (in) | Diameter (mm) | Equivalent Hole Diameter (mm) | Cause |
|---|---|---|---|---|---|---|---|
| 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 |

**Figure 14 Equivalent Hole Diameter for Leaks from Above Ground or Underground Cross-Country Natural Gas or Propylene Pipelines (UKOPA - Reported Values Only)**




## B.2 Example Consequence Analysis Results for Representative Release Scenarios

The hazard ranges for the release cases modelled are provided in Table 21 and Table 22.

**Table 21 Example Jet Fire Consequence Analysis Results**

| Release Scenario | Weather | Height of interest (m) | Flame length (m) | Distance downwind to intensity level 1 (4 kW/m$^2$) (m) | Distance downwind to intensity level 2 (12.5 kW/m$^2$) (m) | Distance downwind to intensity level 3 (35 kW/m$^2$) (m) |
|---|---|---|---|---|---|---|
| 10 mm (Horizontal Impingement) | B1.8 | 0 | 10.8 | 141.2 | 7.3 | 4.8 |
| | D7.5 | | 10.8 | 141.0 | 6.5 | 4.6 |
| | D3.9 | | 10.8 | 141.8 | 7.1 | 4.8 |
| | D1.0 | | 10.8 | 140.8 | 7.4 | 4.9 |
| | E2.6 | | 10.8 | 141.5 | 7.2 | 4.8 |
| | F1.0 | | 10.8 | 140.8 | 7.4 | 4.9 |
| 25 mm (Horizontal Impingement) | B1.8 | 0 | 24.3 | 266.2 | 24.6 | 13.7 |
| | D7.5 | | 25.8 | 257.4 | 23.9 | 13.1 |
| | D3.9 | | 24.8 | 263.1 | 24.4 | 13.5 |
| | D1.0 | | 24.1 | 267.4 | 24.7 | 13.7 |
| | E2.6 | | 24.5 | 265.0 | 24.5 | 13.6 |
| | F1.0 | | 24.1 | 267.4 | 24.7 | 13.7 |
| 25 mm (At 45 Degrees) | B1.8 | 0 | 28.3 | 99.6 | 34.3 | n/a |
| | D7.5 | | 19.8 | 163.0 | 33.9 | 21.7 |
| | D3.9 | | 22.9 | 136.6 | 33.8 | 21.3 |
| | D1.0 | | 31.9 | 83.3 | 35.2 | n/a |
| | E2.6 | | 25.7 | 115.3 | 33.7 | 19.6 |
| | F1.0 | | 31.9 | 83.3 | 35.2 | n/a |

| Release Scenario | Weather | Height of interest (m) | Flame length (m) | Distance downwind to intensity level 1 (4 kW/m$^2$) (m) | Distance downwind to intensity level 2 (12.5 kW/m$^2$) (m) | Distance downwind to intensity level 3 (35 kW/m$^2$) (m) |
|---|---|---|---|---|---|---|
| 25 mm (Vertical) | B1.8 | 0 | 22.2 | 156.4 | 19.2 | n/a |
| | D7.5 | | 15.5 | 252.3 | 26.5 | 13.3 |
| | D3.9 | | 18.0 | 212.6 | 24.3 | 6.6 |
| | D1.0 | | 25.1 | 131.8 | 14.9 | n/a |
| | E2.6 | | 20.2 | 180.2 | 22.0 | n/a |
| | F1.0 | | 25.1 | 131.8 | 14.9 | n/a |
| 75 mm (Horizontal Impingement) | B1.8 | 0 | 62.9 | 333.8 | 79.8 | 45.4 |
| | D7.5 | | 68.9 | 315.1 | 80.1 | 45.3 |
| | D3.9 | | 65.1 | 326.6 | 79.9 | 45.4 |
| | D1.0 | | 62.1 | 336.6 | 79.8 | 45.3 |
| | E2.6 | | 63.7 | 331.1 | 79.9 | 45.4 |
| | F1.0 | | 62.1 | 336.6 | 79.8 | 45.3 |
| 75 mm (At 45 Degrees) | B1.8 | 0 | 74.8 | 124.8 | 95.8 | 51.4 |
| | D7.5 | | 52.2 | 205.1 | 93.3 | 59.1 |
| | D3.9 | | 60.5 | 171.7 | 93.9 | 59.5 |
| | D1.0 | | 84.3 | 104.4 | 98.5 | n/a |
| | E2.6 | | 67.9 | 144.7 | 94.1 | 57.5 |
| | F1.0 | | 84.3 | 104.4 | 98.5 | n/a |

| Release Scenario | Weather | Height of interest (m) | Flame length (m) | Distance downwind to intensity level 1 (4 kW/m$^2$) (m) | Distance downwind to intensity level 2 (12.5 kW/m$^2$) (m) | Distance downwind to intensity level 3 (35 kW/m$^2$) (m) |
|---|---|---|---|---|---|---|
| 75 mm (Vertical) | B1.8 | 0 | 58.7 | 194.6 | 58.5 | n/a |
| | D7.5 | | 41.0 | 315.9 | 74.5 | 37.9 |
| | D3.9 | | 47.5 | 265.5 | 69.4 | 24.4 |
| | D1.0 | | 66.2 | 163.9 | 49.8 | n/a |
| | E2.6 | | 53.3 | 224.7 | 64.3 | 14.6 |
| | F1.0 | | 66.2 | 163.9 | 49.8 | n/a |
| 110 mm (Horizontal Impingement) | B1.8 | 0 | 86.1 | 346.5 | 115.0 | 65.7 |
| | D7.5 | | 94.4 | 328.9 | 115.7 | 66.0 |
| | D3.9 | | 89.1 | 340.3 | 115.2 | 65.8 |
| | D1.0 | | 85.0 | 348.6 | 114.9 | 65.6 |
| | E2.6 | | 87.2 | 344.2 | 115.1 | 65.8 |
| | F1.0 | | 85.0 | 348.6 | 114.9 | 65.6 |
| 110 mm (At 45 Degrees) | B1.8 | 0 | 104.6 | 135.8 | 136.7 | 76.9 |
| | D7.5 | | 73.0 | 223.4 | 132.6 | 83.9 |
| | D3.9 | | 84.6 | 187.0 | 133.9 | 85.0 |
| | D1.0 | | 117.9 | 113.5 | 140.5 | n/a |
| | E2.6 | | 95.0 | 157.5 | 134.6 | 83.1 |
| | F1.0 | | 117.9 | 113.5 | 140.5 | n/a |

| Release Scenario | Weather | Height of interest (m) | Flame length (m) | Distance downwind to intensity level 1 (4 kW/m$^2$) (m) | Distance downwind to intensity level 2 (12.5 kW/m$^2$) (m) | Distance downwind to intensity level 3 (35 kW/m$^2$) (m) |
|---|---|---|---|---|---|---|
| 110 mm (Vertical) | B1.8 | 0 | 82.2 | 211.2 | 85.7 | n/a |
| | D7.5 | | 57.4 | 343.4 | 106.8 | 54.6 |
| | D3.9 | | 66.5 | 288.5 | 99.9 | 37.3 |
| | D1.0 | | 92.6 | 177.6 | 74.6 | n/a |
| | E2.6 | | 74.6 | 244.0 | 93.3 | 25.6 |
| | F1.0 | | 92.6 | 177.6 | 74.6 | n/a |
| FBR (Horizontal Impingement) | B1.8 | 0 | 183.4 | 350.0 | 255.5 | 146.7 |
| | D7.5 | | 197.0 | 350.0 | 254.5 | 148.1 |
| | D3.9 | | 188.1 | 350.0 | 253.6 | 146.5 |
| | D1.0 | | 181.8 | 350.0 | 256.6 | 146.9 |
| | E2.6 | | 185.2 | 350.0 | 254.6 | 146.6 |
| | F1.0 | | 181.8 | 350.0 | 256.6 | 146.9 |
| FBR (At 45 Degrees) | B1.8 | 0 | 243.6 | 172.6 | 335.7 | 203.3 |
| | D7.5 | | 170.1 | 286.5 | 323.3 | 203.9 |
| | D3.9 | | 197.1 | 238.6 | 328.8 | 209.5 |
| | D1.0 | | 274.5 | 143.7 | 344.2 | 173.1 |
| | E2.6 | | 221.2 | 200.5 | 332.5 | 209.8 |
| | F1.0 | | 274.5 | 143.7 | 344.2 | 173.1 |

| Release Scenario | Weather | Height of interest (m) | Flame length (m) | Distance downwind to intensity level 1 (4 $kW/m^2$) (m) | Distance downwind to intensity level 2 (12.5 $kW/m^2$) (m) | Distance downwind to intensity level 3 (35 $kW/m^2$) (m) |
|---|---|---|---|---|---|---|
| FBR (Vertical) | B1.8 | 0 | 191.4 | 267.0 | 221.5 | 54.4 |
| | D7.5 | | 133.6 | 350.0 | 235.5 | 113.4 |
| | D3.9 | | 154.8 | 350.0 | 243.0 | 99.5 |
| | D1.0 | | 215.6 | 223.9 | 200.1 | n/a |
| | E2.6 | | 173.7 | 309.1 | 236.3 | 81.4 |
| | F1.0 | | 215.6 | 223.9 | 200.1 | n/a |

**Table 22 Example Flash Fire Consequence Analysis Results**

| Release Scenario | Weather | Height of interest (m) | Distance to ½ LFL (m) | Distance to LFL (m) | Distance to UFL (m) | Maximum width (at height of interest) to ½ LFL (m) |
|---|---|---|---|---|---|---|
| 10 mm (Horizontal Impingement) | B1.8 | 0 | 33.8 | 24.7 | 10.6 | 5.6 |
| | D7.5 | | 32.5 | 22.4 | 8.9 | 3.2 |
| | D3.9 | | 41.2 | 27.8 | 10.5 | 4.2 |
| | D1.0 | | 57.6 | 40.3 | 12.4 | 19.2 |
| | E2.6 | | 60.4 | 35.8 | 10.7 | 5.6 |
| | F1.0 | | 99.8 | 69.3 | 18.9 | 11.0 |
| 25 mm (Horizontal Impingement) | B1.8 | 0 | 80.7 | 59.0 | 24.2 | 13.5 |
| | D7.5 | | 75.8 | 52.8 | 21.1 | 7.4 |
| | D3.9 | | 96.7 | 65.6 | 24.5 | 9.7 |
| | D1.0 | | 146.8 | 102.4 | 27.6 | 58.2 |
| | E2.6 | | 142.1 | 82.4 | 24.7 | 12.5 |
| | F1.0 | | 246.5 | 163.2 | 40.9 | 49.8 |
| 75 mm (Horizontal Impingement) | B1.8 | 0 | 405.6 | 317.1 | 93.2 | 69.2 |
| | D7.5 | | 234.9 | 159.6 | 62.6 | 18.9 |
| | D3.9 | | 311.0 | 205.8 | 70.6 | 29.2 |
| | D1.0 | | 258.0 | 82.9 | 56.7 | 49.3 |
| | E2.6 | | 495.5 | 359.0 | 99.0 | 48.3 |
| | F1.0 | | 553.8 | 380.8 | 103.0 | 112.5 |

| Release Scenario | Weather | Height of interest (m) | Distance to ½ LFL (m) | Distance to LFL (m) | Distance to UFL (m) | Maximum width (at height of interest) to ½ LFL (m) |
|---|---|---|---|---|---|---|
| 110 mm (Horizontal Impingement) | B1.8 | 0 | 534.5 | 414.7 | 120.7 | 114.2 |
| | D7.5 | | 348.1 | 235.9 | 91.9 | 26.1 |
| | D3.9 | | 461.8 | 306.4 | 101.8 | 48.0 |
| | D1.0 | | 310.8 | 113.2 | 76.6 | 60.1 |
| | E2.6 | | 615.6 | 453.8 | 126.2 | 72.6 |
| | F1.0 | | 552.7 | 393.8 | 131.9 | 65.1 |
| FBR (Horizontal Impingement) | B1.8 | 0 | 181.8 | 142.4 | 96.2 | 36.5 |
| | D7.5 | | 941.8 | 607.2 | 203.1 | 66.7 |
| | D3.9 | | 1237.4 | 696.5 | 199.2 | 95.9 |
| | D1.0 | | 169.2 | 149.6 | 105.7 | 34.9 |
| | E2.6 | | 192.6 | 158.6 | 104.5 | 33.9 |
| | F1.0 | | 159.9 | 138.1 | 90.5 | 30.3 |
| FBR (At 45 Degrees) | B1.8 | 0 | 2.7 | n/a | n/a | 2.9 |
| | D7.5 | | 3.3 | 2.6 | n/a | 3.0 |
| | D3.9 | | 3.5 | 2.9 | n/a | 3.1 |
| | D1.0 | | 3.0 | n/a | n/a | 3.1 |
| | E2.6 | | 3.4 | 2.8 | n/a | 3.1 |
| | F1.0 | | 1.9 | n/a | n/a | 2.8 |

# 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, *2015-16 Licensed Pipelines Performance Report*. This includes data for all licensed pipelines in NSW for the 5-year period: 2011/12 to 2015/16; 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 - Reported Data for Underground Natural Gas Steel Pipelines (January 2010 to September 2017).

The leak frequency data reported in RR1035 (Refer to Section C.1.2) was adopted for the QRA as it is most 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 (Refer to Section C.1.3) was not used since the leak rates (other than ruptures) are not clearly defined for all failure modes. Furthermore, the rupture frequency due to 'TPA' estimated for the JGN Trunk Pipeline using the approach in Annex B of PD 8010-3:2009+A1:2013 is clearly not consistent with NSW performance data.

The leak frequency data derived from the US DoT data (Refer to Section C.1.4) was not used since the total leak frequency is lower than reported in RR1035 and the NSW performance data.

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

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

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

### C.1.1 NSW Performance Report

The average leak frequency from the 2016 NSW Performance Report for all licensed pipelines in NSW for the 5-year period 2011/12 to 2015/16 is 8.2E-05 per km per year.

### C.1.2 UK HSE (RR1035)

The total leak frequency data reported in Section 7.1 of RR1035 for underground natural gas pipelines is comparable to the average leak frequency from the 2016 NSW Performance Report (e.g. 8.35E-05 per km per year for a ≥ 305 mm diameter pipeline with wall thickness ≥ 5 mm to < 10 mm).

**Table 23 Leak Frequencies for Underground Natural Pipelines**

| Failure Mode | Pipeline Diameter (mm) | Wall Thickness (mm) | Leak Frequency (per km per yr) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Pinhole (≤ 25 mm) | Small Hole (> 25 mm to ≤ 75 mm) | Large Hole (> 75 mm to ≤ 110 mm) | Rupture (> 110 mm) | Total Leak Frequency |
| Mechanical Failure | < 115 | All | 4.5E-04 | 1.0E-08 | 1.0E-08 | 1.0E-08 | 4.5E-04 |
| | 127 to < 273 | | 1.5E-04 | 1.0E-08 | 1.0E-08 | 1.0E-08 | 1.5E-04 |
| | ≥ 305 | | 8.7E-06 | 1.0E-08 | 1.0E-08 | 1.0E-08 | 8.7E-06 |
| Corrosion | All | < 5 | 3.1E-04 | 1.0E-08 | 1.0E-08 | 1.0E-08 | 3.1E-04 |
| | | 5 to < 10 | 3.3E-05 | 1.0E-08 | 1.0E-08 | 1.0E-08 | 3.3E-05 |
| | | ≥ 10 | 1.0E-07 | 1.0E-08 | 1.0E-08 | 1.0E-08 | 1.3E-07 |
| Ground Movement / Other | All | All | 1.2E-05 | 2.5E-06 | 1.5E-07 | 2.5E-06 | 1.7E-05 |
| TPA | All | All | 2.2E-05 | 2.4E-06 | 1.0E-07 | 1.0E-07 | 2.5E-05 |
| Total Leak Frequency = | ≥ 305 | 5 to < 10 | 7.6E-05 | 4.9E-06 | 2.7E-07 | 2.6E-06 | **8.35E-05** |
| % = | | | 90.6 | 5.9 | 0.3 | 3.1 | |

### C.1.3 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 JGN Trunk Pipeline (Refer to Table 24). The data applicable for a pipeline with a wall thickness of 8.5 mm.

Leak frequency data is not reported for internal corrosion.

For leaks (other than ruptures) due to 'Ground Movement / Other' or 'TPA', 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).

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 JGN Trunk Pipeline (i.e. location, design factor, wall thickness and depth of cover).

**Table 24 Approx. Leak Frequencies for Underground Natural Gas Pipeline**

| Failure Mode | Approx. Leak Frequency (per km per yr) | | | | | Comments (Refer to Annex B of PD 8010-3:2009+A1:2013) |
|---|---|---|---|---|---|---|
| | Pinhole (≤ 25 mm) | Small Hole (> 25 mm to ≤ 75 mm) | Large Hole (> 75 mm to ≤ 110 mm) | Rupture (> 110 mm) | Total Leak Frequency | |
| Mechanical Failure | 4.0E-05 | 1.6E-05 | 0.0E+00 | 0.0E+00 | 5.6E-05 | |
| Corrosion | 3.2E-05 | 1.1E-05 | 3.0E-06 | 0.0E+00 | 4.6E-05 | No data reported for internal corrosion. |
| Ground Movement / Other | 2.0E-06 | 2.0E-06 | 2.0E-06 | 6.0E-07 | 6.6E-06 | Based on average incident rate (0.02 per 1000 km.yr) and survival values of 0.03 (Rupture) and 0.3 (Leaks). |
| TPA | 1.7E-05 | 1.7E-05 | 1.7E-05 | 8.8E-05 | 1.4E-04 | Proportion of ruptures = 0.63. |
| Total Leak Freq. = | 9.1E-05 | 4.6E-05 | 2.2E-05 | 8.8E-05 | **2.48E-04** | |
| % = | 36.8 | 18.6 | 8.9 | 35.6 | | |

### C.1.4 US Department of Transportation (DoT)

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

To enable a comparison with the UK data, the data for underground transmission pipelines was analysed and the leaks categorised using the same representative hole sizes as reported in the UK (i.e. RR1035 and PD8010). The results are reported in Table 25.

| | | | |
|---|---|---|---|
| Period of Recorded Incident Data = | 7.75 | yrs | (Jan 2010 to Sept 2018) |
| Total Length of Natural Gas Pipelines = | 479980 | km | Note: Average for 2010 to 2017 |

**Table 25 Leak Frequencies for Underground Natural Gas Transmission Pipelines**

| Failure Mode | Approx. Leak Frequency (per km per yr) | | | | |
|---|---|---|---|---|---|
| | Pinhole (≤ 25 mm) | Small Hole (> 25 mm to ≤ 75 mm) | Large Hole (> 75 mm to ≤ 110 mm) | Rupture (> 110 mm) | Total Leak Frequency |
| Mechanical Failure | 2.2E-06 | 5.4E-07 | 2.7E-07 | 0.0E+00 | 3.0E-06 |
| Corrosion | 9.7E-06 | 0.0E+00 | 2.7E-07 | 0.0E+00 | 9.9E-06 |
| Ground Movement / Other | 4.0E-06 | 1.1E-06 | 0.0E+00 | 2.7E-07 | 5.4E-06 |
| TPA | 3.2E-06 | 7.0E-06 | 4.0E-06 | 4.0E-06 | 1.8E-05 |
| Total Leak Freq. = | 1.9E-05 | 8.6E-06 | 4.6E-06 | 4.3E-06 | **3.66E-05** |
| % = | 52.2 | 23.5 | 12.5 | 11.8 | |

## C.2 Ignition Probability

The ignition probabilities adopted in the risk analysis are listed in Section 7.2. This data was based on a review of relevant ignition probability data and ignition probability correlations (Refer to Sections C.2.1 - C.2.2).

1. The total ignition probability was based on OGP Scenario 3, which is release rate dependent (Refer to Section C.2.1).
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 26 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, vapour 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 27 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 – Natural Gas

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

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

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

Pign = 0.0555 + 0.0137 pd^2; 0 ≤ pd^2 ≤ 57

Pign = 0.81; pd^2 > 57

Pign = probability of ignition

p = pipeline operating pressure (bar)

d = pipeline diameter for ruptures (m)

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

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

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

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

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

**Table 28 Ignition Probability – Acton & Baldwin**

| Pipeline Diameter (mm) | Operating Pressure (bar) | Equivalent Hole Diameter (mm) | pd^2 | Probability of Immediate Ignition | Probability of Delayed Ignition | Total Ignition Probability |
|---|---|---|---|---|---|---|
| 508 | 68.95 | FBR | 17.79 | 0.150 | 0.150 | 0.299 |
| | | 110 | 0.83 | 0.031 | 0.031 | 0.061 |
| | | 75 | 0.39 | 0.029 | 0.029 | 0.058 |
| | | 25 | 0.04 | 0.028 | 0.028 | 0.056 |
| | | 10 | 0.01 | 0.028 | 0.028 | 0.056 |

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

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

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

**Table 29 Ignition Probability – EGIG**

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

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

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

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

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

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

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

**Table 30 Ignition Probability – UK HSE (RR 1034)**

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

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

**Table 31 Ignition Probability – Data Cited by UK HSE (RR 1034)**

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

## C.3 Likelihood of Representative Release Scenarios

The estimated likelihood of each representative release scenario is listed in Table 32.

**Table 32 Release Frequency**

| Leak Scenario | Release Frequency (per km per year) | | |
|---|---|---|---|
| | TPA | All Other Failure Modes | Total Release Frequency |
| 10 mm (Horizontal Impingement) | | 5.37E-05 | 5.37E-05 |
| 25 mm (Horizontal Impingement) | 1.10E-05 | | 1.10E-05 |
| 25 mm (At 45 Degrees) | 5.50E-06 | | 5.50E-06 |
| 25 mm (Vertical) | 5.50E-06 | | 5.50E-06 |
| 75 mm (Horizontal Impingement) | 1.20E-06 | 1.26E-06 | 2.46E-06 |
| 75 mm (At 45 Degrees) | 6.00E-07 | 6.30E-07 | 1.23E-06 |
| 75 mm (Vertical) | 6.00E-07 | 6.30E-07 | 1.23E-06 |
| 110 mm (Horizontal Impingement) | 5.00E-08 | 8.50E-08 | 1.35E-07 |
| 110 mm (At 45 Degrees) | 2.50E-08 | 4.25E-08 | 6.75E-08 |
| 110 mm (Vertical) | 2.50E-08 | 4.25E-08 | 6.75E-08 |
| FBR (Horizontal Impingement) | 5.00E-08 | 1.26E-06 | 1.31E-06 |
| FBR mm (At 45 Degrees) | 2.50E-08 | 6.30E-07 | 6.55E-07 |
| FBR mm (Vertical) | 2.50E-08 | 6.30E-07 | 6.55E-07 |
| **Total** | **2.46E-05** | **5.89E-05** | **8.35E-05** |