Technical Report 1 – Preliminary Hazard Analysis

YOUNG TO WELLINGTON GAS PIPELINE

ERM POWER PTY LTD

PRELIMINARY HAZARD ANALYSIS

LAND PARTNERS LIMITED

PREPARED FOR:	**Lisa King**
	Land Partners Limited

DOCUMENT NO:	**J20394-001**
REVISION:	**3**
DATE:	**12 November 2009**

Sherpa Consulting Pty Ltd (ABN 40 110 961 898)
Phone: 61 2 9412 4555
Fax: 61 2 9412 4556
Web: www.sherpaconsulting.com

DOCUMENT REVISION RECORD

REV	DATE	DESCRIPTION	PREPARED	CHECKED	APPROVED	METHOD OF ISSUE
DRAFT	6/10/09	Draft for internal review	J. Bertram	J. Polich	-	-
A	14/10/09	Draft for Client Comment	J. Bertram	J. Polich	J. Polich	PDF by Email
0	15/10/09	Final Report	J. Bertram	J. Polich	J. Polich	PDF by Email
1	22/10/09	Incorporating Principal's Comments	J. Bertram	J. Polich	J. Bertram	PDF by Email
2	2/11/09	Incorporating Client Comments	J. Bertram	P. Johnson	J. Bertram	PDF by Email
3	12/11/09	Including Revised Latest Route Map	J. Bertram	P. Johnson	J. Bertram	PDF by Email

Title: **Young to Wellington Gas Pipeline** **ERM Power Pty Ltd** **Preliminary Hazard Analysis**	**QA Verified:** E. JOHNSON **Date: 12 November 2009**

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ABBREVIATIONS

AC	Alternating Current
API	American Petroleum Institute
AS	Australian Standard
CP	Cathodic Protection
DC	Direct Current
DN	Nominal Diameter
DOC	Depth of Cover
DoP	NSW Department of Planning
DUAP	Department of Urban Affairs and Planning (now NSW Dept. of Planning)
EA	Environmental Assessment
EGIG	European Gas Pipeline Incident Data Group
FHA	Final Hazard Analysis
HAZID	Hazard Identification
HDPE	High Density Polyethylene
HIPAP	Hazardous Industry Planning Advisory Paper
HV	High Voltage
km	kilometres
LFL	Lower Flammability Limit
m	metres
MAOP	Maximum Allowable Operating Pressure
MLV	Main Line Valve
mm	millimetres
MPag	MegaPascal (gauge)
ºC	Degrees Celsius
PE	Polyethylene
PHA	Preliminary Hazard Analysis
QRA	Quantitative Risk Assessment
SCC	Stress Corrosion Cracking
VCE	Vapour Cloud Explosion
WT	Wall Thickness

1. EXECUTIVE SUMMARY AND RECOMMENDATIONS

1.1. Purpose and Scope

ERM Power Pty Ltd (ERM) proposes to construct a natural gas pipeline from an offtake on the Sydney-Moomba Natural Gas Pipeline at Young, NSW. The pipeline will transport gas to the Wellington Power Station Project, which has been approved separately but has not yet been constructed. The pipeline will be approximately 220 km in length and have an outside diameter of up to 508 mm.

This report summarises the objectives, scope of work, methodology and results of the Preliminary Hazard Analysis (PHA) undertaken for the Young to Wellington Pipeline.

1.2. Study Findings

Risk transects showing individual risk of fatality versus the distance from the centreline of the pipe were produced for the proposed pipeline. A number of sensitivity cases were assessed with different levels of safeguards. These cases are:

- Case 1 (Base Case) – 750 mm depth of cover (DOC), no marker tape, 9 mm wall thickness
- Case 2 – 900 mm DOC, no marker tape, 9 mm wall thickness
- Case 3 – 1200 mm DOC, no marker tape, 9 mm wall thickness
- Case 4 – 750 mm DOC, marker tape, 9 mm wall thickness
- Case 5 – 900 mm DOC, marker tape, 9 mm wall thickness
- Case 6 – 1200 mm DOC, marker tape, 9 mm wall thickness

For Case 1 (Base Case), the pipeline risk reaches a level of 1 x 10^{-6} per year (the criteria for residential areas) at a distance of 240 m from the pipeline. The assessment was repeated for the other sensitivity cases. The results of the assessment including the distances to the risk criteria levels required for other land uses are summarised in Table 1.1.

Table 1.1 shows the separation distances required for land uses near the pipeline route. An appropriate level of safeguards may be selected depending on the separation distance to nearby land uses to meet the risk criteria of the DoP.

TABLE 1.1: DISTANCE TO INDIVIDUAL RISK LEVELS

Case	Distance to Individual Risk of Fatality (HIPAP No. 4) at Nearby Land Uses (m)				
	Sensitive Land Uses (0.5 x 10^{-7} per year)	Residential (1 x 10^{-6} per year)	Commercial (5 x 10^{-6} per year)	Active Open Spaces (10 x 10^{-6} per year)	Industrial (50 x 10^{-6} per year)
Case 1, Base Case (750 mm DOC, no marker tape, 9 mm WT)	275	240	140	20	Not reached
Case 2 (900 mm DOC, no marker tape, 9 mm WT)	270	230	130	15	Not reached
Case 3 (1200 mm DOC, no marker tape, 9 mm WT)	267	225	80	Not reached	Not reached
Case 4, (750 mm DOC, marker tape, 9 mm WT)	265	220	60	Not reached	Not reached
Case 5 (900 mm DOC, marker tape, 9 mm WT)	260	215	50	Not reached	Not reached
Case 6 (1200 mm DOC, marker tape, 9 mm WT)	255	200	35	Not reached	Not reached

1.3. Societal Risk

Due to the low population in the area of the pipeline and facilities and the low individual risk levels shown, the societal risk level will be negligible and has not been quantified.

1.4. Risk of Injury

Given the low population density and no residential land within the 4.7 kW/m^2 heat radiation contour, the risk of injury was not quantified.

1.5. Conclusions

A PHA was undertaken for the Young to Wellington gas pipeline. The risk resulting from the operation of the pipeline was assessed to determine the potential impact to local land uses.

Risk levels resulting from the gas supply pipeline were presented as risk transects for a number of sensitivity cases with various levels of pipeline safeguards. Distances to risk criteria levels for various land uses are summarised in Table 1.1.

The results in Table 1.1 show the minimum separation distance to residential zone for different levels of safeguards. An appropriate level of safeguards may be selected from this table to meet the requirements of the DoP criteria for individual risk, taking into account the nearest residential areas to the pipeline.

1.6. Recommendations

1. A number of issues (stress corrosion cracking, fatigue due to pressure cycling) have been identified which will need to be addressed in the detailed design of the gas pipeline.

2. In the event of significant design changes occurring during the detailed design phase, the PHA would typically required an update to a Final Hazard Analysis (FHA) prior to the commencement of pipeline construction.

2. INTRODUCTION

2.1. Background

ERM Power Pty Ltd (ERM) proposes to construct a natural gas pipeline from an offtake on the Sydney-Moomba Natural Gas Pipeline at Young, NSW. The pipeline will transport gas to the Wellington Power Station Project, which has been approved separately but has not yet been constructed. The pipeline will be approximately 220 km in length and have an outside diameter of up to 508 mm.

ERM commissioned Land Partners Limited (Land Partners) to prepare the Environmental Assessment (EA) for the project.

Sherpa Consulting Pty Ltd (Sherpa) was commissioned by Land Partners to undertake the Preliminary Hazard Analysis (PHA) for the pipeline, in accordance with the Director General's Requirements for the Environmental Assessment.

This report summarises the objectives, scope of work, methodology and results of the Preliminary Hazard Analysis (PHA) undertaken for the Young to Wellington Pipeline.

2.2. Study Objectives

The objective of the study was to undertake a Preliminary Hazard Analysis of the Young to Wellington gas pipeline and, in particular, to assess the hazard and risk impacts as given in the Director General's Requirements (Ref. 1), as follows:

'Hazards and Risk Impacts

The Environmental Assessment must include an assessment of the hazards and risk impacts of the project, prepared generally consistent with the approach outlined in Hazardous Industry Planning Advisory Paper *No. 6 (DoP, 1992) and* Multi-level Risk Assessment *(DUAP, 1997) and with specific reference to applicable Australian Standards (including AS2885 Pipelines – Gas and Liquid Petroleum – Operation and Maintenance). The Environmental Assessment shall specifically consider on-going maintenance and safety management of the project, including potential impacts on and from bushfires and floods.'*

The detailed objectives of the study were to:

- Identify hazards that could result from the operation of the pipeline facilities.
- Identify whether the proposed design measures and operational measures are adequate to minimise the hazard and manage residual risks.
- Identify, where required, additional safeguards to further minimise the risk to personnel, people and property.
- Prepare a report summarising the analysis and findings in a form suitable for use by the client and the regulatory authorities.

2.3. Scope

The scope of the assessment is the Young to Wellington Gas Pipeline and associated infrastructure. The scope of the assessment includes gas supply pipeline.

The assessment was based on preliminary design details available at the time of the study. The safeguards assumed for the assessment were based on typical safeguards for similar facilities. The analysis should be updated during detailed design to take account of the safeguards proposed for the final design.

3. DESCRIPTION OF PROPOSED PIPELINE

3.1. Overview

The gas supply for the pipeline will be taken from the Young gas compressor facility on the Moomba-Sydney Gas Pipeline. The pipeline will supply natural gas to the Wellington Power Station.

3.2. Pipeline Route

The pipeline will be about 220 km running through the Local Government Areas of Young, Cowra, Cabonne and Wellington Shires. The pipeline route avoids major towns including Cowra, Molong and Wellington.

The proposed pipeline route is shown in Figure 3.1.

3.3. Pipeline Design

Details of the pipeline design are preliminary at present. The pipeline will be designed to meet the requirements of AS2885:2007, 'Pipelines - Gas and Liquid Petroleum, Design and Construction' (Ref. 2). The following assumptions have been made for the PHA:

- 15.3 MPa Maximum Allowable Operating Pressure (MAOP)
- Up to 508 mm pipeline diameter

A spacing of 30 km between main line valves (MLVs) will be required to meet the requirements of AS2885:2007 (Ref. 2) requirements for R2 areas (semi-rural). Details of the location and design of these stations have not been included in the preliminary design.

The pipeline design includes the following features:

- HDPE fusion-boned epoxy or tri-laminate coating
- Anode or impressed current cathodic protection system
- Cathodic protection test points
- Additional earthing protection measures near power transmission lines
- Marker tape at road and rail crossings, major watercourse crossings and high risk areas
- Marker signs at 200 m spacing or as required as per AS2885:2007 requirements, e.g. intervisible
- Depth of cover 750-1200 mm as per AS2885:2007 requirements
- Concrete weighting at river crossings and locations prone to inundation
- Trench breakers on pipeline at sloped locations to prevent trench erosion

3.4. Surrounding Land Use Categories

The pipeline will pass near a range of land uses including open rural areas. Generally zoning along the pipeline route is rural with limited urban buildup nearby.

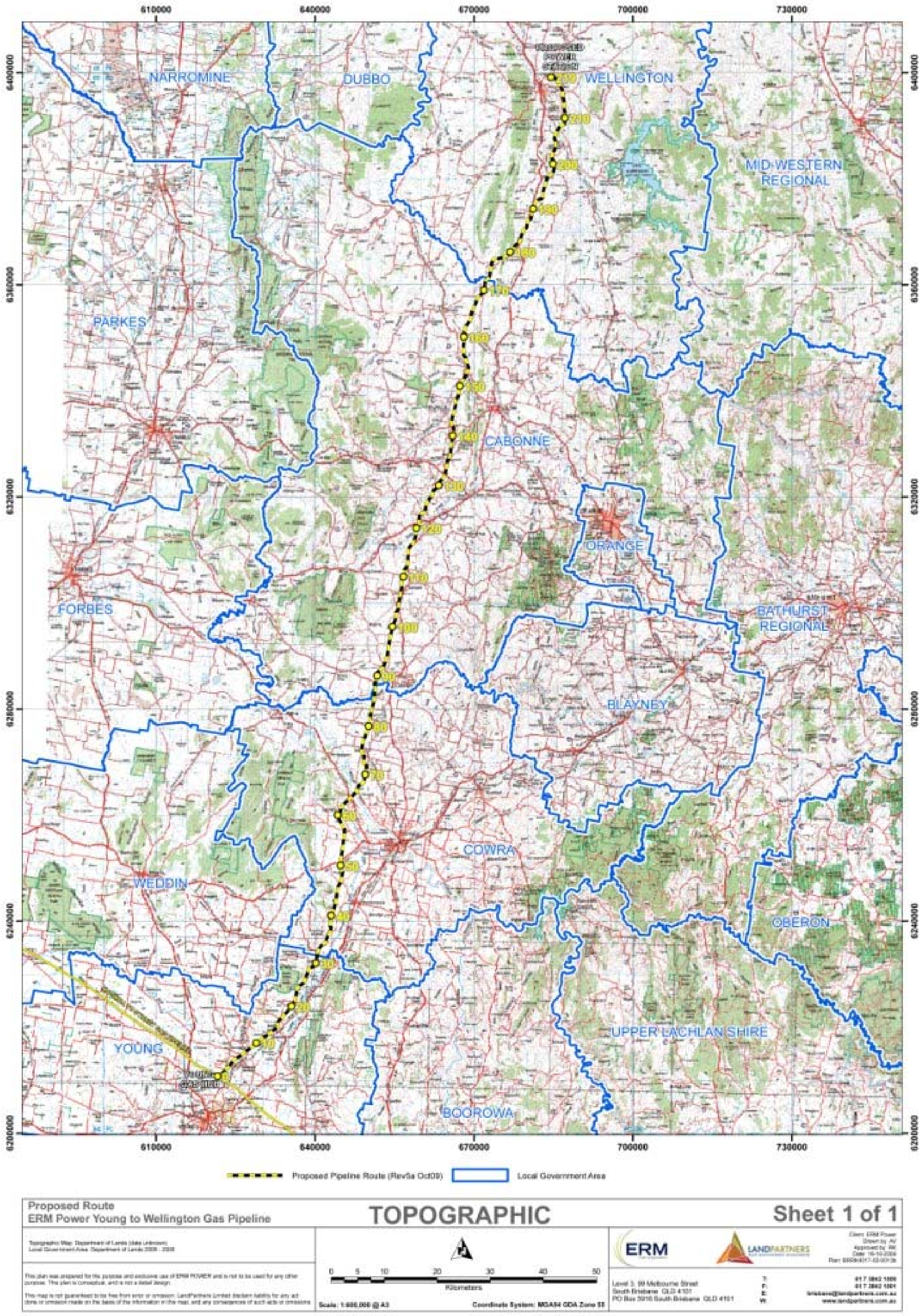

FIGURE 3.1: YOUNG TO WELLINGTON GAS PIPELINE ROUTE

4. METHODOLOGY

4.1. Study Approach

The PHA for the pipeline was undertaken following the guidelines of the NSW Department of Planning. The methodology for undertaking the PHA is as described in the following NSW Department of Planning documents:

- Hazardous Industry Planning Advisory Paper (HIPAP) No. 6, ‘Guidelines for Hazard Analysis’ (Ref. 3)
- HIPAP No. 4 ‘Risk Criteria for Land Use Safety Planning’, (Ref. 4)
- ‘Multi Level Risk Assessment’ (Ref. 5).

The following is an outline of the methodology adopted in this PHA:

- Establish the context, including level of assessment and risk tolerability criteria.
- Undertake hazard identification for the proposed development and identify a list of credible scenarios for carrying forward for quantification of consequences and likelihood.
- Undertake a consequence analysis for the identified credible scenarios. Where off-site impact is found to have the potential to occur, carry the scenario forward for frequency analysis.
- Undertake frequency analysis for the scenarios with the potential for off-site impact.
- Undertake quantitative risk assessment by combining the off-site scenario consequences and their associated frequency in order to generate risk transects for the pipeline.
- From a review of the risk transects, assess the risk to neighbouring land uses against the requirements of the NSW Department of Planning Risk Criteria for Land-Use Safety Planning (Ref. 4).
- Make recommendations for risk reduction, where the risk is found to exceed the criteria.

4.2. Level of Assessment

The Multi Level Risk Assessment guideline (Ref. 5) sets out three levels of risk assessment that may be appropriate for a PHA, as shown in Table 4.1. The guideline was consulted to identify the level of assessment required in this study.

This PHA is based on a Level 2 Risk Assessment where the results are sufficiently quantified to allow an assessment of the offsite risk levels against acceptance criteria.

TABLE 4.1: LEVEL OF ANALYSIS

Level	Type of Analysis	Appropriate if:
1	Qualitative	No major offsite consequences and societal risk is negligible
2	Partially Quantitative	Offsite consequences but with a low frequency of occurrence
3	Quantitative	Where level 1 and 2 are exceeded

Based on a review of the findings of the HAZID, it would not be credible to state that no events had offsite impact without more detailed consequence analysis. Hence a Level 1 Assessment was not considered suitable.

It was decided to follow a Level 2 Assessment (i.e. assess consequences of releases and carry forward incidents with offsite impact to risk assessment).

4.3. Consequence Criteria

The consequences of hazardous incidents which have been assessed in the current study are:

- Release of pressurised natural gas, followed by immediate ignition, resulting in jet fire
- Release of pressurised natural gas, followed by delayed ignition, resulting in flash fire.

The criteria for heat radiation impact from fires used in the study are summarised in Table 4.2.

TABLE 4.2: THERMAL RADIATION CRITERIA

Heat Radiation Level (kW/m^2)	Effect	Critical Criteria
4.7	Will cause pain in 15-20 seconds and injury after 30 seconds exposure.	Injury
6	10% chance of a fatality for extended exposure.	Fatality
10	50% chance of a fatality for extended exposure.	Fatality
14	100% chance of a fatality for extended exposure.	Fatality
23	Likely fatality for extended exposure; chance of fatality for instantaneous exposure. Unprotected steel will reach thermal stress temperatures which can cause failures.	Escalation potential

4.4. Risk Criteria

The risk guidelines provided in the DoP publication ‘Risk Criteria for Land Use Safety Planning’ (Ref. 4) are outlined in the following sections.

4.4.1. Individual Risk of Fatality

The risk criteria adopted for land use safety planning in NSW are summarised in Table 4.3. The figures quoted show the risk criteria for various land use types to an individual, assuming 24 hour exposure to the risk, with no allowance for the protection buildings may offer or for the potential to move away (escape) from a developing incident.

TABLE 4.3: NSW LAND USE PLANNING RISK CRITERIA

Risk Levels/ Probability of Fatality (per annum)	Land-Use	Limit of Exposure at the Following Locations
0.5×10^{-6}	Sensitive	Hospitals, child-care facilities and old age housing developments.
1×10^{-6}	Residential	Residential developments and places of continuous occupancy such as hotels and tourist resorts.
5×10^{-6}	Commercial	Commercial developments, including offices, retail centres, warehouses with showrooms, restaurants and entertainment centres.
10×10^{-6}	Active Open Space	Sporting complexes and active open space areas.
50×10^{-6}	Industrial	Site boundary

4.4.2. Societal Risk of Fatality

The Department of Planning (Ref. 4) suggests that judgments on societal risk be made on the basis of a qualitative approach rather than on specifically set numerical criteria.

Despite the lack of formal societal risk tolerability criteria in NSW, societal risk estimation is warranted only where significant and potentially vulnerable populations exist beyond the boundary of the proposed development.

4.4.3. Risk of Injury

NSW Department of Planning guidelines on land use safety planning (Ref. 4) set criteria for injury risk levels. This is in recognition of the fact that society is concerned with the risk of injury as well as death and that certain members of the community are more vulnerable. The injury risk criteria are discussed in more detail in the following paragraphs.

DoP proposes that a heat radiation level of 4.7 kW/m^2 be considered high enough to lead to injury in people who cannot escape or seek shelter. This level of heat radiation will cause injury after 30 seconds. A risk of injury criteria of 50×10^{-6} p.a. is suggested for fire events. Within the guidelines, this is stated as:

- Incident heat flux at residential areas should not exceed 4.7 kW/m^2 at frequencies of more than 50 chances in a million years.

The Department of Planning also proposes criteria for the risk of injury from explosion overpressure and toxic gas dispersion. These have not been reproduced here as the HAZID did not identify explosion or toxic release events with potential offsite impacts.

5. STUDY ASSUMPTIONS

The following major assumptions were made during the risk assessment.

- The likelihood of vapour cloud explosions is negligible as natural gas will tend to disperse readily in the open air and there are no congested areas near the pipeline which could result in unburnt gas building up and tree growth is restricted within the pipeline easement.
- The release rates were estimated assuming continuous releases with the pipeline operating at the MAOP, except for the isolated rupture case, where a depressuring curve was calculated.
- The direction of gas supply pipeline releases was assumed to be 80% vertical and 20% at 45°.
- The frequency of pipeline releases was based on European Gas Pipeline Incident Data Group (EGIG) data which will be conservative for this proposal, as discussed in Section 8.1.
- The spacing between main line valves will be 30km as per AS2885:2007.

6. HAZARD IDENTIFICATION

6.1. Hazardous Incidents

A hazard identification table for the pipeline is given in APPENDIX A. This table was compiled from a review of similar pipeline risk assessments and the preliminary design details for the proposed pipeline. The hazard identification is used as a basis for identifying a list of scenarios for carrying forward to the quantitative risk assessment.

6.2. Hazardous Materials

The proposed pipeline will transport natural gas, of which the major component is methane. The focus of this PHA was therefore the potential for loss of containment of methane, a highly flammable (hydrocarbon) gas and simple asphyxiant.

6.3. Natural Gas Releases

Ignited gas methane releases from the pipeline could result in:

- Jet fire, if ignited immediately
- Flash fire, if ignition is delayed
- Vapour Cloud Explosion (VCE) if a flash fire occurs within a congested or confined location.

Gas releases could result in a jet fire if ignited immediately, resulting in a jet flame. Heat radiation from the jet fire will impact people within the vicinity of the release.

If ignition is delayed, a vapour cloud may form, however as natural gas is buoyant and will disperse easily, the potential for a significant cloud buildup is low. Ignition of the vapour cloud could result in a flash fire.

In the event of a flash fire, the vapour cloud burns rapidly without a blast wave and will flash back to burn as a jet flame from the release point. In the event of a flash fire, there is a high (100%) chance of a fatality within the vapour cloud, but due to the short duration of the flame, there is a low chance of significant impact outside the vapour cloud radius. However, the impact from the jet fire that continues after the flash fire remains.

A vapour cloud explosion (VCE) could occur if the flame front burns through a vapour cloud that is within a congested area, resulting in turbulence (promoting combustion) and flame front acceleration and, hence, the generation of overpressure. Given the generally remote location, there is a very low likelihood of flash-fire flame-front acceleration and vapour cloud explosion overpressure.

Therefore explosion events (e.g. VCEs) were not considered further in this study and jet fires and flash fires were considered to be the significant scenarios.

6.4. Releases from Pipeline

The main incident of concern that could result from the operation of the pipeline is a loss of containment, release of natural gas to the atmosphere and subsequent ignition. The range of release sizes may range from a small leak to a full bore rupture.

From a literature review of gas pipeline failures, the main cause of pipeline leaks is due to external mechanical damage as a result of third party impact on the pipeline (Ref. 6). Australian industry sources indicate that pipeline failure modes are similar to overseas experience. Anecdotally, failures would appear to be less frequent in Australia compared to overseas experience. However, a compiled source of failure rates for pipelines within Australia is not readily available and estimates of frequency based on reported incidents are therefore not considered reliable.

There are over 25,000 km of major natural gas transmission pipelines in Australia. Very few incidents have been reported for major Australian pipelines. On this basis, generic European data was used for the frequency assessment as it provides a more statistically valid sample size.

The main types of failure incident reported by the various sources (both overseas and Australian) are:

- External interference from heavy equipment (e.g. mechanical damage to pipe during excavation by third parties)
- Scour damage (e.g. river bed scouring, exposing and damaging pipes)
- Construction and material defects
- Internal and external corrosion and stress corrosion cracking
- Subsidence damage (e.g. banks and levees washing away, exposing and damaging pipes, mine subsidence, construction work near the pipeline)
- Faulty construction (e.g. welding defects, lack of weld testing)
- Ground movement (e.g. buckled pipework from excessive ground movement from earthquakes, slips and ground subsidence)
- Error during 'hot tapping'.

Other potential incidents which were identified in the hazard identification table in APPENDIX A include:

- Vehicle loading
- AC induction effects from HV power lines
- Stress corrosion cracking
- Fatigue due to pressure cycling
- Overpressure/ overtemperature.

6.5. Peak Demand Operation

The peak demand operation of the proposed Wellington Power Station may result in pressure cycling from static to dynamic conditions as gas flow to the power station is switched on and off. This cycling may impose additional hazards including:

- Fatigue due to pressure cycling
- Stress corrosion cracking which can occur as a result of pressure cycling (with high gas temperature and certain soil conditions).

6.5.1. Fatigue

Fatigue may result in fracture failure, leading to a pipeline rupture in the worst case. However, the impact of fatigue would be readily detectible from the operating history and maintenance inspections conducted during the pipeline life. Early fatigue impact would require restrictions on the pipeline operation, e.g. pressure restrictions or limits on the pipeline life.

Fatigue will be managed by reviewing the pipeline thermal and pressure cycling at each pipeline MAOP review (5 yearly) to determine if the resulting stress cycling has the potential to cause a defect that could initiate a crack and propagate. The evaluation method of BS7910 will be adopted. If the result is found to be unacceptable, mitigation methods would be incorporated into the pipeline operation to reduce the threat to an acceptable level.

Given the effectiveness of the proposed safeguard and the ongoing monitoring of pressure fluctuations, no increase in the failure rate for this failure mode was included in the frequency analysis.

6.5.2. Stress Corrosion Cracking

Stress corrosion cracking (SCC) is a phenomenon which can occur in pipelines that are subject to pressure cycles under high operating temperatures and in soil conditions which are conducive to corrosion. If detected, stress corrosion cracking may require pipeline repairs or may require derating of the pipeline. If undetected, stress corrosion cracking may lead to pipeline failure.

The pipeline design will make allowance to minimise the impact of stress corrosion cracking, using well known design and assessment protocols, e.g. the Pipeline Research Council International (PRCI, Ref. 7).

This will be provided by use of a HDPE fusion-boned epoxy or tri-laminate coating system with improved SCC resistance for the entire length of the pipeline. This will minimise the impact of external corrosion, in combination with an appropriate design for the cathodic protection system.

In addition, the following typical safeguards will also reduce the likelihood of SCC:

- after-coolers on the gas hub compressor facility with temperature monitoring

- provision of additional wall thickness pipe in the immediate downstream section of pipe from the compressors as required
- the design life of the pipeline will include allowances for fluctuations.

The final design for the pipeline and safeguards will need to take into account specific factors at certain locations and the level of safeguards required may change from the typical safeguards discussed here.

Given the typical safeguards for SCC and the low likelihood of impact, no increase in the failure rate for stress corrosion cracking was included in the frequency analysis.

6.6. Location Specific Hazards

Other hazards specific to locations where the pipeline crosses existing features include the following:

- Impact from vehicle loading or construction work near road and rail crossings
- Alternating current induction and corrosion effects from power lines near the pipeline
- Stray currents from high voltage DC traction lines at rail crossing.

These issues are commonly encountered in pipeline designs in Australia and there are adequate safeguards to mitigate the hazard. The most significant of these are the impact of alternating current (AC) induction and corrosion which is discussed in more detail in the next sections.

6.7. Power Line Impacts on Pipeline

The pipeline route may potentially be located near power transmission lines. This may have a number of potential impacts, including:

- AC induction affects, with the potential to impact personnel working on the pipeline facilities (valve stations, etc)
- Corrosion impacts from AC impact on pipeline coating defects

These impacts and the typical safeguards are discussed in the following sections. The final pipeline design and the safeguards required to minimise the impact of power line impacts may vary depending on location specific factors.

6.7.1. AC Induction Affects

Appropriate safety measures will be designed and adopted to ensure the safety of personnel and equipment. Typical mitigation measures include selective earthing at particular positions on the pipeline, zinc ribbon installed in the trench with the pipeline, inline isolation installed in the pipeline, restricted access to the pipeline and its facilities, and the use of equi-potential grids or other safety equipment during maintenance of the pipeline. The test points for the cathodic protection system may also be made lockable at all locations depending on final requirements.

Given these typical safeguards, the impact of AC induction effects near power lines will be minimised and an allowance for an increased failure rate has not been included in the frequency analysis.

6.7.2. AC Corrosion

AC corrosion occurs at ‘holidays’ (exclusions or defects in the pipeline coating) as a result of the impact of AC induction near powerlines. The mechanism for the process is not clearly understood, but is more likely to occur under the presence of specific conditions including high current density and low soil resistivity.

The impact of AC corrosion and design requirements will be assessed in the detailed design in order to mitigate the load current levels to values that are below the critical value which would result in a high likelihood of impact. Typical safeguards include resistance probes to monitor AC corrosion impact.

AC corrosion is considered to be of low likelihood and no increase in the failure rate for this failure mode was included in the frequency analysis.

6.8. Pipeline Safeguards

The proposed pipeline will be designed and operated in accordance with AS 2885 2007.

The selection and design of the safeguards for protection of pipelines are based on the requirements of AS2885.1 and from previous experience. The following engineered and procedural safeguards are typical of pipeline designs.

6.8.1. Protection Against External Damage

- Marker signs
- ‘One-Call‘/ ‘Dial-before-dig’ services
- Pipeline patrols
- Marker tape

6.8.2. Corrosion Protection

- External coating of pipeline
- ‘Holiday’ detection (testing of coating integrity) prior to burial
- Sacrificial anode or impressed current cathodic protection system
- Gas quality with minimal corrosion enhancing components
- Intelligent pigging to assess pipeline condition

6.8.3. Ground Movement/ Subsidence

- The pipeline will be regularly patrolled to facilitate detection of any ground movement or land subsidence so that investigation can be carried out.
- Where significant ground movement has been detected and stresses are determined to be high, the ground around the pipeline will be dug up to relieve the stresses on the pipe as an additional precautionary measure to mitigate the effect of subsidence prior to reburial.

6.9. Flooding

As discussed in Section 6.4, flooding events have the potential to uncover or dislodge the pipeline, with the potential to overstress the pipe or to increase the risk of external impact. The following typical safeguards are used to manage the impact of this scenario:

- Selection of suitable depth of cover, concrete weighting and extra wall thickness pipe at flood prone areas and watercourse crossing
- Pipeline patrols after flood events
- Remediation of pipe in the event of uncovering or overstressing.

Given the safeguards, this scenario will have a low risk and was not carried forward to the risk assessment.

6.10. Bushfires

Due to the depth of cover, heat radiation impact from bushfires will not affect the pipeline and therefore was not considered further.

7. CONSEQUENCE ASSESSMENT

7.1. Consequence Modelling

Release rates and consequence effects were calculated using the proprietary consequence modelling package Shell FRED Version 5 (Ref. 8).

The assessment took into account the orientation of the release. For buried pipeline, a horizontal jet would be less likely to occur as the jet release would tend to be directed upwards, with the majority of releases in a vertical direction since external impacts would be more likely to occur from above the pipe. Therefore, the assessment of buried pipeline leaks was based on an assumption of 80% of releases being vertical and 20% at 45º.

7.2. Release Scenarios

The hazard identification tables were reviewed to select a set of credible release scenarios and hole sizes to be carried forward for consequence modelling.

7.3. Isolation of Pipeline Releases

For full bore rupture, assuming the shutdown system operates, the pipeline will be isolated and depressured, resulting in the flow rate decreasing over time. The pipeline will be provided with main line valves. A spacing of 30km between valves was assumed as per the AS2885:2007 requirements for R2 areas.

Because of the distance between line valves, some time will elapse before the pipeline will depressurise following detection of a major leak and isolation of the pipeline segment. A depressurising curve was produced for the pipeline rupture case. Two cases were considered for pipeline rupture cases:

- Pipeline rupture followed by operation of the isolation system at an average release rate for the depressurising curve
- Pipeline rupture followed by failure of the isolation system with the release modelled as a continuous release

7.4. Releases from Pipeline

The pipeline release scenarios carried forward for consequence assessment are jet fires and flash fires resulting from a leak or rupture.

As discussed in APPENDIX C, the European Gas Pipeline Incident Data Group collects data on the frequency of pipeline failures and reports statistical data by a number of factors including hole sizes (Ref. 6). The data broadly categorises releases in a range of hole sizes:

- pinholes or small holes
- medium holes or punctures

- ruptures

Pinholes can occur due to mechanisms such as corrosion, weld defects, material defects in the pipe itself. The resistance of the pipeline material to crack propagation (its fracture toughness) is an important feature in determining whether the release could propagate, resulting in a full bore rupture of the pipeline. There is a potential for small holes or cracks to propagate, potentially leading to extensive longitudinal cracking with an equivalent hole size equal to the full bore rupture.

Townsend and Fearnehough (Ref. 9) indicate that the majority of leaks are small (pinholes and small holes) and would be less than 10 mm. They also indicate that small leaks from pinholes and small holes do not generally constitute a significant hazard due to the low release rates involved.

Hole sizes in the range from 20 mm to 80 mm are predominantly caused by puncture from external interference. A statistical analysis of hole size from puncture events indicated 40 mm as the mean hole size for punctures (Ref. 10).

Based on this data, the following hole sizes were selected for release incidents:

- 10 mm diameter for pinholes and small holes.
- 50 mm for medium holes (selected for conservatism over the 40 mm average hole size determined by Fearnehough, Ref. 10).
- Full-bore rupture (508 mm diameter).

The process data used to evaluate the consequences of releases are summarised in Section 3.3. The distance to jet fire heat radiation levels and flash fire impact zones are provided in APPENDIX B.

7.5. Incidents Carried Forward to QRA

Table 7.1 summarises the scenarios with offsite consequences which have been carried forward to the QRA.

The consequence assessment for flash fires showed that in all cases the distance to fatality levels for flash fires was less than for the equivalent release for jet fires. Therefore the consequence impact of flash fires was not carried forward to the risk assessment.

TABLE 7.1: SCENARIOS CARRIED FORWARD TO QRA

Release Scenario	Hole Size (mm)	Release Rate (kg/s)	Offsite Jet Fire Consequences	Offsite Flash Fire Consequences
Pipeline Releases (Lateral)				
Pinhole (45 Deg)	10	2	Carried Forward	Not Carried Forward
Puncture (45 Deg)	50	56	Carried Forward	Not Carried Forward
Rupture - Isolated (45 Deg)	Full Bore (508 mm)	2000	Carried Forward	Not Carried Forward
Rupture - No Isolation (45 Deg)	Full Bore (508 mm)	5742	Carried Forward	Not Carried Forward
Pipeline Releases (Vertical)				
Pinhole (V)	10	2	Carried Forward	Not Carried Forward
Puncture (V)	50	56	Carried Forward	Not Carried Forward
Rupture - Isolated (V)	Full Bore (508 mm)	2000	Carried Forward	Not Carried Forward
Rupture - No Isolation (V)	Full Bore (508 mm)	5742	Carried Forward	Not Carried Forward

8. FREQUENCY ANALYSIS

8.1. Pipeline Incident Frequencies

Frequencies for pipeline releases and jet fires were derived from published historical records of pipeline incidents. Details of the frequency analysis for pipeline incidents are given in APPENDIX C. The frequencies of jet fire fire incidents were estimated based on:

- The frequency of the initiating leak
- The probability of ignition for jet fires
- The reduction in frequency gained by the proposed safeguards.

8.1.1. Pipeline Safeguards

The assessment of the frequency of pipeline incidents took into account the proposed safety measures.

Additional depth of cover will reduce the likelihood of impact by third party impact. The minimum depth of cover required by AS2885:2007 for natural gas pipelines in rural locations is 750 mm. Additional depth of cover is required where the pipeline route passes near residential housing, at road and rail crossings and at other locations where there is an increased risk of external interference.

The specification proposed for the pipeline gas supply pipework has not been nominated in the preliminary design. For general cross-country locations, pipe with a specification of API 5l X65 or X70 would be used. For an operating pressure of 15.3 MPa, a pipeline diameter of 508 mm, and a design factor of 0.80, the wall thickness for X70 pipe will be about 9 mm. A minimum wall thickness of 9 mm was assumed for all sensitivity cases.

Marker tape is an additional safeguard typically applied above the buried pipeline to indicate the presence of high pressure pipelines. Generally, this will be used at road and rail crossings, major watercourse crossings and other high risk locations.

As the design is not finalised, a number of sensitivity cases with different levels of safeguards was considered:

- Case 1 (Base Case) – 750 mm depth of cover (DOC), no marker tape, 9 mm wall thickness
- Case 2 – 900 mm DOC, no marker tape, 9 mm wall thickness
- Case 3 – 1200 mm DOC, no marker tape, 9 mm wall thickness
- Case 4 – 750 mm DOC, marker tape, 9 mm wall thickness
- Case 5 – 900 mm DOC, marker tape, 9 mm wall thickness

- Case 6 – 1200 mm DOC, marker tape, 9 mm wall thickness

9. QUANTITATIVE RISK ASSESSMENT

9.1. Overview

The quantitative risk resulting from the operation of linear infrastructure such as pipelines is commonly presented as risk transects, i.e. a graph of estimated risk level versus the lateral distance from the centreline of the pipe. The transect shows the risk level that a receiver would be exposed to at any lateral distance from the pipe. The graph can also be used to estimate the distance to the relevant risk criteria and to show whether there is adequate separation distance from the pipeline to adjacent land uses.

The calculation of risk is assessed by combining the consequence of the event (in this case the distance to heat radiation levels estimated in Section 7) with the frequency of occurrence (from Section 8). The risk for all incidents is accumulated to show the total risk to an individual at any point near the pipeline.

9.2. Pipeline Risk Profile

The risk transect for the pipeline for all cases is shown in Figure 9.1. The results are tabulated in Table 9.1 to show the distances to the NSW DoP planning risk criteria for all cases. Table 9.1 shows the separation distances required for land uses near the pipeline route. An appropriate level of safeguards may be selected depending on the separation distance to nearby land uses to meet the risk criteria of the DoP.

TABLE 9.1: DISTANCES TO RISK CRITERIA LEVELS FOR PIPELINE

Case	Distance to Individual Risk of Fatality (m)				
	Sensitive (hospitals, nursing homes)	Residential	Commercial	Active Open Spaces	Industrial
	(5×10^{-7} per year)	(1×10^{-6} per year)	(5×10^{-6} per year)	(1×10^{-5} per year)	(5×10^{-5} per year)
Case No. 1 (DN508, 750 mm DOC, 9 mm WT, no marker tape)	275	240	140	20	Not reached
Case No. 2 (DN508, 900 mm DOC, 9 mm WT, no marker tape)	270	230	130	15	Not reached
Case No. 3 (DN508, 1200 mm DOC, 9 mm WT, no marker tape)	267	225	80	Not reached	Not reached
Case No. 4 (DN508, 750 mm DOC, 9 mm WT, marker tape)	265	220	60	Not reached	Not reached
Case No. 5 (DN508, 900 mm DOC, 9 mm WT, marker tape)	260	215	50	Not reached	Not reached
Case No. 6 (DN508, 1200 mm DOC, 9 mm WT, marker tape)	255	200	35	Not reached	Not reached

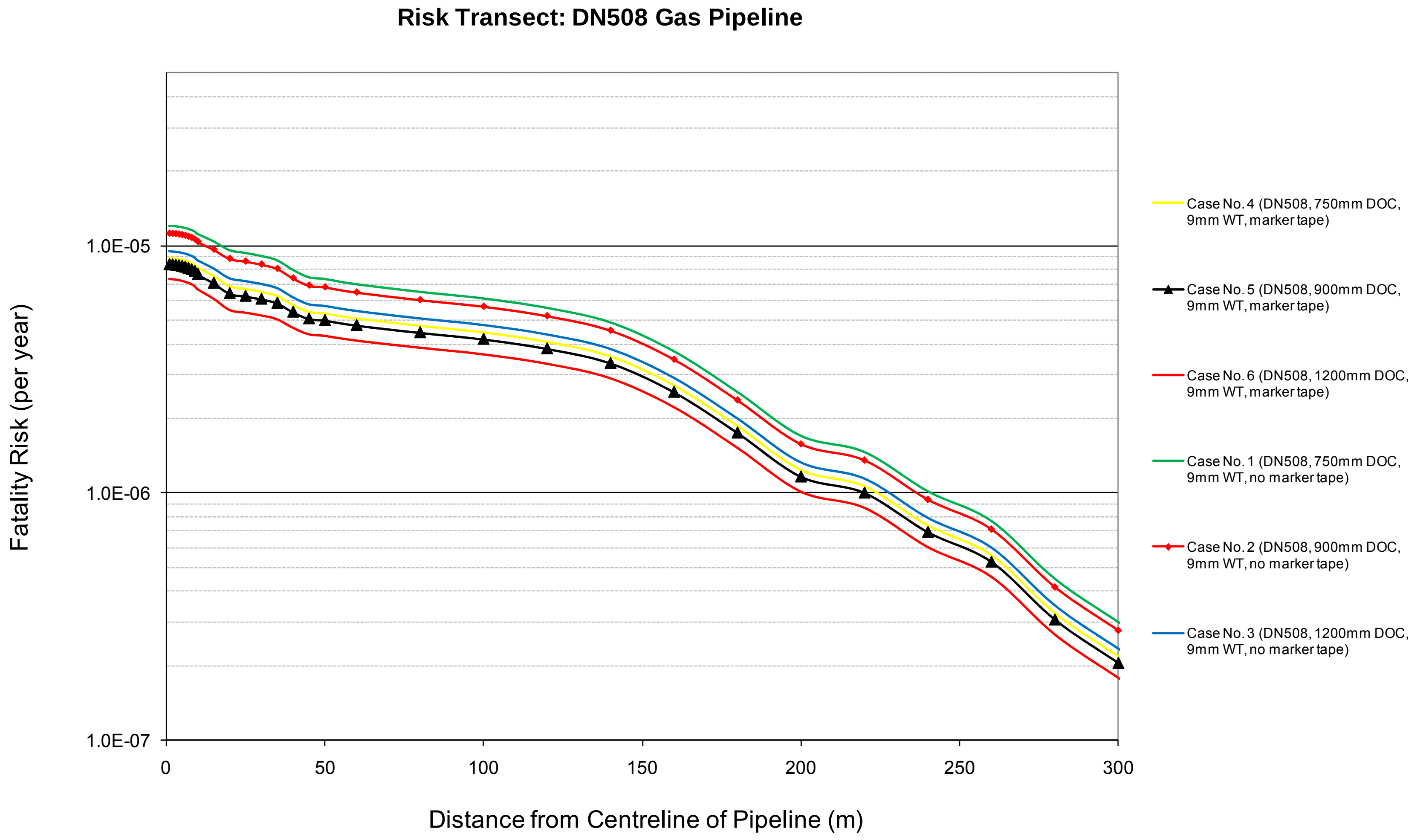

FIGURE 9.1: PIPELINE RISK TRANSECT – ALL CASES

9.3. Societal Risk

Societal risk is calculated by assessing the impact to the entire population located in the area around the proposed pipeline and therefore depends on the population density in the area. Given the low population density in the area and the low individual risk, the societal risk level resulting from the pipeline operation is negligible and has not been quantified.

9.4. Risk of Injury

Given the low population density and no residential land within the 4.7 kW/m^2 heat radiation contour, the risk of injury was not quantified.

9.5. Conclusions

A PHA was undertaken for the Young to Wellington Gas Pipeline. The risk resulting from the operation of the pipeline was assessed to determine the potential impact to local land uses.

Risk levels resulting from the gas supply pipeline were presented as risk transects for a number of sensitivity cases with various levels of pipeline safeguards. Distances to risk criteria levels for various land uses are summarised in Table 9.1.

The results in Table 9.1 show the minimum separation distance to residential zone for different levels of safeguards. An appropriate level of safeguards may be selected from this table to meet the requirements of the DoP criteria for individual risk, taking into account the nearest residential areas to the pipeline.

9.6. Recommendations

1. A number of issues (stress corrosion cracking, fatigue due to pressure cycling) have been identified which will need to be addressed in the detailed design of the gas pipeline.
2. In the event of significant design changes occurring during the detailed design phase, the PHA would typically required an update to a Final Hazard Analysis (FHA) prior to the commencement of pipeline construction.

APPENDIX A. HAZARD IDENTIFICATION TABLE

TABLE A.1: HAZARD IDENTIFICATION TABLE FOR PIPELINE

No.	Component	Hazardous Incident	Cause	Consequence	Protection or Safety Measure	Comments/Recommendations
1	Pipeline	External interference and release	• Third party impact	• Potential impact on pipeline causing leak of natural gas. • Jet fire if ignited. • Potential injury/fatality	• Depth of cover • Wall thickness • Pipeline patrols	Carried forward to risk assessment
2	Pipeline	Scouring / erosion at waterways /drains	• Flooding • Runoff	• Exposed pipeline may be subject to external impact	• Depth of cover • Extra wall thickness provided at waterways/drain crossings as required • Pipeline patrols • Concrete weighting • Trench breakers	Not carried forward to quantitative risk assessment
3	Pipeline	Floatation of pipeline at watercourses	• Pipeline buoyancy • Cover eroded	• Exposed pipeline may be subject to external impact • Pipe stress	• Pipeline patrols • High integrity pipeline • Depth of Cover • Concrete weighting	Not carried forward to quantitative risk assessment
4	Pipeline	High vehicular loading on pipeline	• Vehicle loading • Rail/ road crossings	• Potential impact on pipeline causing leak of natural gas. • Jet fire if ignited. • Potential injury/fatality	• Depth of cover at road / rail crossings • Pipeline design to take account of additional stresses	Not carried forward to quantitative risk assessment
5	Pipeline	Corrosion	• Stray currents • AC induction near power lines • Coating defects	• Potential impact on pipeline coating • Pinhole leaks • Jet fire if ignited	• Pipeline coating • Cathodic protection • Holiday coating checks • Cathodic protection test points • Intelligent pigging	Carried forward to quantitative risk assessment

No.	Component	Hazardous Incident	Cause	Consequence	Protection or Safety Measure	Comments/Recommendations
6	Pipeline	Stress corrosion cracking	• Corrosive soil conditions in combination with high gas temperature and pressure cycling	Potential leak, jet fire if ignited	• Pipeline coating • Coolers on compressor outlet • Pressure cycling not to exceed design criteria • Cathodic Protection	Not carried forward to quantitative risk assessment
7	Pipeline	Weld/material defects	• Incorrect materials/ specification • Incorrect weld procedures	Potential leak, jet fire if ignited	• Welding procedures • Material Certificates • Weld joints radiographed (100%) • Hydrostatic testing • QA/QC	Carried forward to quantitative risk assessment
8	Pipeline	Overpressure	• Control failure	Pipeline / equipment damage	• Pipeline designed to meet full MAOP • Monitoring of system pressure • Line break valves	Not carried forward to quantitative risk assessment
9	Pipeline	Over-temperature	• Compressor cooler failure	Pipeline / equipment damage	• Monitoring of compressor outlet temperature. • Temperature rating of pipeline and equipment	Not carried forward to quantitative risk assessment
10	Pipeline	AC Induction impact on pipeline from adjacent powerlines	• Pipeline near power lines	Pipeline damage (corrosion impact) Personnel impact	• AC induction safeguards as required	Not carried forward to quantitative risk assessment
11	Pipeline	Stray current and DC voltage impact from railway line	• Pipeline near rail lines	Corrosion and induction	• Design to include control devices, for example, Transformer Rectifier Assisted Drainage (TRAD) unit to divert stray currents	Not carried forward to quantitative risk assessment

No.	Component	Hazardous Incident	Cause	Consequence	Protection or Safety Measure	Comments/Recommendations
12	Pipeline	Mine subsidence	• Pipeline near mine subsidence areas	Pipeline damage	• The proposed pipeline route would not cross any known areas of mine subsidence.	Not carried forward to quantitative risk assessment

APPENDIX B. CONSEQUENCE ASSESSMENT

B1. Introduction

This appendix documents the consequence assessment of the Young to Wellington Gas Pipeline. In particular, the following activities undertaken for the consequence analysis are described:

- Selection of release scenarios and hole size
- Jet fire modelling approach
- Flash fire modelling approach
- Dispersion modelling approach
- Results of consequence assessment and associated heat radiation effects

B2. Modelling Approach

B2.1. Leak and Effect Modelling

The consequence modelling for the jet fire scenarios was undertaken using Shell FRED 5.0, which was developed by Shell Global Solutions (Ref. 8).

The impact from flash fire incidents is modelled in Shell FRED as the dispersion distance to half the lower flammability limit (LFL). It is assumed that in a flash fire there is a 100% chance of fatality occurring within the fireball.

B2.2. Meteorological Conditions

The following typical weather conditions were assumed for the consequence assessment:

- "D" Pasquill stability class and 5m/s wind speed for jet fires and flash fires
- "F" Pasquill stability class and 2m/s wind speed for flash fires
- 30° C ambient temperature
- 70% relative humidity

For the assessment of impact from flash fires, the greatest distance for downwind impact was carried forward.

B2.3. Orientation of Release

The angle of release from the pipeline was specified as follows:

- Vertical where the release is 90 degrees to the horizontal plane. Releases due to third party impact will tend to occur on the top of the pipeline.

- Horizontal releases will tend to scour the ground around the pipeline resulting in a crater which will deflect the jet upwards. The release is modelled as a jet flame at 45 degrees to the horizontal plane.

NOTE: In the consequence distance tables, the flame length reported is the total length including flame lift-off from the release point and length of the flame, not the lateral distance from the pipeline. For releases at an angle from vertical, the flame length reported (which results in 100% chance of fatality) may be greater in some cases than the distance to heat radiation levels which result in fatality. This will result in conservative risk levels near the pipeline.

B2.4. Release Rate Scenarios

The leak scenarios and representative hole sizes selected for the analysis are:

- Small pipework release, due to corrosion or defects – 10 mm
- Medium size release (for example, punctures) 50 mm
- Full Bore Rupture 508 mm

The release rates for jet fires were modelled assuming the release occurs at the Maximum Allowable Operating Pressure (MAOP) of the pipeline (15.3 MPag). Releases from 10 mm, 50 mm holes and full bore rupture (unisolated) were modelled as continuous releases. A depressuring curve was undertaken to model the isolated case for full bore rupture.

To determine the pressure drop, a depressuring curve was determined using Shell FRED. This curve was calculated using a line pressure of 15.3 MPa and a pipe length of 30km. A leak rate of 1,800 kg/s was used for the isolated release case, based on the average of the initial release rate and the release rate 60 seconds after isolation.

B3. Summary of Findings

The release rates, jet fire and flash fire impact distances evaluated for the pipeline are summarised in Table B.1.

A number of cases were assessed for the consequence assessment of the pipeline as follows:

- Case 1 (Base Case) – 750 mm depth of cover (DOC), no marker tape, 9 mm wall thickness
- Case 2 – 900 mm DOC, no marker tape, 9 mm wall thickness
- Case 3 – 1200 mm DOC, no marker tape, 9 mm wall thickness
- Case 4 – 750 mm DOC, marker tape, 9 mm wall thickness
- Case 5 – 900 mm DOC, marker tape, 9 mm wall thickness
- Case 6 – 1200 mm DOC, marker tape, 9 mm wall thickness

TABLE B.1: PIPELINE CONSEQUENCE MODELLING RESULTS

ID Tag	Release Description	Pressure (barg)	Temp (ºC)	Hole Size (mm)	Release Rate (kg/s)	Release Orient'n	Distance to Heat Radiation Level (m)						Distance to Flash Fire Impact (m) D5 Flash Fire (to Half LFL)		Distance to Flash Fire Impact (m) F2 Flash Fire (to Half LFL)	
							Flame Length	4.7 kw/m²	6 kw/m²	10 kw/m²	14 kw/m²	23 kw/m²	Length	Width	Length	Width
							(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
1	Pinhole	153	30	10	2	45º	16	22	21	18	17	15	10.5	2.2	13.6	2.4
2	Puncture	153	30	50	56	45º	60	87	81	70	64	57	49.6	10.2	55.1	11.1
3	Rupture - Isolation	153	30	Full Bore (508mm)	2000	45º	240	360	337	287	266	231	n/a	n/a	n/a	n/a
4	Rupture - No Isolation	153	30	Full Bore (508mm)	5742	45º	381	589	543	471	434	381	n/a	n/a	n/a	n/a
5	Pinhole	153	30	10	2	Vertical	15	16	15	11	10	8	2.9	2.5	2.5	1.6
6	Puncture	153	30	50	56	Vertical	56	64	57	45	40	31	15.3	11.7	12.7	12.4
7	Rupture - Isolation	153	30	Full Bore (508mm)	2000	Vertical	223	265	240	189	164	131	83.0	62.0	74.0	58.0
8	Rupture - No Isolation	153	30	Full Bore (508mm)	5742	Vertical	355	436	394	322	273	228	164.0	109.6	170.0	94.8

APPENDIX C. PIPELINE INCIDENT FREQUENCIES

C1. Pipeline Release Frequencies

C1.1. Generic Pipeline Failure Data

The failure rate data used for the assessment of the frequency of pipeline releases was derived from the European Gas Pipeline Incident Data Group (EGIG, Ref. 6). The European data are useful because of the significant exposure in terms of kilometre years experienced (approximately 3.15 kilometre-years from 1970-2007) which gives a statistically significant basis for estimating release frequencies. The data also give the frequency of different causes of failure. Also included are factors such as wall thickness, depth of cover, probability of ignition, etc.

The EGIG data are considered conservative when applied to pipelines in Australia. This is because there is a higher density of pipelines and higher population densities along pipeline routes in Europe than in Australia. This will tend to result in higher failure rates for European pipelines compared with the experience of pipelines in Australia, particularly for incidents caused by external interference.

AS2885-2007 is a risk based standard which emphasises the protection of pipelines from external interference. It has been previously noted that the reported failure frequency of pipeline incidents is significantly lower than that experienced in Europe, however the causes for this difference are unclear (Ref. 11). It is believed that low population densities and relatively new pipelines result in the low incident frequencies (about 150 incidents reported since 1965).

Differences between design, construction and operational standards from different geographical areas have been noted; however it is difficult to then conclude decisively which are the significant factors that determine expected incident frequencies.

The overall failure frequency reported by EGIG for the period 1970-2007 was 0.37 incidents per 1000 km-yr.

C1.2. Base Failure Frequencies

Table C.1 summarises the data derived from the EGIG report for the period 1970-2007. The data are categorised by the identified cause of the incident and show the relative frequency of each cause. The most frequent cause of pipeline failures is due to external interference (50%) with the next most likely causes being construction/ material defects (17%) and corrosion (15%).

The incidence of hot-tap errors (taken as the likelihood of tapping into the wrong pipeline or inadvertently impacting an adjacent pipeline) will be insignificant as there will only be one offtake in the vicinity on the existing main gas pipeline. Therefore the frequency for hot-tap errors has been set to zero.

TABLE C.1: BASE FREQUENCIES FOR PIPELINE RELEASES

Cause	Pipeline Base Frequency by Cause and Hole Size (per 1000 km-yr)		
	Pinhole-Crack (d<10 mm)	Hole (10 mm < d <50 mm)	Full Bore Rupture
External Interference	0.05	0.1	0.03
Construction/Material Defect	0.04	0.015	0.01
Corrosion	0.0525	0.0025	0
Ground Movement	0.008	0.008	0.009
Hot tap error	0	0	0
Other/Unknown	0.022	0.003	0
Total	**0.1725**	**0.1285**	**0.049**

C1.3. Additional Safeguards

The base frequencies given in Table C.1 were then adjusted to take account of the additional safeguards including:

- Marker tape/ no marker tape as per sensitivity cases
- Depth of cover (750 – 1200 mm depth of cover as per sensitivity cases)
- Wall thickness (9 mm minimum wall thickness)

The provision of these safeguards will result in a reduction in the likelihood of external interference leading to pipeline damage.

Marker Tape

Corder (Ref. 12) has reported that a damage reduction factor of 1.67 was achieved when marker tape is provided above pipelines based on experimental data derived from testing undertaken by British Gas. This factor was used to reduce the frequency of impacts resulting from external interference for sensitivity cases with marker tape.

Depth of Cover

Table C.2 summarises the risk reduction factors from the testing reported by Corder (Ref. 12). Note that a reduction factor of 1.0 resulted for depths of cover of 1.11m and that lower depths of cover result in a reduction factor greater than 1, i.e. there is an increase of the relative frequency of external impact.

TABLE C.2: REDUCTION FACTORS FOR DEPTH OF COVER

Depth of Cover (m)	Reduction Factor
0.75	1.35
0.9	1.21
1	1.11
1.1	1.02
1.2	0.92
1.4	0.73

Marker Tape

The EGIG database (Ref. 6) summarises pipeline failure frequencies by wall thickness. Based on the data, the following factors are used for pipe with varying wall thickness.

TABLE C.3: FREQUENCY MULTIPLYING FACTOR FOR WALL THICKNESS

Pipewall Thickness (mm)	Pinhole	Puncture	Rupture (Full bore Release)
2.5 (0-5mm)	4.0	2.4	5.8
7.5 (5-10 mm)	1.0	1.0	1.0
12.5 (10-15mm)	0.5	0.5	0.5

C2. Pipeline Failure Cases Assessed

A number of sensitivity cases have been assessed taking into account:

- Depth of cover
- Marker tape

The following cases were assessed:

- Case 1 (Base Case) – 750 mm depth of cover (DOC), no marker tape, 9 mm wall thickness
- Case 2 – 900 mm DOC, no marker tape, 9 mm wall thickness
- Case 3 – 1200 mm DOC, no marker tape, 9 mm wall thickness
- Case 4 – 750 mm DOC, marker tape, 9 mm wall thickness
- Case 5 – 900 mm DOC, marker tape, 9 mm wall thickness
- Case 6 – 1200 mm DOC, marker tape, 9 mm wall thickness

C3. Revised Pipeline Failure Frequencies

The revised failure frequencies incorporating risk reduction factors for the base case frequency assessment are summarised in Table C.4.

TABLE C.4: REVISED FREQUENCIES FOR PIPELINE RELEASES (CASE NO. 1)

Cause	Pipeline Revised Frequency by Cause and Hole Size (per 1000 km-yr)		
	Pinhole-Crack (d<10 mm)	Hole (10 mm < d <50 mm)	Full Bore Rupture
External Interference	0.061	0.121	0.036
Construction/Material Defect	0.040	0.015	0.010
Corrosion	0.053	0.003	0.000
Ground Movement	0.008	0.008	0.009
Hot tap error	0.000	0.000	0.000
Other/Unknown	0.022	0.003	0.000
Total	**0.183**	**0.150**	**0.055**

C4. Pipeline Ignition Probabilities

The probability of ignition used in the frequency assessment was based on the EGIG 2005 Report (Ref. 6), Section 3.4.3, summarised in Table C.5.

TABLE C.5: PROBABILITY OF IGNITION FOLLOWING PIPELINE GAS RELEASE

Hole Size	Ignition Probability
Pinhole (10 mm)	4%
Hole (50 mm)	2%
Rupture (< 406 mm diameter)	10%
Rupture (> 406 mm diameter)	33%

C5. Probability of Leak Detection

It is unlikely that pinholes and punctures would be readily detected by remote monitoring and may depend on the operating conditions at the time of the leak. Small releases in remote locations may not be readily detected until a routine patrol of the pipeline occurs. Therefore it was assumed that pinhole and puncture releases would not be detected for some time and the release rate was modelled as a steady-state release at the maximum allowable operating pressure (MAOP).

It was assumed that the gas supply pipeline will be provided with a remote shutdown capability consisting of automatic line break facilities located at the inlet to the compressor station and at the inlet to the delivery station and with main line valves spaced at 30km. The stations will be provided with telemetry which will allow remote monitoring of the pipeline operating conditions. A pipeline rupture would be readily detected by a sudden drop in pipeline pressure which would indicate to the operator to initiate closure of the main line shutoff valves.

In the case of pipeline rupture, depressuring of the line would occur rapidly if the loss of pressure is detected and the isolation valve is remotely operated by the operator. The shutdown will fail if pressure detection fails or if the operator fails to close the shutoff valve. The probability of failure to detect a leak and isolate the pipeline following a rupture has been calculated using a fault tree as shown in Figure C.1. The data used for equipment failure rates and human error probabilities is shown in Table C.6.

TABLE C.6: FAILURE RATE DATA FOR FAULT TREE ANALYSIS OF SHUTDOWN FAILURE

Component Failure	Source Reference	Failure Rate (x 10^{-6} per year)	Testing Frequency	Failure Probability (per demand)
Pressure Switch fails to function on pressure drop	CCPS 2.1.4.1.3 (Ref. 13)	0.4	Annual	1.8×10^{-3}
Isolation valve fails to close	CCPS 3.5.3.3	-	-	2.2×10^{-3}
Failure of SCADA System to send signal	OREDA (Ref. 14)	1.05	Monthly	0.044
Human Error – Operator Fails to Initiate Shutdown	HEART - Type E (Ref. 15)	-	-	.02

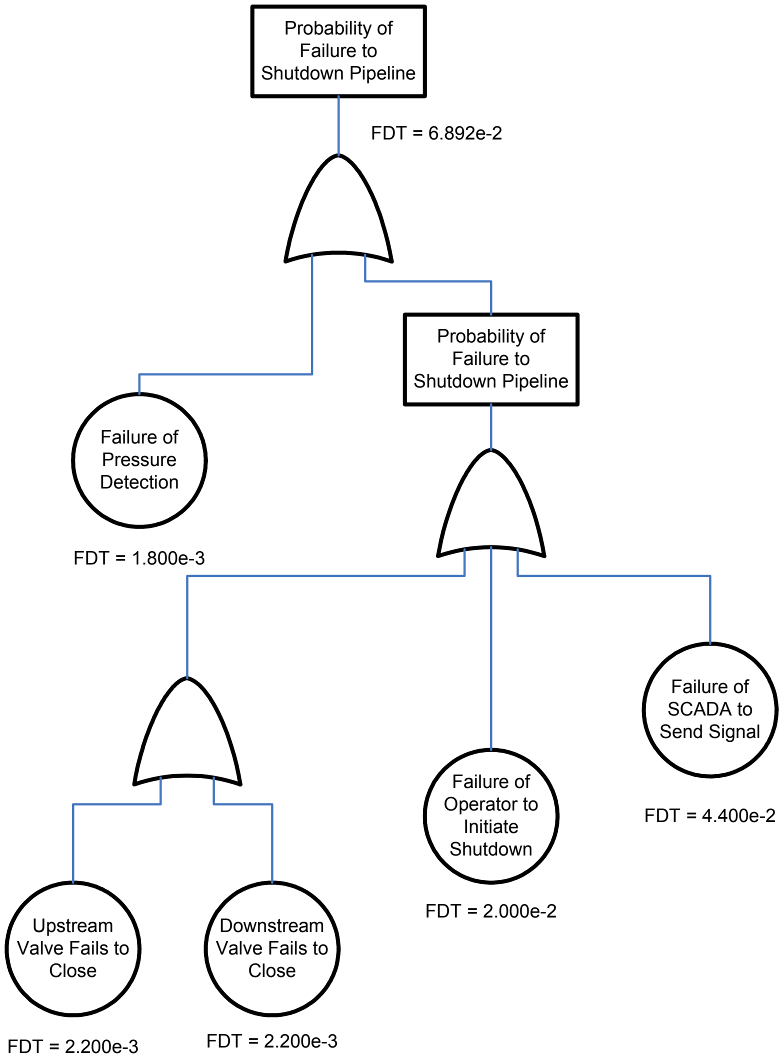

FIGURE C.1: FAULT TREE FOR PROBABILITY OF FAILURE OF PIPELINE SHUTEDOWN

Therefore the probability of failure of the shutdown system in the event of a rupture is 0.069.

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