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PRELIMINARY HAZARD ANALYSIS OF THE NATURAL GAS DELIVERY PIPELINE BETWEEN YOUNG AND BOMEN IN NSW

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Preliminary Hazard Analysis of the Natural Gas Delivery Pipeline between Young and Bomen in NSW

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EXECUTIVE SUMMARY

E1 Introduction

To meet the rising demand for natural gas to the towns in the central south of NSW and to a new power station at Uranquinty, the East Australian Pipeline Pty Ltd (EAPL), a wholly owned subsidiary of APA Group, is proposing to loop the existing 12” Young to Bomen pipeline with an 18” pipeline which would run parallel to the existing pipeline.

Due to the potentially hazardous nature of natural gas, the pipeline is classified as *potentially hazardous* as per the definition by the NSW Department of Planning.

As one element of the planning approval process, the NSW Department of Planning requires a Preliminary Hazard Analysis (PHA) to be prepared in accordance with the requirements of Hazardous Industry Planning Advisory Paper (HIPAP) No. 6: *Guidelines for Hazard Analysis* (Reference 1) and for the risk to be evaluated and compared with their risk criteria, as specified in their HIPAP No. 4: *Risk Criteria for Landuse Planning* (Reference 2).

The aim of this PHA is to ensure that there are no constraints, from a risk point of view, to the location of the new 18” pipeline alongside the existing pipeline.

The objective of this PHA is to present hazards and risks associated with the natural gas pipeline from the point where the pipeline leaves the compressor station at Young up to the point where the pipeline enters the metering station at Bowmen.

The PHA will:

- identify and analyse the acute hazards and risks associated with the pipeline;
- assess the findings against the risk criteria currently in use by NSW Department of Planning; and
- identify opportunities for risk reduction, and make recommendations as appropriate.

The methodology for the PHA is well established in NSW. The assessment has been carried as per the Hazardous Industry Advisory Paper (HIPAP) No 4, Risk Criteria for Land Use Planning and in accordance with HIPAP No 6, Guidelines for Hazard Analysis. These documents describe the methodology and the criteria to be used in PHAs as currently required by Planning NSW for major *potentially hazardous* development.

E2 Results

The main hazard associated with the gas pipeline is associated with the transport of natural gas, which is a flammable gas held under pressure.

The failure modes assessed in the PHA are derived from historical failures of similar pipelines. The predominant mode in which a hazardous incident may be generated is associated with a rupture or leak.

A leak would generally only have the potential to cause injury or damage if there was ignition, which resulted in a fire or explosion incident. The factors involved are:

- Failure must occur causing a release. There are several possible causes of failure, with the main ones being corrosion and damage to the pipeline by external agencies.

- The released material must come into contact with a source of ignition. In some cases this may be heat or sparks generated by mechanical damage while in others, the possible ignition source could include non-flame proof equipment, vehicles, or flames some distance from the release.

- Depending on the release conditions, including the mass of material involved and how rapidly it is ignited, the results may be a localised fire (for example, a so called jet fire) or a flash fire. Due to the open layout of the area surrounding the pipeline, an explosion of the vapour cloud formed through the release is considered highly unlikely.

- Finally, for there to be a risk, people must be present within the harmful range (consequence distance) of the fire or explosion. How close the people are will determine whether any injuries or fatalities result.

E3 Risk Assessment and Conclusions

The qualitative and quantitative analysis showed that:

- The risk of fatality at the nearest residential area is well below the criterion for new installations of one chance in a million per year (1×10^{-6}/yr) and remains within the pipeline easement.

- It follows that the 10×10^{-6} per year fatality risk contour (relevant for open spaces) remains well within the pipeline easement and does not encroach into any open spaces. The criterion for open spaces is therefore satisfied.

- It also follows that the 50×10^{-6} per year fatality risk contour (relevant for industry and business) remains well within the pipeline easement and does not encroach into any business or industrial zones. The criterion for industrial and business zoning is therefore satisfied.

- The 50 x 10^{-6} per year injury and propagation risk contours remain well within the pipeline easement. The criteria for injury and propagation risks are therefore satisfied.

As the risk of fatality does not extend anywhere outside the boundaries, it is considered that the proposed development does not have a significant impact on societal risk.

GLOSSARY

APT	Australian Pipelines Trust
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
HIPAP	Hazardous Industry Planning Advisory Paper
HSE	Health and Safety Executive (UK)
LFL	Lower Flammable Limit
MAOP	Maximum Allowable Operating Pressure
MPa	Mega Pascal (unit for pressure)
MSDS	Material Safety Data Sheet
MW	Mega Watt (unit for energy output)
NG	Natural gas
OH&S	Occupational Health and Safety
PHA	Preliminary Hazard Analysis
QRA	Quantitative Risk Analysis
SCADA	Supervisory Control and Data Acquisition

REPORT

1 INTRODUCTION

1.1 BACKGROUND

To meet the rising demand for natural gas the towns in the central south of NSW and to a new power station at Uranquinty, the East Australian Pipeline Pty Ltd (EAPL), a wholly owned subsidiary of APA Group, is proposing to loop the existing 12” Young to Bomen Pipeline with an 18” Pipeline which would run parallel to the existing pipeline.

Due to the potentially hazardous nature of natural gas, the pipeline is classified as *potentially hazardous* as per the definition by the NSW Department of Planning.

As one element of the planning approval process, the NSW Department of Planning requires a Preliminary Hazard Analysis (PHA) to be prepared in accordance with the requirements of Hazardous Industry Planning Advisory Paper (HIPAP) No. 6: *Guidelines for Hazard Analysis* (Reference 3) and for the risk to be evaluated and compared with their risk criteria, as specified in their HIPAP No. 4: *Risk Criteria for Landuse Planning* (Reference 4).

This document presents the PHA of the natural gas pipeline and forms an appendix to the Environmental Assessment for this pipeline.

1.2 SCOPE AND AIM OF STUDY

The aim of this PHA is to ensure that there are no constraints, from a risk point of view, to the location of the proposed new main gas line between Young and Bomen.

The objective of this PHA is to present the hazards and risks associated with the natural gas pipeline from the Bomen Meter Station up to the entrance to the Young Compressor Station.

Through the evaluation of likelihood and consequence of the major hazards, the risks to the community associated with proposed gas pipeline may be estimated and compared to Department of Planning risk criteria.

The pipeline included in this PHA includes all pipe and associated features:

- From the point where the pipeline leaves the compressor station at Young;

- Up to the point where the pipeline enters the metering station at Bowmen.

The PHA does not assess the risk associated with any pipe downstream of the meter station or the meter station itself at Bowmen, nor does it include the Young compressor station or any pipe upstream of the compressor station.

The scope of this report includes the following:

- Systematic identification and documentation of the major hazards, based on the information supplied and relevant experience with similar pipelines.

- Establishment of the consequence of each identified hazard and determination as to their offsite effects. This process is generally qualitative, with relevant quantitative calculations/modelling being completed where necessary.

- The frequency of occurrence is estimated based on historical data. If such data is unavailable, assumptions and qualitative discussions are presented.

- Determination of the acceptability (or otherwise) risk by comparison of the qualitative or quantitative assessment of the identified risks with the criteria specified in the NSW Department of Planning HIPAP No. 4 (Reference 4).

- Identification of risk reduction measures as deemed necessary.

At the time this PHA was conducted, design of the gas pipeline was in its preliminary stages. Detailed information was therefore not available for review. In situations where such information could impact on the PHA, assumptions have been made. These assumptions are intentionally conservative and have been stated in the report.

As a result of this conservatism, the results of the PHA are also inherently conservative, and this should be noted in their interpretation and application beyond the scope of this work.

2 SITE AND PROCESS DESCRIPTION

2.1 SITE LOCATION AND SURROUNDING LAND USES

The proposed pipeline will run south west from the Young Compressor Station towards the Bowmen Meter Station. Initially only part of the pipeline will be constructed, the length required being determined through consultation with the gas users.

The existing pipeline is bi-directional also enabling Moomba gas from South Australia to flow to Victoria and Bass Strait gas from Longford to flow to Sydney. The new (parallel) pipeline will also be bi-directional.

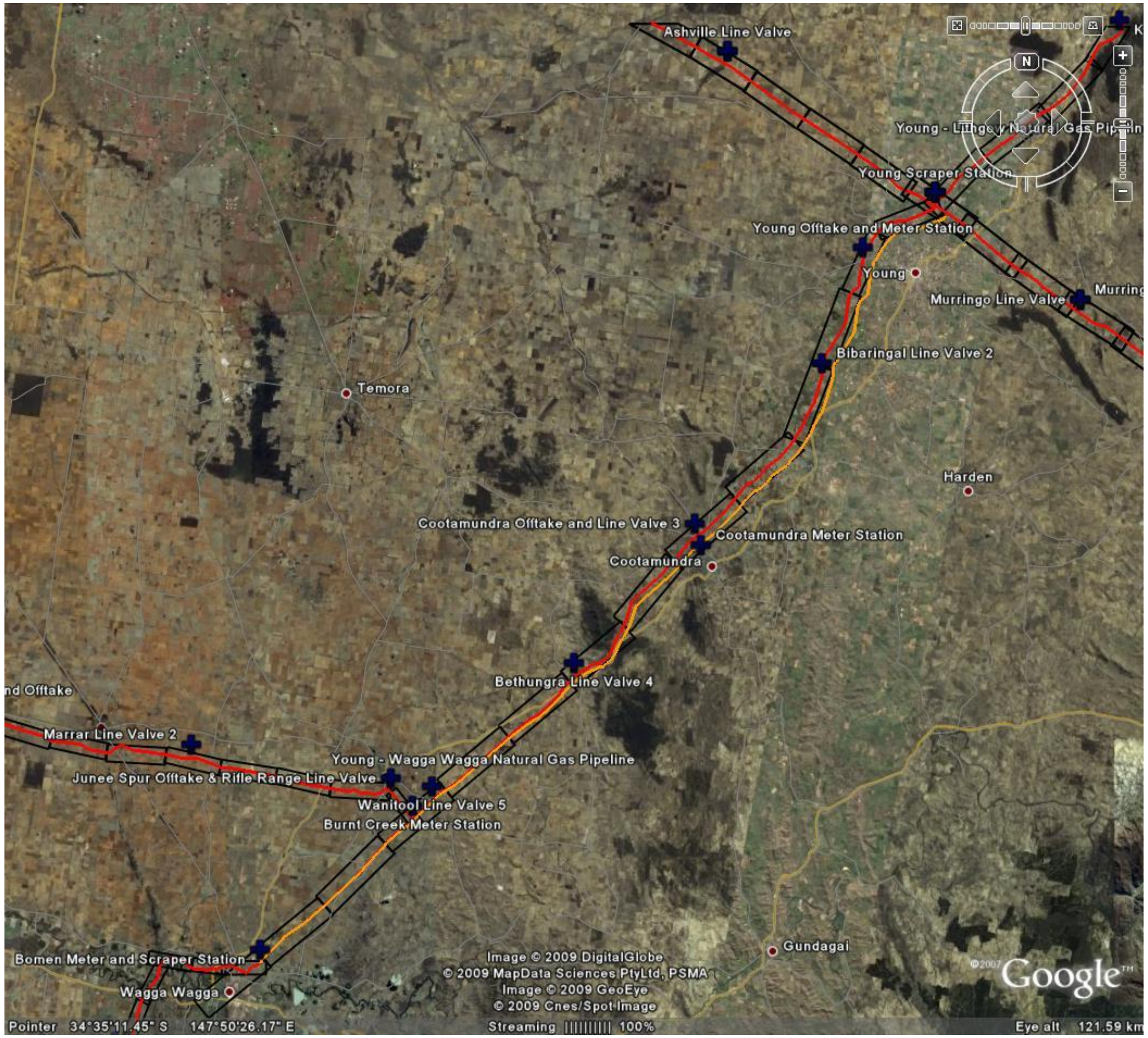
The pipeline route traverses the Young, Cootamundra, Harden and Junee Shire Council areas in NSW. The area is predominantly used for grazing and cropping.

The pipeline will be entirely located inside the existing easement. The pipeline construction will require a working width slightly wider than the easement.

The relevant Local Environmental Plans and Regional Planning Instruments associated with the proposed pipeline route include the:

- Young Local Environmental Plan
- Cootamundra Shire Local Environmental Plan
- Harden Shire Local Environmental Plan
- Junee Shire Local Environmental Plan
- Wagga Wagga Local Environmental Plan
- Western New South Wales Regional Environmental Plan.

Figure 1 – Corridor for Pipeline Route



2.2 Design and Operation

The pipeline would be a buried class 600, steel pipe with a proposed maximum allowable operating pressure 10.2MPa.

The pipeline would be designed and built to AS2885 (Reference 5), *Pipelines Gas and Liquid Petroleum*.

The assumptions as to the technical details made for the pipeline in this PHA are given in Table 1 below, and further in the listing below the table.

Table 1 – Summary of Preliminary Assumptions Made in the PHA for the Pipeline Design

Item	**Pipeline Design**
Percent operational	All data used in the present risk assessment are for a pipeline pressurised 100% of the time.
Pipe Diameter	450 mm NB (nominal bore)
Pipe Length	130 kilometre
Maximum Allowable Operating Pressure (MAOP)	10.2 MPa, ANSI Class 600
Actual operating pressure	8.5 MPa
Temperature	25^{o}C
Class Location to AS2885	R1 (broadly rural) with 40 hectare blocks with some R2 (rural residential) as per AS2885 definitions.
Pipe Thickness	6.8 mm to 9.7mm
Depth of Cover	At least 900mm (or 450mm in rock if encountered)
Number of flanges	5 flange joints per mainline valve (MLV) with four MLVs along the pipeline.
Features	Pressure indication and Actuator Line Break (ALB) on each MLV.
Design Standard	As per AS2885 requirements

The ALB feature is associated with emergency isolation of the pipeline. All MLVs are fitted with ALBs. The ALB allows a drop in line pressure to be quickly ascertained.

For the purposes of the present risk assessment, closure of the MLV using ALB system in case of a major leak is assumed to be able to be triggered automatically by a sudden drop of pressure or manually by the operator in the control room. The SCADA system, which includes telemetered data from the valve stations instrumentation, would give the operator sufficient details upon which to make a decision to close the valve.

2.3 OPERATING HOURS AND STAFFING

The gas pipeline would be pressurised 100% of the time.

2.4 SECURITY

The gas pipeline would be buried. MLVs along the pipeline would be surrounded by security fence. Any buildings associated with MLVs would have intruder detection fitted on the doors which would be telemetered to the Young Control Room.

3 STUDY METHODOLOGY

3.1 INTRODUCTION

The methodology for the PHA is well established in Australia. The assessment has been carried as per the Department of Planning's HIPAP No 6 (*Guidelines for Hazard Analysis*, Reference 3) and HIPAP No 4 (*Risk Criteria for Land Use Planning*, Reference 3). These documents describe the methodology and the criteria to be used in PHAs, as required by the Department of Planning for major "potentially hazardous" development.

There are five stages in risk assessment (as per Reference 3):

Stage 1. Hazard Identification: The hazard identification includes a review of potential hazards associated with the pipeline. The hazard identification includes a comprehensive identification of possible causes of potential incidents and their consequences to public safety and the environment, as well as an outline of the proposed operational and organisational safety controls required to mitigate the likelihood of the hazardous events from occurring.

The tasks involved in the hazard identification of the proposed gas pipeline included a review of all relevant data and information to highlight specific areas of potential concern and points of discussion, including drafting up of preliminary hazard identification word diagram. The review takes into account both random and systematic errors, and gives emphasis not only to technical requirements, but also to the management of the safety activities and the competence of people involved in them. This step was undertaken as a desktop exercise only. The hazard identification word diagram is presented in Section 4.3.

Stage 2. Consequence and Effect Analysis: The consequences of identified hazards are assessed using current techniques for risk assessment. Well established and recognised correlations between exposure and effect on people are used to calculate impacts.

Stage 3. Frequency Analysis: For incidents with significant effects, whether on people, property or the biophysical environment, the incident frequency are estimated, based on historical data. A probabilistic approach to the failure of pipes is used to develop frequency data on potentially hazardous incidents.

Stage 4. Quantitative Risk Analysis: The combination of the probability of an outcome, such as injury or death, combined with the frequency of an event gives the risk from the event. In order to assess the merit of the proposal, it is necessary to calculate the risk at a number of locations so that the overall impact can be assessed. The risk for each incident is calculated according to:

Risk = Consequence x Frequency

Total risk is obtained by adding together the results from the risk calculations for each incident, i.e. the total risk is the sum of the risk calculated for each scenario.

The results of the risk analysis are presented in four forms:

- Individual Fatality Risk, i.e. the likelihood (or frequency) of fatality to notional individuals at locations around the site, as a result of any of the postulated fire and explosion events. The units for individual risk are probability (of fatality) per million per year. Typically, the result of individual risk calculation for a gas pipeline is shown in the form of a risk transect.

- Injury risk, i.e. the likelihood of injury to individuals at locations around the pipeline as a result of the same scenarios used to calculate individual fatality risk.

- Propagation risk, i.e. the likelihood that an incident at the pipeline propagates to industrial areas in the vicinity.

- Societal risk takes into account the number of people exposed to risk. Whereas individual risk is concerned with the risk of fatality to a (notional) person at a particular location (person 'most at risk', i.e. outdoors), societal risk considers the likelihood of actual fatalities among any of the people exposed to the hazard. Societal risk are presented as so called *f-N curves*, showing the frequency of events (f) resulting in N or more fatalities. To determine societal risk, it is necessary to quantify the population within each zone of risk surrounding a facility. By combining the risk results with the population data, a societal risk curve can be produced.

The risk results are then assessed against the guidelines adopted by the Department of Planning (Reference 4).

Stage 5. Risk reduction: Where possible, risk reduction measures are identified throughout the course of the study in the form of recommendations.

3.2 RISK CRITERIA

Having determined the risk from a development, it must then be compared with accepted criteria in order to assess whether or not the risk level is tolerable. If not, specific measures must be taken to reduce the risk to a tolerable level. Where this is not possible, it must then be concluded that the proposed development is not compatible with the existing surrounding land uses.

3.2.1 Individual Risk Criteria

The individual fatality risk is the probability of fatality to a person or a facility at a particular point. It is usually expressed as chances per million per year (pmpy). It is assumed that the person would be at the point of interest 24 hours per day for the whole year. By convention in NSW, no mitigation is allowed, i.e. any possible evasive action that could be taken by a person exposed to a hazardous event, e.g. by walking out of a toxic cloud or a heat radiation. The assessment of fatality, incident propagation and injury risk should include all components contributing to the total risk, i.e. fire and explosion.

The Department of Planning uses a set of guidelines on acceptable levels or individual risk which are in line with the criteria used elsewhere in the world. These guidelines are published in the Hazardous Industry Planning Advisory Paper No. 4: *Risk Criteria for Land Use Safety Planning* (Reference 4). The criteria for maximum tolerable individual risk from a new development are shown in Table 2 below. The criteria have been chosen so as not to impose a risk which is significant when compared to the background risk we are already exposed to. This table shows the criteria for individual risk of fatality, injury and propagation of an incident.

Table 2 – Criteria for Tolerable Individual Risk from a New Development

Land Use		Maximum Tolerable Risk (pmpy[1])
Fatality risk criteria:		
Hospitals, Schools, etc		0.5
Residential areas, hotels, etc		**1**
Offices, retail centres, etc		5
Open space, recreation areas etc		10
Neighbouring industrial areas		50
Overpressure for Safety Distances:		
Property damage and accident propagation	14 kPa	50 Adjacent potentially hazardous installation, land zoned to accommodate such installations, or nearest public building
Injury risk levels	7 kPa	50 At residential areas
Maximum Heat Radiation:		
Injury risk levels	4.7 kW/m^2	50 At residential areas
Property damage and accident propagation	23 kW/m^2	50 Adjacent potentially hazardous installation or land zoned to accommodate such installations

In order to put these risks into perspective, published information on the level of risk to which each of us may be exposed from day to day due to a variety of activities has been shown in Table 3 below. Some of these are voluntary, for which we may accept a higher level of risk due to a perceived benefit, while some are involuntary. Generally, we tend to expect a lower level of imposed or involuntary risk especially if we do not perceive a direct benefit.

Table 3 – Risk to Individuals

Activity / Type of Risk	Published levels of risk (pmpy[1])
VOLUNTARY RISKS (AVERAGED OVER ACTIVE PARTICIPANTS)	
Smoking	5,000
Drinking alcohol	380
Swimming	50
Playing rugby	30
Travelling by car	145
Travelling by train	30
Travelling by aeroplane	10
INVOLUNTARY RISKS (AVERAGED OVER WHOLE POPULATION)	
Cancer	1,800
Accidents at home	110
Struck by motor vehicle	35
Fires	10
Electrocution (non industrial)	3
Falling objects	3
Storms and floods	0.2
Lightning strikes	0.1

3.2.2 Societal Risk Criteria

Societal risk is concerned with the potential for an incident to coincide in time and space with a human population. Societal risk takes into account the potential for an incident to cause multiple fatalities. Therefore, two components are relevant, namely:

- the number of people exposed in an incident; and
- the frequency of exposing a particular number of people.

In the absence of published criteria in HIPAP 4 (Reference 4), the criteria in the 1996 regional study of Port Botany by the Department of Planning[2] have been used for indicative purposes, as presented in Table 4 below.

[1] pmpy = per million per year

[2] then the Department of Urban Affairs and Planning

Table 4 - Criteria for Tolerable Societal Risk

Number of fatalities (N) [-]	Acceptable limit of N or more fatalities per year	Unacceptable limit of N or more fatalities per year
1	3×10^{-5}	3×10^{-3}
10	1×10^{-6}	1×10^{-4}
100	3×10^{-8}	3×10^{-6}
1000	1×10^{-9}	1×10^{-7}

The societal risk criteria specify levels of societal risk which must not be exceeded by a particular activity. The same criteria are currently used for existing and new developments. Two societal risk criteria are used, defining acceptable and unacceptable levels of risk due to a particular activity. The criteria in Table 4 above are represented on the societal risk (f-N) curve as two parallel lines. Three zones are thus defined:

- Above the unacceptable/intolerable limit the societal risk is not acceptable whatever the perceived benefits of the development.
- The area between the unacceptable and the acceptable limits is known as the ALARP (as low as reasonably possible) region. Risk reduction may be required for potential incidents in this area.
- Below the acceptable limit, the societal risk level is negligible regardless of the perceived value of the activity.

3.3 Risk Calculations

In order to determine the cumulative risk from all identified hazards, a series of spreadsheets were used. The computer software tool ISORIS from the Warren Centre for Advanced Engineering (Ref 6) was also used as a back-up to control the output from the spreadsheet calculations. First, base information on the incidents, including type, location, processing conditions and frequency were entered into a spreadsheet. This spreadsheet calculates the leak rate for each incident using standard orifice flow equations for vapour or liquid, as appropriate. The spreadsheet also determines the base consequences for each incident in terms of total radiant heat release rate and TNT equivalent. See Appendix 1 for a printout of the incident listing from the spreadsheet.

3.4 Safety Management Systems

3.4.1 Safety Management in General

In quantitative risk assessments, incidents are assessed in terms of consequences and frequencies, leading to a measure of risk. Where possible, frequency data used in the analysis comes from actual experience, e.g. near misses or actual incidents. However, in many cases, the frequencies used are generic, based on historical information from a variety of facilities and processes with different standards and designs.

As with any sample of a population, the quality of the management systems (referred to here as "safety software") in place in these historical facilities will vary. Some will have little or no software, such as work permits, planned maintenance and modification procedures, in place. Others will have exemplary systems covering all issues of safe operation. Clearly, the generic frequencies derived from a wide sample represent the failure rates of an "average facility". This hypothetical average facility would have average hardware and software safety systems in place.

If an installation which has significantly below average safety software in place is assessed using the generic frequencies, it is likely that the risk will be underestimated. Conversely, if a facility is significantly above average, the risk will probably be overestimated. However, it is extremely difficult to quantify the effect of software on facility safety. Incorporating safety software as a means of mitigation has the potential to significantly reduce the frequency of incidents and also their consequences if rigorously developed and applied. The risk could also be underestimated if safety software is factored into the risk assessment but is not properly implemented in practice. Practical issues also arise when attempting to factor safety software into the risk assessment – applying a factor to the overall risk results could easily be misleading as in practice it may be the failure of one aspect of the safety software that causes the accident, while all other aspects are managed exemplarily.

In this study it is assumed that the generic failure frequencies used apply to installations, which have safety software corresponding to accepted industry practice and that this site has similar management practices and systems. This assumption it is believed, will be conservative in that it will overstate the risk from well managed installations.

3.4.2 Audits of Safety Management System

As per the requirements by the Department of Water and Energy, yearly audits are carried out of the Safety and Operating Plan for then pipelines under the responsibility of the APA Group. This new pipeline is no different to existing pipelines.

4 HAZARD IDENTIFICATION

4.1 HAZARDOUS MATERIALS

The gas may be sourced either from the Moomba in South Australia or from Victoria. The composition of natural gas is shown in Table 5. Natural gas is composed predominantly of methane gas.

Table 5 – Composition of Natural Gas

Component	South Australia Mole %	Victoria Mole %
methane	95.73	88.9
ethane	2.02	6.79
propane	0.47	0.47
n-butane	0	0.03
n-pentane	0	0
i-pentane	0	0
hexane	0	0
nitrogen	1.23	0.56
carbon dioxide	0.91	3.17
TOTAL	**100**	**100**

The properties of methane gas are presented in Table 6 below.

Table 6 - Properties of Methane Gas

Molecular weight (g/mol)	17
Relative density of the gas (atmospheric temp. and pressure)	0.6
Heat of combustion (MJ/kg)	50
Flammable range (vol. % in air)	5 to 15
Ratio of specific heats (Cp + Cv)	1.31
Flash point	-218^{o}C

4.2 SUMMARY OF HAZARDS IDENTIFIED

A total of 10 potentially hazardous scenarios were identified for the gas pipeline, as listed in Table 7 below. The *Hazard Identification Word Diagram* in Table 8 details these hazards, their potential initiating events as well as their proposed controls.

Table 7 - Summary of Identified Hazards

Number	Hazardous Event Potential
1	Mechanical damage to the pipeline
2	Corrosion
3	Nearby explosion at neighbouring natural gas pipeline
4	Pressure excursion
5	Spontaneous loss of integrity of pipe (rupture)
6	Erosion
7	Land subsidence
8	Aircraft, train or heavy vehicle crash
9	Damage to pipeline through terrorism / vandalism
10	Neighbouring bush fire

A leak of flammable natural gas would generally only have the potential to cause injury or damage if there was ignition, which resulted in a fire or (in case of confinement) an explosion incident. The factors involved are:

- The pipeline must fail in a particular mode causing a release. There are several possible causes of failure, with the main ones being corrosion and damage by external agencies.

- The released material must come into contact with a source of ignition. In some cases this may be heat or sparks generated by mechanical damage while in others, the possible ignition source could include non-flame proof equipment, vehicles, or flames some distance from the release.

- Depending on the release conditions, including the mass of flammable material involved and how rapidly it ignited, the results may be a localised fire (for example a jet fire), a flash fire or an explosion of the vapour cloud formed through the release.

- Finally, for there to be a risk, people must be present within the harmful range (consequence distance) of the fire or explosion. How close the people are will determine whether any injuries or fatalities result.

Environmental damage from gas fire incidents are generally associated with a failure to control fire water used.

Natural gas is a buoyant, flammable gas which is lighter than air (relative density of 0.6). On release into the open the non-ignited gas tends to disperse rapidly at altitude. Ignition at the point of release is possible, in which case the gas would burn as a jet (or torch) flame. On release in an enclosed area an explosion or a flash fire is possible.

The gas is non-toxic, posing only an asphyxiation hazard. Due to its buoyancy, any release of credible proportions from operations of this scale, in the open, would not present an asphyxiation hazard. With standard confined space entry procedures and appropriate security arrangements to prevent unauthorised access to any of the facilities the risk associated with asphyxiation from natural gas should be minimal.

Locally, the pressure of the compressed gas may be hazardous in case of an uncontrolled release. These hazards, while of importance for people working with the gas pipeline, do not have implications beyond the immediate location of the release unless the released gas is ignited. Therefore, the risk associated with of non-ignited compressed gas does not form part of the scope of the present risk assessment. This potential risk would, however, need to be closely managed through job safety analysis (JSA) and/or other risk assessment practices used by management and maintenance workers (in accordance with NSW Occupational Health and Safety Act and its associated legislation (Reference 7)).

4.3 HAZARD IDENTIFICATION WORD DIAGRAM

The Hazard Identification Word Diagram, included in Table 8 below, provides a summary of the hazardous incidents identified for the proposed pipeline and their associated mitigating features.

While the table below provides an overview of the preventative and protective features proposed and recommended for the site, these safeguards are further detailed in Section 5.2.

Table 8 – Hazard Identification Word Diagram

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
SECTION OF FACILITY: Natural Gas pipeline			
1. Mechanical impact on the pipeline causes leak of natural gas from the pipeline.	3rd party involvement e.g. digging or trenching, or other earth work. 1st party involvement. Non through wall damage, i.e. part wall or delayed failure damage.	Massive release of natural gas (NG). If ignition, then possibility of flash or jet fire. Physical explosion from the pressure of the pipeline creates projectiles (earth, sand, stones). Injury and property damage.	- Buried pipeline to AS2885 requirements. - Rural zoning. Mainly large farming developments with some smaller lots. - Signage along pipe route, including Dial-Before-You-Dig information. Drawings available to Dial-Before-You-Dig. Pipeline route within easement. - Resistance of pipelines to penetration through use of pipe thickness and adequate design factor as per AS2885. - MLV stations will be clearly marked and surrounded by security fencing. All pipes and valves are of robust design and construction. - Automatic shut down through automatic line break detection and valve closure if large hole in pipe. Manual shut down by Network Controller in Control Centre in Young if pressure drop. - NG disperses readily upwards, minimising chances of ignition. Explosion not credible in unconfined situation.

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
2. Corrosion leads to leak of natural gas from the gas pipeline.	Damage of pipeline coating due to excavation inspection damage leads to corrosion. Construction damage or coating flaw or faulty materials	Release of gas. If ignition, a jet fire is possible. Injury and property damage.	- Cathodic protection for external corrosion. Internal corrosion virtually absent with clean hydrocarbon. - Coating on external surfaces of pipelines. - Routine inspection of pipeline (including regular patrol and pigging). Visual and sound indications if leak. - Pipeline to be constructed to facilitate internal (pigging) inspection (minimise dips). - Cathodic protection. Inductive current and fault levels to be managed as per AS2885 and AS4853 and other specific standards requirements for pipelines in the vicinity of high voltage transmission lines. - NG disperses readily upwards, minimising chances of ignition. - Gas is odourised, allowing for detection and subsequent response in case of a small leak before it can develop into a larger leak. - QA during production and installation, construction DCVG.

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
3. Nearby explosion at neighbouring natural gas pipeline or tie-offs.	Incident (wear and tear, mechanical impact, lightning strike etc. etc.) at the parallel natural gas pipeline.	Possible damage to gas pipeline with release of natural gas (NG). If ignition, then possibility of flash or jet fire. Injury and property damage.	- Internal risk management procedures / systems by gas pipeline operator. - Pipeline integrity plan (incl. protection, pigging etc. to monitor integrity of pipeline and coating inspection). - 24 hour monitoring of natural gas pipelines. - Dial-Before-You-Dig and signposting. - NG disperses readily upwards, minimising chances of ignition. Explosion not credible in unconfined situation. - Buried pipelines. - Thickness and grade of pipelines. - The pipelines are separated by at least 7 meters from each other. Further, the existing pipeline is buried at 750mm depth while the new pipeline will be buried at 900mm depth. It is unlikely that an explosion in one pipeline would expose the other pipeline and in which case research has shown that the adjacent pipeline cannot be damaged by the radiative heating (Ref 8).
4. Pressure excursion leads to failure of the pipeline.	Operational error upstream or downstream facility.	Overpressuring the gas pipeline causing failures, leaks and release of natural gas. If ignition, then possibility of fire. Injury and property damage.	- Pipelines constructed and hydrotested to AS2885 requirements. - The gas pipeline can operate against closed head (i.e. the main valve at the entrance to the site may be closed). - Continuous observation of pressure of pipeline from Control Centre at Young (NSW). Lack of control for several hours required before pressure could exceed critical levels. - High-pressure trip and automatic line-break protection isolating flow of natural gas. - Mechanical over pressure protection & controls at compressor stations.

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
5. Spontaneous loss of integrity of pipe	Construction defect or operational error (repeated).	Massive release of natural gas. If ignition, then possibility of flash or jet fire. Injury and property damage.	- X-raying of welds as required. - 100% UT of ERW seam weld. - Cathodic protection. - Design for pipelines to limit crack propagation to about two pipe lengths. - Pipeline complying with AS2885 and other specific standards. - Pipeline has integrity management plan. - Pipeline subject to CP monitoring, ILI and DCVG at regular intervals.
6. Erosion results in damage to piping and equipment.	Flooding	Potential for flood waters to wash away soil cover. May cause pipeline to be exposed. Possibility of damage to coating and subsequent corrosion issues. If not corrected may eventually lead to failure of pipeline.	- Control of erosion through regular and periodic patrols and inspections (aerial patrols, ground patrols after heavy rain/flooding, landowner liaison). - Repair to soil cover if erosion.
7. Land subsidence results in pipeline damage.	Mining activities in area or earthquake creates.	Failure of pipeline resulting in potential for rupture or massive leak. Release of natural gas. If ignition, then possibility of flash or jet fire. Injury and property damage.	- Site is not affected by mine subsidence. - Pipe to be designed to AS2885 requirements in terms of strength of material and design.

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
8. Aircraft, train or heavy vehicle crash result in damage to pipeline resulting in hazardous releases.	Aircraft crash. Heavy vehicle crash.	Potential damage to pipeline resulting in hazardous releases, fire / explosion.	- Buried pipeline unlikely to be susceptible to aircraft, train or heavy vehicle crash. - MLVs will be located safely away from potential road or train crash locations. - MLVs will be surrounded by security fencing which will assist in containing a vehicle. - Automatic line break isolation valves minimises amount of gas released if gas pipe is damaged. Possibility of remote activation of isolation valves by Young Controller. - Aviation safety standards to apply.
9. Damage to pipeline through terrorism / vandalism.	Malicious damage.	Massive release of natural gas. If ignition, then possibility of flash or jet fire.	- Buried pipeline. - MLVs surrounded by security fence. - Any building doors will be fitted with intruder alarms.
10. Neighbouring fire.	Bush / brush fire.	Possible heat radiation at pipeline. If damage to pipe and equipment then possibility of release of hazardous material and fire risk.	- Control of vegetation in easement. - Buried pipeline is unlikely to be affected by heat radiation. - Above ground valves are fire safe.

5 POTENTIAL HAZARDOUS INCIDENTS AND THEIR CONTROL

Safety management systems allow the risk from potentially hazardous installations to be minimised by a combination of hardware and software factors. It is essential to ensure that hardware systems and software procedures used are reliable and of the highest standard in order to assure safe operation of the installations.

Safety features of particular interest to the present project are detailed below.

5.1 HARDWARE SAFEGUARDS, GENERAL

Hardware safeguards include such factors as the layout and design of the installations and equipment, and their compliance with the relevant codes, technical standards, and industry best practice.

All systems handling dangerous goods will need to comply with the following Acts, Regulations and Codes in their latest edition. Below are listed some of the most relevant:

- AS 2885 for high pressure pipeline;
- AS 4041 - 2006 Pressure Piping
- AS 1074 - Steel Tubes & Tubulars;
- AS 1836 - Welded Steel Tubes for Pressure Purposes;
- AS 1210 - Unfired Pressure Vessel Code;
- AS 2919, AS 3765.1 or AS 3765.2 - Protective clothing; and
- AS1345 - Identification of the Contents of Pipes, Conduits and Ducts.

Pipe fittings, supports, and all other ancillary items will also need to comply with appropriate Australian Standards whether referenced above or not.

5.2 HARDWARE SAFEGUARDS, SPECIFIC

Leak of Natural Gas from the Gas pipeline

Australian Standard AS2885 (Reference 5) sets the minimum standard for high-pressure pipelines in Australia. This code gives detailed requirements for the design, construction and operation of gas and liquid petroleum pipelines. It has gained wide acceptance in the Australian pipeline industry. AS2885 also sets the classification of locations which guide the designer in the assessment of potential risks to the integrity of the pipeline, the public, operating and maintenance personnel as well as property and the environment.

AS2885 accommodates changes in population density by its location classification scheme concept. The classification scheme allows broad division of the pipeline design requirements according to whether the pipeline is to be installed in rural, semi-rural, suburban or urban areas. For each of these classifications the minimum design requirements in terms of wall thickness and depth of cover are specified.

The pipeline will run in areas classified as *Class R1 - Broadly Rural* for most part of the length of the run (as per the AS2885.1 so called *primary location classes*).. Some areas are or are expected in the near future to be classified as *R2 – Rural Residential.*

The so called *secondary location class* will be defined during the AS2885.1 risk assessment (not part of the scope for this assessment).

Allowance is made in AS2885 for the improvement in safety performance possible through the use of thick walled pipe with a low design factor. AS2885 also mandates that the integrity of the pipeline be maintained throughout the pipeline operating life.

The proposed safeguards for the pipeline are detailed below. The safeguards have been grouped together under the potential hazardous events associated with the pipeline (as defined in the Hazard Identification Word Diagram in Table 8 above). These incidents have been collated by a group of six European gas transmission companies, based on pipeline incidents relevant to pipeline design and operation in Europe (Reference 9). The data was collated covers a length-time of more than 970,000 km-yrs. Experience within Australia (EAPL, AGL etc.) indicates that the learning from these incidents can be directly translated to the Australian conditions.

- <u>External interference</u> is historically by far the main cause of loss of gas and accounts for about 40% of all incidents leading to a release of gas.

  For the pipeline under study, this potential is minimised in the present development through the fact that AS2885 requires the pipeline to be buried to 750mm (or 450mm in rock). Note that the new pipeline will be buried at 900mm depth while the existing pipeline is buried at 750mm depth.

  Further, signage will be provided along the pipe route, including Dial Before You Dig information.

  The pipeline presents a certain resistance to penetration through use of appropriate pipe thickness (6.8 to 9.7 mm) and adequate design factor as per AS2885.

  In the very unlikely event of damage to the pipeline, which causes a major leak, a sudden pressure drop would result in alarm initiation in the Control Room in Young allowing automatic or remote activated closing of the mainline valves of either side of the leak thus minimising the amount of gas that could be released into the atmosphere.

  Note also that natural gas disperses readily upwards, reducing chances of ignition. Explosion is not credible in an unconfined situation.

Valve stations are potentially more at risk of a loss of containment due to the presence of small bore attached piping, which is required for pressure tappings. These small-bore pipes are historically known to be more vulnerable to failure.

The major mitigating features at the valve station are firstly the fact that the valve site is conspicuous and therefore reduces significantly the accidental mechanical interference for which a buried pipe is vulnerable. Secondly, the instrumentation off-take line would most likely be installed with a restriction orifice, which would severely restrict the potential outflow caused by damage to the instrumentation. Thirdly, the layout and siting of the valve stations will be subjected to a rigorous Hazard and Operability Study (HAZOP), which will result in improvements to the design to limit their hazard potential.

- *Construction defect / material failure:* This is a known cause of failure of pipelines and accounts for approximately 15% of all incidents.

  For the pipeline under study, the Australian Pipelines Code (AS2885) would be adopted as a minimum requirement for the design and construction. The pipeline would be constructed of ERW piping of 457 mm diameter (NB). The pipe seam weld will be 100% examined ultrasonically and the circumferential butt welds will be 100% radiographed.

  The pipeline will also be also subject to 1.25x hydrotest minimum.

  Further, inherent design safeguards will be provided by ensuring that the piping is manufactured from high tensile steel of known quality, and subject to quality control inspections to ensure high standard.

- *Corrosion:* Corrosion accounts for approximately 15% of all historical incidents. The result of the corrosion is mainly pinholes and cracks.

  The pipeline under study will be coated with fusion bond epoxy (FBE) and be cathodically protected. Regular pipeline patrols will be undertaken. A corrosion protection team will survey the pipeline each year to identify any areas where cathodic protection has become ineffective. Potential corrosion leaks will be detected by in-line inspection and protected against by cathodic protection systems. Gas is odourised, improving likelihood of detection and response to a pinhole leak before it develops into a larger leak. A number of corrosion detection techniques, including ILI, DCVG & CP surveys.

  Note that internal corrosion virtually absent with clean hydrocarbon.

  In the unlikely event of a corrosion leak, it can be detected through the fact that the vegetation is browning off around ground leak (lack of oxygen) and that a small hole will be sonic – possible detection through high pitched sound.

- *Hot tap by error*: Hot-tapping or hot tapping by error (i.e. hot-tapping the wrong pipeline) is possible and has occurred in the past in the world (approximately 15% of all incidents).

For the pipeline under study, this possibility is prevented through the fact that hot tapping is a highly specialised field in Australia and only very few, highly trained, groups can perform this task.

Further, the neighbouring pipeline is much smaller diameter (12 inch (or 305mm) compared with the 18 inch (or 457mm) of the new pipeline) making it even more unlikely that a specialised crew would mistake one pipeline for the other.

- *Ground movement*. Earthquakes account for about 5% of all historical incidents could potentially cause a failure of a pipeline due to the high forces involved. Earthquakes are not particularly common in this area and steel pipelines have been shown to be very resistant to failure in these circumstances.

- *Flooding:* A geotechnical study was completed for the existing pipeline. The information in this study will be used also for the new pipeline. Further, the pipeline route will be subject to routine inspections and, if required, to maintenance and repair of cover as required (e.g. if erosion is identified).

- *Land subsidence or mining activity*: Site is not affected by mine subsidence. The information from the geo technical study performed for the existing pipeline will be used also for this new pipeline.

- *Aircraft, train or truck crash:* The gas pipeline, being buried, is unlikely to be damaged in case of an aircraft, train or truck crash. There will be no above ground facilities adjacent to train crossings. Few facilities are closer to road. All will be fenced and appropriate barrier will be installed. The preventative and protective features of this site makes the risk of such crashes negligible. This scenario, while theoretically possible, does not appear credible for the present development at this stage of the development.

- *Damage to pipe through terrorism / vandalism / unlawful entry to site / sabotage:* The pipe will be buried for the most part. Further, where above ground structures (i.e. at the valve stations), the site would be fenced with access control.

- *Bush / grass fire:* A bush fire is highly unlikely to affect a buried gas pipeline. The bush fires that have burned over for example the main Moomba to Wilton natural gas pipeline have not damaged the gas pipeline or any of its above ground facilities. A bush /grass fire asset protection zone will be decided in consultation with rural fire services. Clearance zone will be provided at the off-take compound with control of vegetation. The risk of damage to the pipeline from a bush fire or grass fire to the pipeline or above ground facilities is very low if not negligible.

- *Other / unknown causes*. Rare or unknown causes form about 10% of all historical incidents. They are mainly of the pinhole crack category. The following potential incidents have been canvassed for the present development:

  - *Valve gland nut leak or flange leak or maintenance failure at valves and scraper stations*. The pipeline is designed with the minimum number of flanges and welded connections are used wherever possible. Periodic surveillance will be carried out of the pipe and valve points. All valves will be exercised periodically. All above ground valve sites are fenced and secured to exclude the public. Icing up at leak point improves detection. Further, the gas is odourised which would improve the likelihood of a small leak and subsequent response, before it develops into a larger leak.

Nearby explosion. The potential for a domino incident due to an incident at the gas mainline was canvassed. The preventative features for this type of incident include internal risk management procedures / systems in use by the APA Group managing both pipelines; the pipeline integrity plans (incl. systems in use to monitor integrity of pipeline and coating inspection); their thickness and grade; and the 24 hour monitoring of natural gas and pipeline. Further, natural gas disperses readily upwards, minimising chances of ignition and making explosion not credible in unconfined situation; and the fact that all pipelines are buried at a depth of at least 750mm (450mm in rock).

Further, the Pipeline Research Council International (PRCI) commissioned the Battelle Memorial Institute to assess available validated models to assist gas companies in determining the minimum spacing between adjacent pipelines to help ensure safe and reliable operation in the event of a rupture. The result of this work was published 2nd April 2002 and was reviewed by Mr Bill Holmes and reported in Ref 8. The research showed that for the rupture of a pipeline to cause damage to an adjacent pipeline the sequence of events expected is:

1. Loss of integrity of the initiating pipeline leads to formation of a crater.

2. The escaping gas is ignited and forms a sustained flame.

3. The flame heats the uncovered adjacent pipeline.

Further, it showed that if the crater does not expose the adjacent pipeline, then it cannot be damaged by radiative heating.

The report by Battelle discusses the development and application of a pair of models that may be used to assess appropriate pipeline spacing. The first can be termed the “crater” model and the second the “radiative” model.

The “crater” model estimates the size of the crater produced by the initial rupture. In the report the crater width versus depth of cover were estimated. For the 900mm cover proposed for the Young Wagga Loop the crater diameter is estimated to be about 7m maybe as big as 9m (4.5m radius). From observations of such craters they are reasonably symmetric about the pipeline. Therefore, there should be at least 2m of soil remaining to protect the adjacent pipeline from radiative heating. In such a case there is no need for the second “radiative” model and the adjacent pipeline is considered safe from such an event.

- *Operational error causes pressure excursion leading to failure of the pipeline*. The pipeline is to be hydrotested at a minimum of 1.38 times the MAOP (maximum allowable operating pressure) and can operate against closed head.

The potential for a gas release is extremely small. The proposed development does not increase in any significant way the risk of a bush fire in the forested areas through which the pipeline travels. As a consequence, local fire brigades will not have any significant demand on their resources.

5.3 SOFTWARE SAFEGUARDS

The APA Group has a commitment to Occupational Health and Safety (OH&S) and has numerous policies and procedures to achieve a safe workplace. Written safety procedures are established and reviewed periodically.

The pipeline will need to comply with all codes and statutory requirements. In addition, special precautions are observed as required by the site conditions, in particular, standards and requirement on the handling of pressurised, flammable gases. All personnel required to work on gas pipelines are trained in their safe use and handling, and are provided with the relevant safety equipment.

The APA Group would have the responsibility of managing the gas pipeline and ensuring that experienced personnel are appropriately trained.

A defined Maintenance Management system, setting out requirements for tests, inspections and repairs.

A Permit to Work system (including Hot Work Permit) and Control of Modification systems is in use to control work on pipelines and to control pipeline and structure from substandard and potentially hazardous modifications.

Injury and incident management is proceduralised and people are trained in how to report incidents. There is an established incident reporting and response, providing 24 hour coverage.

Protective Systems would be tested to ensure they are in a good state of repair and function reliably when required to do so. This would include scheduled testing of trips, alarms, gas detectors, relief devices and fire protection systems.

6 CONSEQUENCE ANALYSIS

6.1 EVALUATION TECHNIQUES

As natural gas is non toxic, the evaluation of consequences requires only the determination of fire radiation and explosion overpressure. For both fires and explosions, it is necessary to determine the leak rate and duration for each incident. Radiation effects are then determined using the point source method while overpressure effects are determined using the TNT equivalent model in Reference 10.

The explanation of the nomenclature used in the equations below is listed in Table 11 at the end of this Chapter.

6.1.1 Leak Rates

For gas or vapour flows (as for natural gas), the appropriate equation is:

$$\dot{m} = 0.8AP\sqrt{\frac{M\gamma}{zRT}(\sqrt{\frac{2}{\lambda+1}}^{\frac{\gamma+1}{\gamma-1}}}$$

Note that this applies to the condition known as critical or choked flow, which applies when the internal pressure is more than double the atmospheric pressure (approximately).

6.1.2 Duration

The duration of a leak would depend on the hardware systems available to isolate the source of the leak, the nature of the leak itself and the training, procedures and management of the facility. While in some cases it may be argued that a leak would be isolated within one minute, the same leak under different circumstances may take longer to isolate.

The approach used in this study for failure scenarios identified is to assume that once the leak or rupture is established it will be continuous. This is a conservative assumption, particularly for major and rupture leaks which would quickly depressure and burn with less intensity.

The mass of flammable gas contained in a cloud which could flash or explode is set at the total amount which would leak out in 3 minutes. This is based on the assumption that a cloud travelling in the direction of the wind would either encounter a source of ignition within this time[3] or would disperse to concentrations below the Lower Flammable Limit (LFL).

6.1.3 Radiation Effects - The Point Source Method

Radiation effects are evaluated using the point source method, which assumes that a fire is a point source of heat, located at the centre of the flame, and radiating a proportion of the heat of combustion. The radiation intensity at any distance is then determined according to the inverse square law, making allowance for the attenuating effect of atmospheric water vapour over significant distances (e.g. 100m or more).

$$I = \frac{Qf\tau}{4\Pi r^2}$$

The rate of heat release, Q, is given by:

$$Q = \dot{m}H_C$$

6.1.4 Explosion Effects - The TNT Model

For explosions, the amount of gas or vapour resulting from the leak is important. For gases this is the total quantity leaking out for the duration of interest.

The equivalent mass of TNT is then determined using the following relationship:

$$m_{TNT} = \frac{\alpha H_C m_V}{4600}$$

The overpressure effect from the vapour cloud is determined using a correlation developed for TNT, which relates the scaled distance (a function of actual distance and mass of TNT) to the overpressure. The scaled distance is given by the relationship in equation:

$$\lambda = \frac{r}{(m_{TNT})^{1/3}}$$

6.2 IMPACT ASSESSMENT

The above techniques allow the level of radiation or overpressure resulting from fires and explosions to be determined at any distance from the source. The effect or impact of heat radiation on people is shown in Table 9 while Table 10 shows the effects of explosion overpressure.

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[3] In a relatively moderate wind force of say 4 m/s, the cloud would after 3 minutes have covered a distance of 240 metres.

Table 9 - Effects of Heat Radiation

Radiant Heat Level (kW/m^2)	Physical Effect (effect depends on exposure duration)
1.2	Received from the sun at noon in summer
2.1	Minimum to cause pain after 1 minute
4.7	Will cause pain in 15-20 seconds and injury after 30 seconds' exposure
12.6	Significant chance of fatality for extended exposure High chance of injury
23	Likely fatality for extended exposure and chance of fatality for instantaneous (short) exposure
35	Significant chance of fatality for people exposed instantaneously

Table 10 – Effect of Explosion Overpressure

Overpressure (kPa)	Physical Effect
3.5	90% glass breakage. No fatality, very low probability of injury
7	Damage to internal partitions & joinery 10% probability of injury, no fatality
14	Houses uninhabitable and badly cracked
21	Reinforced structures distort, storage tanks fail 20% chance of fatality to person in building
35	Houses uninhabitable, rail wagons & Facility items overturned. Threshold of eardrum damage, 50% chance of fatality for a person in a building, 15% in the open
70	Complete demolition of houses Threshold of lung damage, 100% chance of fatality for a person in a building or in the open

Table 11 – Nomenclature for Section 6

Label	Explanation
A	Area of hole, m^2
C_p	Average liquid heat capacity, kJ/kg.K
f	Fraction of heat radiated
H_c	Heat of combustion, kJ/kg
H_v	Heat of vaporisation, kJ/kg
I	Radiant heat intensity kW/m^2
M	Molecular weight
m	Mass, kg
m_v	Mass of vapour (in cloud), kg
m_{TNT}	Equivalent mass of TNT, kg
$\dot{m}$	Mass flow rate of leak, kg/s
P	Pressure, Pa
P_1	Upstream absolute pressure, Pa
Q	Heat release rate, kW
R	Universal gas constant, 8.314 J.K/mol
r	Distance from fire/explosion, m
T	Temperature, K
T_1	Storage temperature, K
T_b	Boiling point, K
t	Duration of leak/time, seconds
z	Gas compressibility factor
α	Explosion efficiency factor
γ	Ratio of specific heats (~1.4)
λ	Scaled distance
ρ	Density, kg/m^3
τ	Atmospheric transmissivity

6.3 CONSEQUENCE CALCULATIONS – NATURAL GAS INCIDENT

This initial outflow rates estimated for natural gas releases are shown in Table 12. The results predict that the rate of decrease in outflow rate for a full bore rupture is dramatic with a drop to less than half of the initial flow within seconds and further rapid decay. However, the present PHA has assumed that the initial release rate remains until isolation can be achieved.

Table 12 – Release Rates

Small leak (5mm)	Intermediate leak (25 mm)	Massive leak (100 mm)	Full bore (guillotine)
0.29 kg/s	7.2	115 kg/s	2.4 tonnes/s (first few seconds)

The distance from the source of the fire to the specified heat radiation for jet fire scenarios is listed in Table 13 below.

Table 13 – Heat Radiation Distances from Jet Fires

Hole size	Distance to Heat radiation (metres)		
	$4.7kW/m^2$	$12.5kW/m^2$	$23.5kW/m^2$
Small leak (5mm)	6	4	3
Intermediate leak (25 mm)	30	18	14
Massive leak (100 mm)	120	74	55
Full bore (guillotine)[4]	525	310	240

The distance from the source to the envelope of the flash fire is presented in Table 14 below. According to established correlations between overpressure effects and heat radiation, the pressure wave of 70kPa (scaled distance of 4) is taken as defining the foot print of an equivalent size flash fire. Fatality for a person within this foot print is assumed as 100% while fatality for a person outside the foot print is assumed as 0%. The assumptions for flash fires are according to those in the *Hazard Analysis* course notes (Ref 11).

Table 14 – Flash Fire Consequence Distances

Hole size	Distance to Heat radiation (metres)		
	$4.7kW/m^2$	$23.5kW/m^2$	100% fatality
Small leak (5mm)	25	15	12
Intermediate leak (25 mm)	40	35	30
Massive leak (100 mm)	150	80	70
Full bore (guillotine)[5]	350	315	250

[4] The event resulting from a full bore rupture is more likely to result in a short flash fire of great intensity followed by a longer duration jet fire of les intensity as the pipeline depressurises through the rupture.

The distance from the source of the release to the specified overpressure for explosion scenarios is listed in Table 15 below.

Table 15 – Overpressure Distances from Explosions

Hole size	Distance to Explosion Overpressure (metres)		
	7 kPa	**14 kPa**	**70 kPa**
Small leak (5mm)	30	25	15
Intermediate leak (25 mm)	120	75	40
Massive leak (100 mm)	300	200	75
Full bore (guillotine)	450	380	220

The calculations sheets are included in Appendix 1.

[5] The event resulting from a full bore rupture is more likely to result in a short flash fire of great intensity followed by a longer duration jet fire of les intensity as the pipeline depressurises through the rupture.

7 FREQUENCY ANALYSIS

7.1 GENERIC EQUIPMENT FAILURES

A summary of all incident scenarios that are incorporated into the PHA are listed in Appendix 1. The frequency of each postulated equipment failure was determined using the data in the table below.

The frequencies used for all below ground gas piping and for all pipelines installed as per AS2885 (Reference 5) requirements are based on incident statistics between 1988 and 1992, gathered by the European Gas Pipeline Incident Data Group (EIGPIDG), Reference 12.

This data source has been chosen based on the extensive statistical significance of the data available (1,470,000 kilometre-years)[6] and because of the similarities between the Australian Standard requirements and the requirements used in the European countries included in the incident statistics (Britain, Belgium, France, Netherlands, and Germany). These statistics provide details of leak rates for small and large holes but do not provide information on rupture frequencies.

Rupture frequency data is therefore taken from the British Gas failure data as sourced by the British Gas Corporation Engineering Research Station (Reference 13) over 250,000 km-yrs.

Two different wall thicknesses will be used depending on the location of the pipeline. In general, the pipeline will be constructed in 6.8mm thick pipe. Where the pipeline goes under roads or railways or where it passes major centres it will be constructed in thicker pipe (9.7mm wall thickness).

The failure frequencies for 6.5mm and 9.7mm thick pipelines as per references 12 and 13 are listed below.

Table 16 - Equipment Failures and Associated Frequencies

Type of Failure	Failure Rate (pmpy)
GAS PIPELINES (>100mm NB; 6.8 mm pipe thickness)	
<20 mm hole – steel pipeline	0.055/ m
<80 mm hole – steel pipeline	0.138 / m

[6] As a comparison, the available statistics in Australia are based on (only) 160,000 km-yrs. The available statistics from the US Dept of Transportation Office of Pipeline Safety is based on 970,000 km-yrs but the standards used in the US are understood to be further from the Australian standards than those in use in Europe (as included in the EGPIDG).

Type of Failure	Failure Rate (pmpy)
Guillotine fracture (full bore) – steel pipeline	0.0015 / m
GAS PIPELINES (>100mm NB; 9.7 mm pipe thickness)	
<20 mm hole – steel pipeline	0.027/ m
<80 mm hole – steel pipeline	0.076 / m
Guillotine fracture (full bore) – steel pipeline	0.0007 / m

7.2 PROBABILITY OF FLAMMABLE OUTCOME

The probability of ignition if leak were based on the Cox, Lees and Ang data (Reference14), as follows:

Table 17 – Ignition Probability

Leak size (mm)	Probability of ignition
<20mm	0.027
20 to 100 mm	0.019
>100 mm	0.235

The probability of a delayed ignition is taken as $M^{0.333}$, with M being the mass (in tonnes) of flammable vapour in the cloud (Reference 15). This equation was used to determine the probability of a flash fire or an explosion.

The probability of the delayed ignition resulting in an explosion was taken as 0.1 and as a flash fire as 0.1.

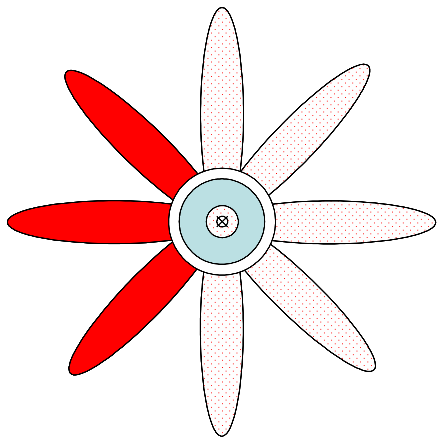
The probability of a jet fire was taken as:

$$P_{\text{jet fire}} = P_{\text{ignition}} - P_{\text{explosion}} - P_{\text{flash fire}}$$

The frequency of outcome of each individual incident scenario is listed in the spreadsheet in Appendix 1.

Jet fires are directional (as opposed to flash fires that are omni directional). While a jet fire can be directed towards any point in the sphere, about one third of all jet fires are assumed to be directed towards a boundary. This is based on the concept depicted in Figure 2 below, with the dark jets being those assumed to be directed towards the boundary and the light being assumed to be directed away from the boundary.

Figure 2 – Jet Fire Distribution



7.3 RELATIONSHIP BETWEEN EXPOSURE AND EFFECT

The relationship between exposure and effect was estimated based on the probit equation for heat radiation from jet fires. In the case of flash fires, 100% fatality was assumed for anyone engulfed within the flaming cloud, and 0% probability outside it.

8 RISK RESULTS AND COMPARISON WITH RISK CRITERIA

8.1 OVERALL INDIVIDUAL RISK OF FATALITY

Figure 3 and Figure 4 show the risk-transect for individual fatality from the 6.8MM and the 9.7MM (wall) thick natural gas pipeline respectively. The risk criterion which is relevant for residential development (1 pmpy) is never reached for either pipeline. The pipeline does not travel next to any sensitive development (such as schools, hospitals etc.) where lower risk criteria would be relevant.

Figure 3 – Individual Fatality Risk Transects for the 6.8MM Gas Pipeline

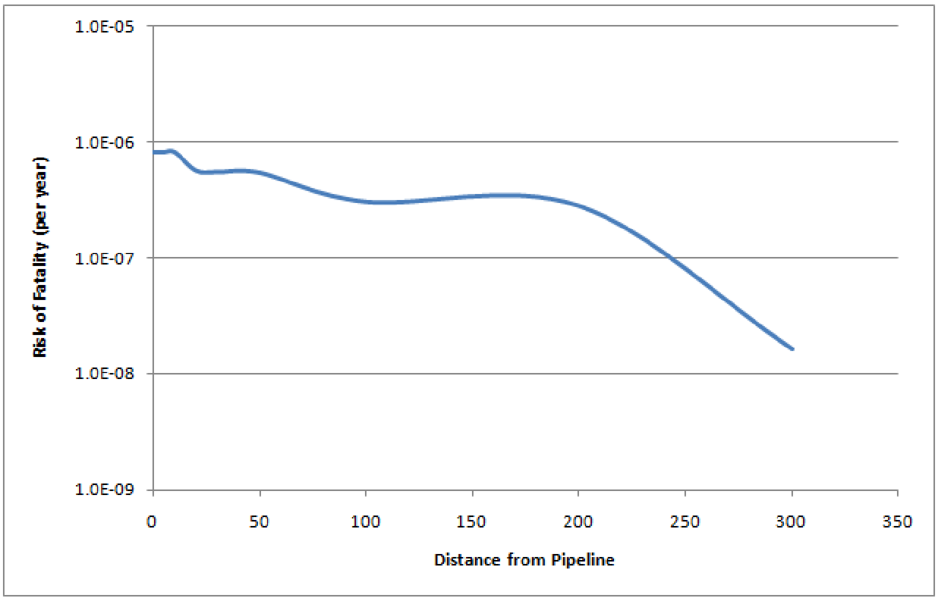
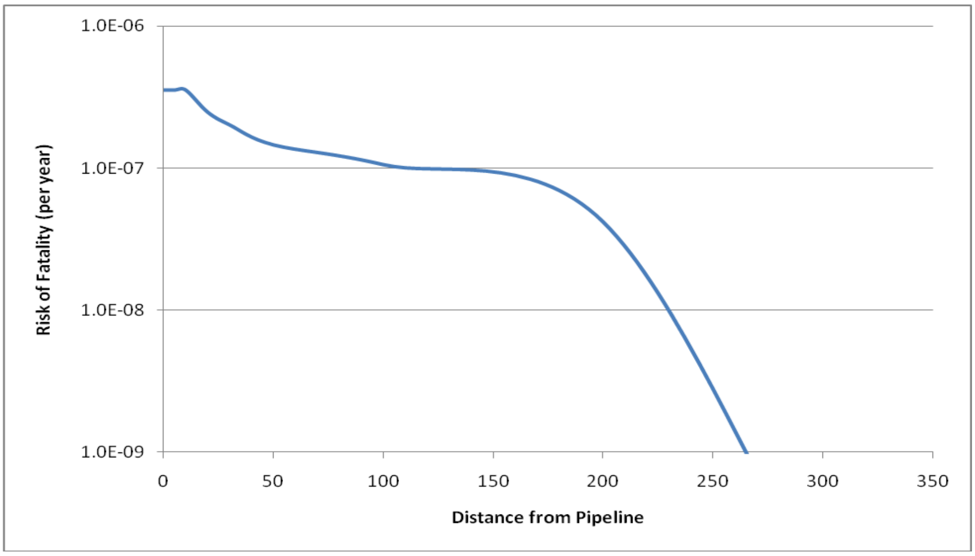


Figure 4 – Individual Fatality Risk Transects for the 9.7MM Gas Pipeline



8.2 INJURY RISK

Figure 5 and Figure 6 show the injury risk-transect for the 6.8MM and the 9.7MM (wall) thick natural gas pipeline respectively. The risk criterion which is relevant for residential development (50 pmpy) is never reached for the pipeline.

Figure 5 – Injury Risk Transects for the 6.8MM Gas Pipeline

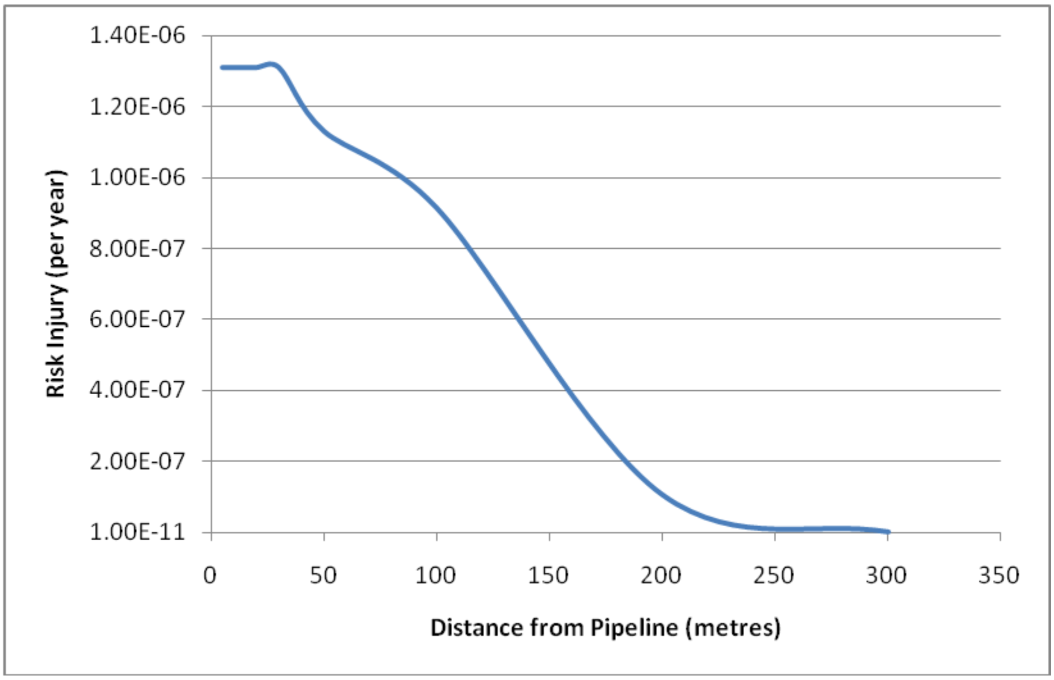
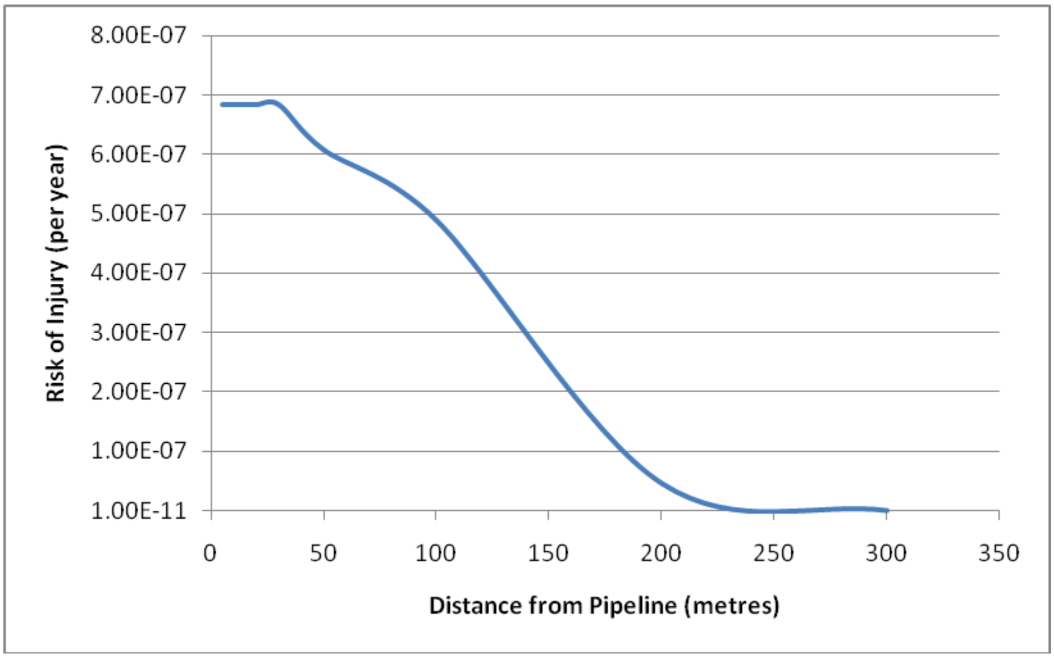


Figure 6 – Injury Risk Transects for the 9.7MM Gas Pipeline



8.3 PROPAGATION RISK

Figure 7 and Figure 6 show the injury risk-transect for the 6.8MM and the 9.7MM (wall) thick natural gas pipeline respectively. The risk criteria relevant for residential development (50 pmpy) is never reached for the pipeline.

Figure 7 – Propagation Risk Transects for the 6.8MM Gas Pipeline

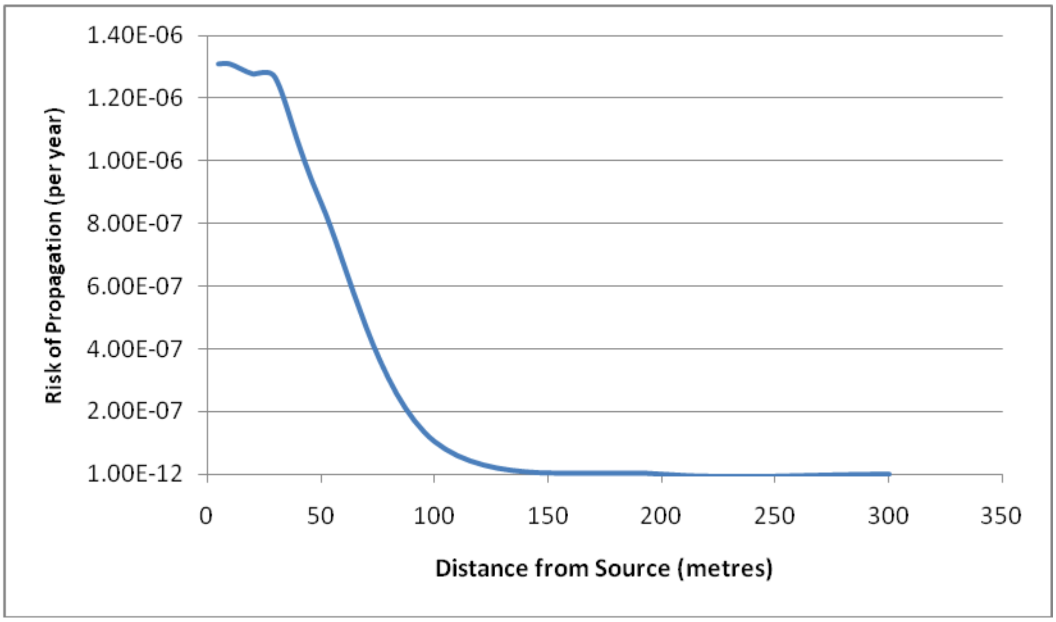
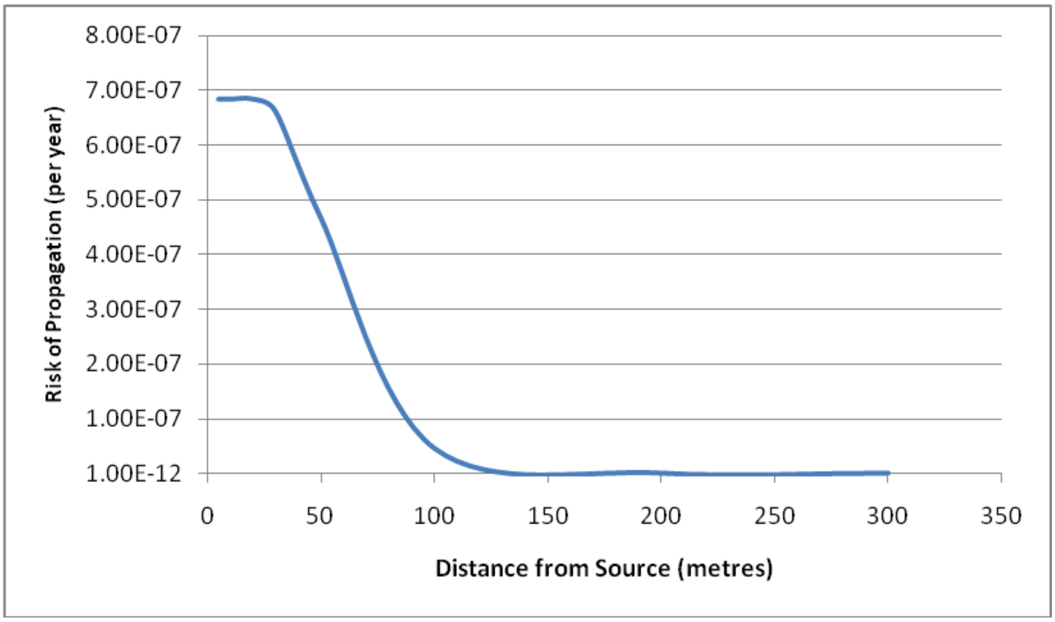


Figure 8 – Propagation Risk Transects for the 9.7MM Gas Pipeline



8.4 ADHERENCE TO RISK CRITERIA

The quantitative analysis showed that:

Individual Risk of Fatality: The risk of fatality associated with the gas pipeline is well below the criterion for new installations of one chance in a million per year (1×10^{-6}/yr). The 1×10^{-6}/yr individual fatality risk for the pipeline is contained well within the pipeline easement.

It follows that the risk of fatality at the nearest open space and the nearest industrial area are also well below the criterion of ten and fifty chances per million years respectively (10×10^{-6}/yr and 50×10^{-6}/yr) and contained within the pipeline easement.

Injury Risk: The risk of injury at the nearest residential area is well below the criterion for new installations of fifty chances per million years (50×10^{-6}/yr).

Propagation Risk: The risk of propagation of an incident at the gas pipeline does not encroach into any other industrial areas and is well below the criterion of fifty chances per million years (50×10^{-6}/yr).

Societal Risk: The risk of fatality does not extend anywhere close to any residential and is well within the criteria for business / industrial areas. It is therefore considered that the proposed pipeline does not have a significant impact on societal risk.

9 CONCLUSIONS

9.1 OVERVIEW OF RISK

The main hazard associated with the proposed gas pipeline is associated with the handling of natural gas (predominantly composed of methane gas), which is a flammable gas held under pressure.

The predominant mode in which a hazardous incident may be generated is associated with a rupture or leak.

A leak would generally only have the potential to cause injury or damage if there was ignition, which resulted in a fire or explosion incident. The factors involved are:

- Failure must occur causing a release. There are several possible causes of failure, with the main ones being corrosion and damage to the equipment by external agencies.
- The released material must come into contact with a source of ignition. In some cases this may be heat or sparks generated by mechanical damage while in others, the possible ignition source could include non-flame proof equipment, vehicles, or flames some distance from the release.
- Depending on the release conditions, including the mass of material involved and how rapidly it is ignited, the results may be a localised fire (for example a so called jet fire) or a flash fire. As the pipeline runs through open areas, an explosion of the vapour cloud formed through the release is considered highly unlikely.
- Finally, for there to be a risk, people must be present within the harmful range (consequence distance) of the fire or explosion. How close the people are will determine whether any injuries or fatalities result.

9.2 SUMMARY OF RISK RESULTS

Even though many of the assumptions in this PHA are conservative, the results show that the risk associated with the gas pipeline is very low. The most stringent risk criteria, as required by the NSW Department of Planning, are adhered to.

Appendix 1

Risk Calculation Sheets 6.8MM Pipeline

Preliminary Hazard Analysis of the Natural Gas pipeline between Young and Bomen in NSW

Appendix 1 – Risk Calculation Sheets (6.8MM Pipeline)

The calculations sheets for the 6.8mm thick pipeline are provided below for reference. The calculations sheets for the 9.7mm pipeline can be provided if required.

OUTFLOW RATES						
Gas flow rate = 0.8 x A x P {M/zRT x [(2/gamma + 1)^0.5]^(gamma+1)/(gamma-1)}^0.5						
R =	8.314	J.K/mol				
T =	293	K				
gamma =	1.31	ratio of specific heat				
z =	1	assume ideal gas				
M =	18	g/mol				
P =	8.50E+06	Pa	Pipeline Op. Pressure			
LATERAL GAS SUPPLY PIPELINE RISK ASSESSMENT						
Leak size (m)	Cross section	Flow rate (kg/s)				
5.00E-03	1.96E-05	2.88E-01	Pipeline Op. Pressure			
2.50E-02	4.91E-04	7.21E+00	Pipeline Op. Pressure			
1.00E-01	7.85E-03	1.15E+02	Pipeline Op. Pressure			
4.57E-01	1.64E-01	2.41E+03	Pipeline Op. Pressure			

FREQUENCY ASSESSMENT

EGPIDG Data for 457mm pipelines (Failure rate per million kilometers per year)

Pipe thickness (mm)	5.9	6.8	7.1	8.1	8.5	9.7
Ext interference						
pinhole	62	38	35	20	17	10
hole	148	130	120	100	95	68
Corrosion						
pinhole	0	0	0	0	0	0
hole	0	0	0	0	0	0
Construction/Material defect						
pinhole	9	9	9	9	9	9
hole	0	0	0	0	0	0
Ground movement						
pinhole	3	8	8	8	8	8
hole	8	8	8	8	8	8
Hot tap by error						
pinhole	0	0	0	0	0	0
hole	0	0	0	0	0	0
TOTAL PINHOLE	74	55	52	37	34	27
TOTAL HOLE	156	138	128	108	103	76

BRITISH GAS DATA FOR RUPTURE FREQUENCY - RURAL APPLICATION (Failure rate per million kilometers per year)

Pipe thickness (mm)	5.9	6.8	7.1	8.1	8.5	9.7
Rurpture	2.2	1.6	1.4	1	0.9	0.7

Steel Pipe

Leak size (m)	Frequency of failure (per km per year) for a pipe thickness of 6.5 mm	Probability of failure of automatic emergency isolation valve [-]	Probability of ignition (Cox, Lees and Ang)	Freq. of flammable outcome (per km per year)
<20mm	5.50E-05	1.00E+00	0.01	5.50E-07
20 to 100 mm	1.38E-04	1.00E+00	0.07	9.66E-06
>100 mm	1.60E-06	1.00E+00	0.3	4.80E-07

Mass of gas between two MLVs

diam pipe:	4.57E-01	m	assumes perfect gas		mass = n (mole) x M (g/mole)	
Cross section pipe	6.56E-01	m2	pV=nRT		M(methane) g/mole	16
Dist between MLVs (ap	2.60E+04	m	n=PV/RT			
Volume gas between M	1.71E+04	m3	n =	5.95E+04		
Mass gas between MLVs		kg	mass =	9.52E+05	kg	952
				952	tonnes	

Mass in Flammable cloud (tonnes) - ALB fail to operate (kg)	Mass in Flammable cloud (tonnes) - ALB operate correctly and max mass in cloud is mass of gas between two MLVs (kg)	Probability of flash or explosion if ignited [-] (Ref HAZAN Course, $P=M^{0.333}$. Taken as "flash and explosion" due to the volatile nature of natural gas)	Probability of flash fire if ignited [-] (Assume 90% flash if "flash or explosion")	Probability of explosion if ignited [-] (Assume 10% explosion if "flash and explosion")	*Hazard Analysis Course Notes*, Risk Management Group, SHE Pacific, 1999	Tweeddale, *Managing Risks and Reliability in Process Plants*
1.30E+00	1.30E+00	0.11	0.10	0.01		
2.08E+01	2.08E+01	0.27	0.25	0.03		
4.33E+02	4.33E+02	0.76	0.68	0.08		

	Freq. of flash fire (per km per year)	Freq. of exposion (per km per year)	Freq. of jet fire (per km/yr)	Freq. of flash fire (per year, for the entire pipeline length)	Freq. of explosion (per year, for the entire pipeline length)	Freq. of jet fire (per year, for the entire length of the pipeline)
	5.40E-08	6.00E-09	4.90E-07	7.02E-06	7.80E-07	4.90E-06
	2.39E-06	2.65E-07	7.01E-06	3.11E-04	3.45E-05	7.01E-05
	3.63E-07	3.63E-08	8.04E-08	4.72E-05	4.72E-06	8.04E-07
				3.65E-04	**4.00E-05**	**7.58E-05**

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JET FIRE - POINT SOURCE METHOD

Assume :		***Probit Y = -A + B x ln(Q x t^n)***		**Length of jet**		
Heat of combustion Hc=	50000 kJ/kg	A	-14.9	***F. P. Lees***	L = 6M$^{0.5}$	for 0<M<50 kg/s
Radiation efficiency =	0.15	B	2.56		(M = mass flow rate, kg/s)	
Transmissivity =	1	n	1.333			
Duration of exposure =	60 s					for M>50 kg/s
Duration for total mass of vapour in cloud	180 s					
Mass burn rate = outflow rate						

Jet Fire

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame metres	Distance to Heat Radiation (m) 4.7kW/m^2	12.5kW/m	23.5kW/m^2	Probit value Y = -14.9 + 2.56 ln(I$^{1.333}$ t) 4.7kW/m^2	12.5kW/m^2	23.5kW/m^2	Probability of fatality 4.7kW/m^2	12.5kW/m^2	23.5kW/m^2
5.00E-03	Pipeline Op. Pressure	2.88E-01	2.16E+03	3.22	6.1	3.7	2.7	0.9	4.2	6.3	0	0.28	0.95
2.50E-02	Pipeline Op. Pressure	7.21E+00	5.40E+04	16.11	30.3	18.6	13.7	0.9	4.2	6.3	0	0.28	0.95
1.00E-01	Pipeline Op. Pressure	1.15E+02	8.65E+05	64.42	121.0	74.2	54.7	0.9	4.2	6.3	0	0.28	0.95
4.57E-01	Pipeline Op. Pressure	2.41E+03	1.81E+07	700.12	553.1	339.1	250.0	0.9	4.2	6.3	0	0.28	0.95

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame metres	Heat radiation (kW/m2) at Distance from Centre of Flame (in metres). 1	2	5	10	20	30	50	100	200	300
5.00E-03	Pipeline Op. Pressure	2.88E-01	2.16E+03	3.22	172	43	7	2	0	0	0	0	0	0
2.50E-02	Pipeline Op. Pressure	7.21E+00	5.40E+04	16.11	4303	1076	172	43	11	5	2	0	0	0
1.00E-01	Pipeline Op. Pressure	1.15E+02	8.65E+05	64.42	68841	17210	2754	688	172	76	28	7	2	1
4.57E-01	Pipeline Op. Pressure	2.41E+03	1.81E+07	700.12	1437736	359434	57509	14377	3594	1597	575	144	36	16

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame metres	Distance to this heat radiation from the source (in metres) 1	2	5	10	20	30	(takes into account the length of the flame) 50	100	200	300
5.00E-03	Pipeline Op. Pressure	2.88E-01	2.16E+03	3.22	3	4	7	12	22	32	52	102	202	302
2.50E-02	Pipeline Op. Pressure	7.21E+00	5.40E+04	16.11	9	10	13	18	28	38	58	108	208	308
1.00E-01	Pipeline Op. Pressure	1.15E+02	8.65E+05	64.42	33	34	37	42	52	62	82	132	232	332
4.57E-01	Pipeline Op. Pressure	2.41E+03	1.81E+07	700.12	351	352	355	360	370	380	400	450	550	650

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame metres	Probit 1	2	5	10	20	30	50	100	200	300
5.00E-03	Pipeline Op. Pressure	2.88E-01	2.16E+03	3.22	13	8	2	-3	-7	-10	-14	-18	-23	-26
2.50E-02	Pipeline Op. Pressure	7.21E+00	5.40E+04	16.11	24	19	13	8	4	1	-3	-7	-12	-15
1.00E-01	Pipeline Op. Pressure	1.15E+02	8.65E+05	64.42	34	29	23	18	13	10	7	2	-3	-5
4.57E-01	Pipeline Op. Pressure	2.41E+03	1.81E+07	700.12	44	39	33	28	23	21	17	12	8	5

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame	Probability of fatality									
5.00E-03	Pipeline Op. Pressure	2.88E-01	2.16E+03	3.22	1.00	1.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.50E-02	Pipeline Op. Pressure	7.21E+00	5.40E+04	16.11	1.00	1.00	1.00	1.00	0.12	0.00	0.00	0.00	0.00	0.00
1.00E-01	Pipeline Op. Pressure	1.15E+02	8.65E+05	64.42	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.00	0.00	0.00
4.57E-01	Pipeline Op. Pressure	2.41E+03	1.81E+07	700.12	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame	Probability of reaching 4.7kW/m2									
5.00E-03	Pipeline Op. Pressure	2.88E-01	2.16E+03	3.22	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.50E-02	Pipeline Op. Pressure	7.21E+00	5.40E+04	16.11	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00
1.00E-01	Pipeline Op. Pressure	1.15E+02	8.65E+05	64.42	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00
4.57E-01	Pipeline Op. Pressure	2.41E+03	1.81E+07	700.12	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame	Probability of reaching 23kW/m2									
5.00E-03	Pipeline Op. Pressure	2.88E-01	2.16E+03	3.22	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.50E-02	Pipeline Op. Pressure	7.21E+00	5.40E+04	16.11	1.00	1.00	1.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00
1.00E-01	Pipeline Op. Pressure	1.15E+02	8.65E+05	64.42	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00
4.57E-01	Pipeline Op. Pressure	2.41E+03	1.81E+07	700.12	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00

VCE - TNT METHOD

Equivalent mass TNT = [Explosion efficiency compared with TNT] x [Mass of vapour in cloud] x [Heat of combustion of vapour] / 4,600 =

Scaled distance = Radius [metres] / (MTNT)0.333

Explosion efficiency =	4%	
Hc =	50000	kJ/kg
Mass in cloud after (s) =	180	

Leak size(mm) (m)	Location	Burn rate (kg/s)	Mass in cloud (k (kg)	M(TNT) (kg)	Scaled distance 5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m	400 m
5.00E-03	Pipeline Op. Pressure	2.88E-01	5.19E+01	2.26E+01	1.8	3.5	7.1	10.6	17.7	35.4	70.9	106.3	141.7
2.50E-02	Pipeline Op. Pressure	7.21E+00	1.30E+03	5.64E+02	0.6	1.2	2.4	3.6	6.1	12.1	24.3	36.4	48.5
1.00E-01	Pipeline Op. Pressure	1.15E+02	2.08E+04	9.02E+03	0.2	0.5	1.0	1.4	2.4	4.8	9.6	14.5	19.3
4.57E-01	Pipeline Op. Pressure	2.41E+03	4.33E+05	1.88E+05	0.1	0.2	0.4	0.5	0.9	1.8	3.5	5.3	7.0

Leak size(mm) (m)	Location	Burn rate (kg/s)	Mass in cloud (k (kg)	M(TNT) (kg)	Overpresure (kPa) 5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m	400 m
5.00E-03	Pipeline Op. Pressure	2.88E-01	5.19E+01	2.26E+01	100	80.0	22.0	7.0	6.0	2.0	0.0	0.0	0
2.50E-02	Pipeline Op. Pressure	7.21E+00	1.30E+03	5.64E+02	100	100	95	80	30	9	3	2	0
1.00E-01	Pipeline Op. Pressure	1.15E+02	2.08E+04	9.02E+03	100	100	100	100	95	45	15	7	4
4.57E-01	Pipeline Op. Pressure	2.41E+03	4.33E+05	1.88E+05	100	100	100	100	100	100	80	40	11

Leak size(mm) (m)	Location	Burn rate (kg/s)	Mass in cloud (k (kg)	M(TNT) (kg)	Probability of fatality 5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m	400 m
5.00E-03	Pipeline Op. Pressure	2.88E-01	5.19E+01	2.26E+01	1.00	1.00	0.20	0.03	0.02	0.00	0.00	0.00	0.00
2.50E-02	Pipeline Op. Pressure	7.21E+00	1.30E+03	5.64E+02	1.00	1.00	1.00	1.00	0.35	0.05	0.01	0.00	0.00
1.00E-01	Pipeline Op. Pressure	1.15E+02	2.08E+04	9.02E+03	1.00	1.00	1.00	1.00	1.00	1.00	0.09	0.03	0.02
4.57E-01	Pipeline Op. Pressure	2.41E+03	4.33E+05	1.88E+05	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.62	0.05

FLASH FIRE

Distance to fatality for flash fires= dist. To 70kPa = scaled distance of 4

Leak size(mm) (m)	Location	Burn rate (kg/s)	Mass in cloud (k (kg)	Flash fire danger zone (m)	Probability of Fatality 5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m	400 m
5.00E-03	Pipeline Op. Pressure	2.88E-01	5.19E+01	10	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0
2.50E-02	Pipeline Op. Pressure	7.21E+00	1.30E+03	30	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0
1.00E-01	Pipeline Op. Pressure	1.15E+02	2.08E+04	80	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0
4.57E-01	Pipeline Op. Pressure	2.41E+03	4.33E+05	180	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0

Leak size(mm) (m)	Location	Burn rate (kg/s)	Mass in cloud (k (kg)	Flash fire danger zone (m)	Probability of 4.7kW/m2 5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m	400 m
5.00E-03	Pipeline Op. Pressure	2.88E-01	5.19E+01	10	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0
2.50E-02	Pipeline Op. Pressure	7.21E+00	1.30E+03	30	1.00	1.00	1.00	1.00	0.00	1.00	0.00	0.00	0
1.00E-01	Pipeline Op. Pressure	1.15E+02	2.08E+04	80	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0
4.57E-01	Pipeline Op. Pressure	2.41E+03	4.33E+05	180	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0

Leak size(mm) (m)	Location	Burn rate (kg/s)	Mass in cloud (k (kg)	Flash fire danger zone (m)	Probability of 23kW/m2 5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m	400 m
5.00E-03	Pipeline Op. Pressure	2.88E-01	5.19E+01	10	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0
2.50E-02	Pipeline Op. Pressure	7.21E+00	1.30E+03	30	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0
1.00E-01	Pipeline Op. Pressure	1.15E+02	2.08E+04	80	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0
4.57E-01	Pipeline Op. Pressure	2.41E+03	4.33E+05	180	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0

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RISK ASSESSMENT 6.8MM WALL PIPELINE

	Frequency (per metre per year)		
	Flash fire	Explosion	Jet fire
<20mm	1.46E-10	1.62E-11	1.32E-09
20 to 100 mm	6.49E-10	7.21E-11	1.90E-09
>100 mm	2.85E-10	2.85E-11	6.30E-11

Risk of fatality from jet fires (per m per yr)

Note: The calculation uses the distance from the source of the release (i.e. not the centre of the flame)

	5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m
<20mm	1.32E-09	1.32E-09	1.32E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20 to 100 mm	1.90E-09	1.90E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
>100 mm	6.30E-11	6.30E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Risk of fatality from jet fires (per m per yr)

Note: The calculation takes into account that jet fires are directional.

	5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m
<20mm	4.41E-10	4.41E-10	4.41E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20 to 100 mm	6.34E-10	6.34E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
>100 mm	2.10E-11	2.10E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Risk of fatality from flash fires (per m per yr)

	5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m
<20mm	1.46E-10	1.46E-10	1.46E-10	1.46E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20 to 100 mm	6.49E-10	6.49E-10	6.49E-10	6.49E-10	6.49E-10	0.00E+00	0.00E+00	0.00E+00
>100 mm	2.85E-10	2.85E-10	2.85E-10	2.85E-10	2.85E-10	2.85E-10	2.85E-10	0.00E+00

Risk of fatality from explosions (per m per yr)

	5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m
<20mm	1.62E-11	1.62E-11	1.62E-11	1.62E-11	5.67E-12	8.10E-13	1.62E-13	1.62E-14
20 to 100 mm	7.21E-11	7.21E-11	7.21E-11	7.21E-11	7.21E-11	7.21E-11	6.49E-12	2.16E-12
>100 mm	2.85E-11	2.85E-11	2.85E-11	2.85E-11	2.85E-11	2.85E-11	2.85E-11	1.76E-11

Total fatality (per m per yr)

	5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m
<20mm	6.0E-10	6.0E-10	6.0E-10	1.6E-10	5.7E-12	8.1E-13	1.6E-13	1.6E-14
20 to 100 mm	1.4E-09	1.4E-09	7.2E-10	7.2E-10	7.2E-10	7.2E-11	6.5E-12	2.2E-12
>100 mm	3.3E-10	3.3E-10	3.1E-10	3.1E-10	3.1E-10	3.1E-10	3.1E-10	1.8E-11
Total risk of fatality (per metre per year)	**2.3E-09**	**2.3E-09**	**1.6E-09**	**1.3E-09**	**9.4E-10**	**3.9E-10**	**3.2E-10**	**2.0E-11**

not taking into account any overlapping effect

Divide pipeline into segments of 300 metres each.

In this particular case there is almost no overlapping of the effect zones, so no adjustment needs to be made for overlapping effect zones.

		5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m
Total risk of fatality (per pipeline effect zone)		**6.9E-07**	**6.9E-07**	**4.9E-07**	**3.9E-07**	**2.8E-07**	**2.3E-07**	**9.6E-08**	**5.9E-09**
metres	**0**	**5**	**10**	**20**	**30**	**50**	**100**	**200**	**300**

Frequency of reaching 4.7kW/m2 (jet and flash)								
	5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m
	1.47E-09	1.47E-09	1.47E-09	1.47E-09	0.00E+00	1.46E-10	0.00E+00	0.00E+00
	2.55E-09	2.55E-09	2.55E-09	2.55E-09	2.55E-09	2.55E-09	0.00E+00	0.00E+00
	3.48E-10	3.48E-10	3.48E-10	3.48E-10	3.48E-10	3.48E-10	3.48E-10	3.48E-10
Total	**4.37E-09**	**4.37E-09**	**4.37E-09**	**4.37E-09**	**2.90E-09**	**3.04E-09**	**3.48E-10**	**3.48E-10**
Divide into segments of 300m each to account for any overlapping effects								
	1.31E-06	**1.31E-06**	**1.31E-06**	**1.31E-06**	**8.69E-07**	**9.13E-07**	**1.04E-07**	**1.04E-07**

	Frequency of reaching 23 kW/m2 (jet and flash)							
	5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m
	1.47E-09	1.47E-09	1.46E-10	1.32E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2.55E-09	2.55E-09	2.55E-09	2.55E-09	2.55E-09	0.00E+00	0.00E+00	0.00E+00
	3.48E-10	3.48E-10	3.48E-10	3.48E-10	3.48E-10	3.48E-10	3.48E-10	2.85E-10
Total	**4.37E-09**	**4.37E-09**	**3.04E-09**	**4.22E-09**	**2.90E-09**	**3.48E-10**	**3.48E-10**	**2.85E-10**
Divide into segments of 300m each to account for any overlapping effects								
	1.31E-06	**1.31E-06**	**9.13E-07**	**1.27E-06**	**8.69E-07**	**1.04E-07**	**1.04E-07**	**8.54E-08**

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