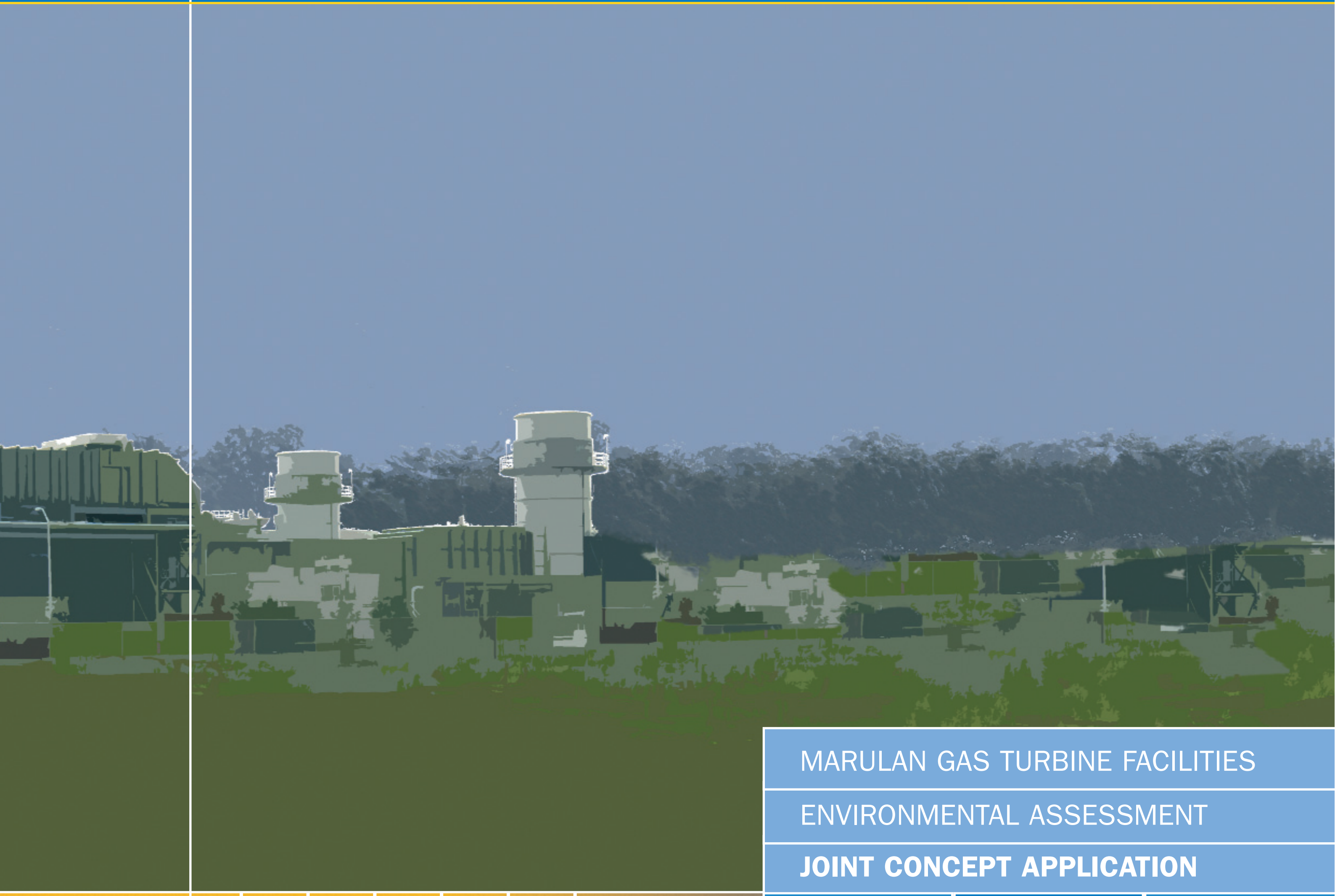
Appendix H
Preliminary Hazard Analysis – Gas Pipeline



MARULAN GAS TURBINE FACILITIES

ENVIRONMENTAL ASSESSMENT

JOINT CONCEPT APPLICATION

VOLUME 2 | APPENDICES | August 2008

REPORT RISK ASSESSMENT OF THE NATURAL GAS DELIVERY PIPELINE TO DELTA ELECTRICITY AND ENERGY AUSTRALIA FACILITIES AT MARULAN, NSW

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Report Risk Assessment of Natural Gas Delivery Pipeline to Proposed Delta Electricity and EnergyAustralia Facilities at Marulan, NSW

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Rev	Date	Description	Prepared By	Reviewed By	Authorised By
A	09/01/2008	Draft for Comment	Karin Nilsson	Delta Electrcity / EnergyAustralia	Nicole Brewer (URS)
B	14/05/2008	Final Report	Karin Nilsson	Delta Electrcity / EnergyAustralia	Nicole Brewer (URS)
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EXECUTIVE SUMMARY

E1 Introduction

To meet the rising demand for electricity in NSW, Delta Electricity (Delta) and EnergyAustralia are proposing to build and operate two separate gas turbine Facilities at a site approximately 12km north of the village of Marulan.

Due to the potentially hazardous nature of materials utilised on site, the facilities are classified as *potentially hazardous* as per the definition by the NSW Department of Planning and hence a series of Preliminary Hazard Analyses (PHAs) have been prepared in accordance with the requirements by the Department for new developments.

The aim of this PHA is to ensure that there are no constraints, from a risk point of view, to the location of the connection to the gas mainline and the route of the gas delivery pipeline. The objective of this PHA is to present hazards and risks associated with the natural gas pipeline from the junction at the Moomba to Sydney pipeline up to the entrance to the site at battery limit.

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 delivery 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 leak. This 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 50×10^{-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.

E4 Recommendations

The risk assessment carried out in this study assumed that the pipeline would be operated with appropriate consideration to safety and safety management at all stages.

The following recommendations emphasise the assumptions made in this risk assessment. The recommendations are listed in the order in which they were listed in the study.

Recommendation 1: To ensure adequate safety of the operation of the gas delivery pipeline it is necessary to install an automatic emergency isolation valve at the off take point of the gas mainline, which would isolate the natural gas supply from the gas mainline in case of a major leak at the gas delivery pipeline. In this risk assessment, the reliability of this automatic valve to close on demand is set as 95% (SIL1). A major leak is regarded as one which results in a mass flow through the hole in the pipe of 5 kg/s or more.

Recommendation 2: It is recommended that an assessment is carried out of the safety management system implemented and used as relevant to the gas delivery pipeline within the first year of operation.

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
SIL	Safety Integrity Level

REPORT

1 INTRODUCTION

1.1 BACKGROUND

To meet the rising demand for electricity in NSW, Delta and EnergyAustralia are proposing to build and operate two separate gas turbine Facilities at a site approximately 12km north of the village of Marulan.

Due to the potentially hazardous nature of materials utilised on site, the facilities are 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 (series of) Preliminary Hazard Analyses (PHAs) 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).

Three separate PHAs have been prepared, as follows:

- *Preliminary Hazard Analysis of Delta's Proposed Gas Fired Turbine Facility at Marulan*, NSW, Planager Pty Ltd, March 2008 (Reference 3).
- *Preliminary Hazard Analysis of EnergyAustralia's Proposed Gas Fired Turbine Facility at Marulan*, NSW, Planager Pty Ltd, March 2008 (Reference 4).
- *Report Risk Assessment of Natural Gas Delivery Pipeline to Delta Electricity and EnergyAustralia Facilities at Marulan, NSW*, Planager Pty Ltd, March 2008 (i.e. the present report).

This document presents the PHA of the natural gas delivery 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 connection to the main gas line and the route of the gas delivery pipeline to the respective facility.

The objective of this PHA is to present the hazards and risks associated with:

- The natural gas pipeline from the junction at the Moomba to Sydney pipeline up to the entrance to the sites at battery limit.

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 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 2).

- Identification of risk reduction measures as deemed necessary.

At the time this PHA was conducted, design of the Facilities and the associated gas delivery 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 Marulan Site is located on Canyonleigh Road, Brayton, approximately 12km northwest of Marulan. The site is 19.6 km from the Marulan Highway turnoff and 10.3 km from the Canyonleigh-Brayton Road turnoff.

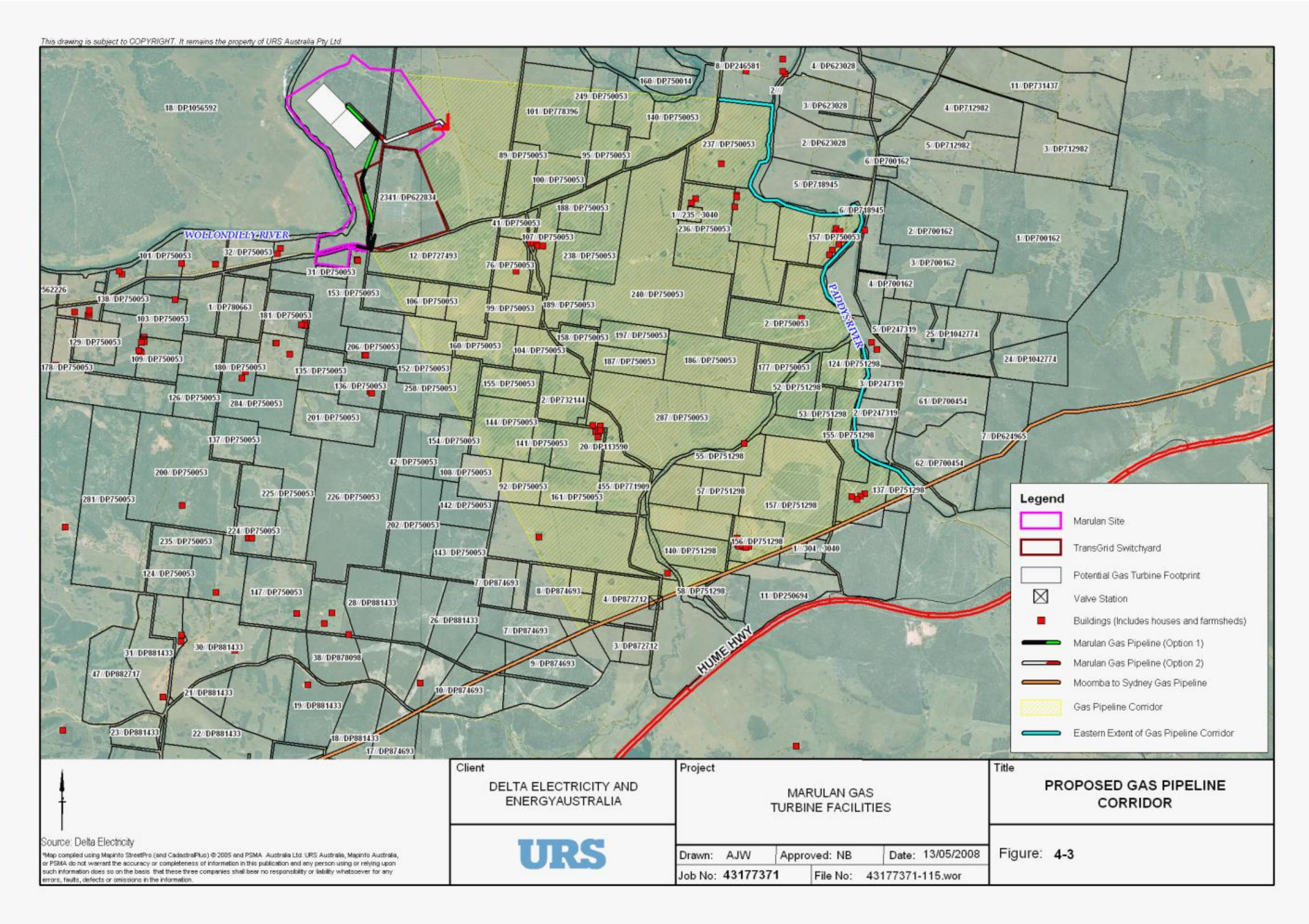
Australian Pipelines Trust (APT) manages the Moomba to Sydney main gas delivery pipeline (referred to as *the gas mainline* in this report). The natural gas mainline is delivering gas from Moomba in South Australia through to Sydney and runs approximately southwest at a distance of about 6km from the proposed site. The gas delivery pipeline would be connected to an off-take point at this gas mainline.

At this stage, the location of the connection to the Moomba to Sydney main gas delivery pipeline and the preferred route for the gas delivery pipeline to the Marulan Site has not been determined. However, the corridor for the pipeline route is included as part of this Preliminary Environmental Assessment, as shown in Figure 1.

Delta and EnergyAustralia request that the Minister approve the Concept Plan Application for the pipeline corridor and determine that further assessment to decide the preferred location for the gas main connection and the pipeline routes would be assessed subsequently, when all route options have been considered and easements negotiated. There are no specific constraints on the location of the connection point of the lateral to the Moomba to Sydney main gas delivery pipeline.

The local landholders who may be affected by the gas delivery pipeline corridor would be contacted as part of the consultation process. The Proponents would enter negotiations for an easement for the gas pipeline across the relevant properties.

Figure 1 – Corridor for Pipeline Route



2.2 GAS DELIVERY PIPELINE – DESIGN AND OPERATION

It is proposed that one approximately 6km to 10km long gas delivery pipeline (depending on the location of the connection point to the gas mainline) would transport the gas from the gas mainline to each Facilities gas receiving stations.

The delivery pipeline will be designed to deliver gas at a nominal maximum pressure of 6.2 MPa up to the gas receiving area where it will be reduced to 2.5 MPa prior to use by the gas turbines. This can be achieved using a pipeline of approximately 18 inches (457mm) diameter.

The pipeline will be compliant with AS2885 (Reference 5). However, the detailed design of the gas supply pipeline is not completed and the assumptions as to the technical details made for 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 Gas Delivery 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	457 mm NB (nominal bore)
Pipe Length	Between 6km and 10km depending on the final route
Maximum Allowable Operating Pressure (MAOP)	6.2 MPa, ANSI Class 300
Actual operating pressure	4.4-5.0 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	9 to 13mm
Depth of Cover	At least 750mm (or 450mm in rock if encountered)
Number of flanges	10 flanges
Features	Pressure indication, flow indication and transmitter and non return valve) at the gas mainline off-take point. Emergency isolation valve at the gas mainline off-take point.
Design Standard	As per AS2885 requirements

The gas delivery pipeline would be hot tapped onto the gas mainline.

The engineering design is not completed and hence the instrumented protective systems required for the pipeline operation and safety have not been defined. Hence, assumptions have had to be made in this respect giving rise to the following recommendation:

Recommendation 1: *To ensure adequate safety of the operation of the gas delivery pipeline, it is necessary to install an automatic emergency isolation valve at the off take point at the gas mainline, which would isolate natural gas supply from the gas mainline in case of a major leak at the gas delivery pipeline. In this risk assessment, the reliability of this automatic valve to close on demand is set as 95% (SIL1). A major leak is regarded as one which results in a mass flow through the hole in the pipe of 5 kg/s or more.*

The pressure tapping points associated with the emergency isolation valve are assumed to allow a drop in line pressure to be quickly ascertained. For the purposes of the present risk assessment, closure of the emergency isolating valve at the off-take point at the gas mainline is assumed to be able to be triggered either automatically by the sensor (e.g. upon a rapid loss of pressure), or 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 FACILITIES

The turbines at Delta and EnergyAustralia sites will be fuelled by the natural gas supplied via the gas delivery pipeline. A risk evaluation of the Facilities is provided in References 3 and 4.

2.4 OPERATING HOURS AND STAFFING

The gas delivery pipeline would be pressurised 100% of the time except for the very occasional non destructive testing (carried out about 5 yearly as per AS2885 requirements).

2.5 SECURITY

The gas delivery pipeline would be located below ground. The off-take point at the gas mainline would be surrounded by a security fence.

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 1) and HIPAP No 4 (*Risk Criteria for Land Use Planning*, Reference 1). 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 1):

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 hazard identification word diagram is then reviewed and complete in a workshop which included people with operational / engineering / risk assessment expertise. 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. The final 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 three 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 and irritation 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.

- 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 2).

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 Planing 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 2). 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.

While the gas pipeline would be located in rural areas, the more rigorous criterion for residential areas (as shown in bold in the table below) has been applied as the relevant criteria for the proposed development.

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:	

Land Use		Maximum Tolerable Risk (pmpy[1])
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

[1] pmpy = per million per year

Activity / Type of Risk	Published levels of risk (pmpy[1])
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 2), 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.

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.

[2] then the Department of Urban Affairs and Planning

- 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, the computer software tool ISORIS from the Warren Centre for Advanced Engineering (Reference 6) was used. 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.

Information on the frequency, location and consequences of each incident was extracted from the spreadsheet and processed by the ISORIS program. This program is designed to take consequence and frequency information and determine risk levels to individuals at all locations within a user-defined grid. From the output of ISORIS risk contours can be drawn and overlayed on a site map.

ISORIS can determine risks to persons in the open or in buildings. For this study, risks in the open have been determined. In the case of radiation, persons are more at risk in the open due to the lack of shelter, while for explosions the risk is greater inside due to the potential for the building to collapse.

To assess injury risk and the potential for knock-on or domino incidents, ISORIS can also determine the frequency of exceeding a given level of heat radiation or explosion overpressure.

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 Recommendations for Safety Management System

Recommendation 2: *It is recommended that an assessment is carried out of the safety management system implemented and used as relevant to the gas delivery pipeline within the first year of operation.*

4 HAZARD IDENTIFICATION

4.1 HAZARDOUS MATERIALS

Natural gas is composed predominantly of methane gas. The composition of natural gas from Moomba to Sydney pipeline is shown in Table 5.

Table 5 – Composition of Natural Gas

Component	Mole %
methane	87
ethane	8.46
hydrogen	0.36
nitrogen	3.61
carbon monoxide	0.09
carbon dioxide	0.34
ethylene	0.03
Hydrogen sulphide (H_2S)	0.04
oxygen	0.07
TOTAL	**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 6 potentially hazardous scenarios were identified for the gas delivery 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	Leak of natural gas from the gas supply pipeline
2	Flooding results in damage to piping and equipment.
3	Land subsidence or mining activity results in pipeline damage.
4	Aircraft crash results in damage to pipeline resulting in hazardous releases.
5	Damage to pipeline through terrorism / vandalism
6	Neighbouring 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. The pipeline was reviewed in a workshop, to determine the potentially hazardous scenarios relevant to that section.

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 Supply Pipeline			
1. Leak of natural gas from the gas supply pipeline.	Mechanical impact (e.g. 3rd party involvement digging or trenching, or other earth work).	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. - Automatic shut down through automatic line break detection and valve closure on the Sydney to Moomba pipeline if large hole in pipe. Manual shut down by Network Controller in Control Centre in Young if pressure drop. - Reverse flow from Gas Turbine Facility prevented through automatic isolation of valve at gas receiver station. - Control of vegetation within easement to minimise risk of bush / brush fire. - NG disperses readily upwards, minimising chances of ignition. Explosion not credible in unconfined situation.

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
Continued 1. Leak of natural gas from the gas supply pipeline.	Leaking pipe due to corrosion. Damage of pipeline coating due to excavation inspection damage leads to corrosion.	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). - Control of vegetation within easement to minimise risk of bush / brush fire. - 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.
As above.	Nearby explosion at neighbouring natural gas or ethane pipeline or tie-offs.	Possible damage to supply 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 natural gas and ethane gas pipeline operator. - Pipeline integrity plan (incl. protection, pigging etc. to monitor integrity of pipeline and coating inspection). - 24 hour monitoring of natural gas and ethane pipelines. - Dial-Before-You-Dig and signposting. - NG disperses readily upwards, minimising chances of ignition. Explosion not credible in unconfined situation. - Buried natural gas and ethane pipelines. - Thickness and grade of pipelines.

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
Continued 1. Leak of natural gas from the gas supply pipelines.	Operational error at Gas Turbine Facility causes pressure excursion leading to failure of the pipeline.	Release of natural gas. If ignition, then possibility of fire. Injury and property damage.	- Pipelines constructed and hydrotested to AS2885 requirements. - The supply pipeline can operate against closed head (i.e. the main valve at the entrance to the site may be closed).
As above.	Operational error at Sydney to Moomba pipeline causes pressure excursion leading to failure of the pipeline.	Overpressuring the supply pipeline causing failures, leaks and release of natural gas. If ignition, then possibility of fire. Injury and property damage.	- Continuous observation of pressure of pipeline from Agility's Control Centre at Young (NSW). Lack of control for several hours required before pressure could exceed critical levels. - Continuous monitoring of pressure of the pipelines supplying natural gas to the Facilities. - High-pressure trip at the Moomba to Sydney pipeline (both at Wilton and Moomba) automatically closes the valve in case of pressure excursion. Wilton trip is tested 6-monthly (through simulation of high pressure). Automatic line-break protection isolating flow of natural gas. - The supply pipeline to the Facilities is to be designed to the same pressure rating as the main Moomba to Sydney pipeline.
As above.	Construction defect or operational error (repeated) causes spontaneous loss of integrity of pipe.	Massive release of natural gas. If ignition, then possibility of flash or jet fire. Injury and property damage.	- X-raying of welds as required. - Thickness of pipe material and temperature cycling make this scenario highly unlikely. - Cathodic protection. - Design for pipelines to prevent crack propagation. - Pipeline complying with AS2885 and other specific standards.

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
2. Flooding results in damage to piping and equipment.	Flooding, erosion.	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. - Repair to soil cover if erosion.
3. Land subsidence or mining activity results in pipeline damage.	Land subsiding due to 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.
4. Aircraft crash results in damage to pipeline resulting in hazardous releases.	Aircraft crash.	Potential damage to pipeline resulting in hazardous releases, fire / explosion.	- Buried pipeline unlikely to be susceptible to aircraft crash. - Automatic isolation valves at each end of the pipelines minimises amount of gas released if gas pipe is damaged. - Civil aviation safety authority (CASA) will be informed about the site and potential aviation hazards. Aviation safety standards to apply.
5. Damage to pipeline through terrorism / vandalism.	Malicious damage.	Massive release of natural gas. If ignition, then possibility of flash or jet fire.	- Buried pipeline.
6. Neighbouring fire.	Bush / brush fire. Fire / gas release on site propagates to outside site boundary.	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.

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 facility.

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 Facility 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 - 1992 SAA Pressure Piping Code (was CB18);
- 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 Supply 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. Some areas are or are expected in the near future to be classified as *R2 – Rural Residential.*

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 lateral 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 8). 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.

- External interference 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.

  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).

  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 (9 to 13 mm) and adequate design factor as per AS2885.

  In the very unlikely event of a damage to the pipeline, which causes a major leak, a valve would be activated at the Moomba to Sydney Pipeline off-take end (preventing uncontrolled flow from this pipeline). If the leak is substantial, the activation would be automatic. If the automatic trip is not activated then shut down would be manual by closing the remote operated isolation valve.

  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. The Australian Pipelines Code (AS2885) would be adopted as a minimum requirement for the design and construction of the pipeline. The pipeline would be constructed of seamless piping of 457 mm diameter (NB) and will be 100% radiographed (including all welds).

  The thickness of the pipe-wall, the relatively low operating pressure and the material grade used re factors that makes this pipeline unlikely to be susceptible to unzipping (Reference 5). 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.

  Recommendation 3: Any issues relating to temperature cycling to be taken into account during detailed design in order to avoid stress corrosion cracking.

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

  The gas supply pipeline will be coated with either polyethylene coating or fusion bound epoxy (FBE). 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 visual inspection and protected against by cathodic protection systems. 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). 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.

- *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.

- *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. There are no valves in public areas. Icing up at leak point improves detection.

- *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 natural gas pipeline owner(s) and operators; 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 pipeline will be buried at a depth of at least 750mm (450mm in rock).

- *Terrorism / vandalism.* The delivery pipeline will be subject to regular and periodic surveillance. Further, the pipeline is buried and no valve points at public areas. Valve systems are surrounded by security fencing.

- *Operational error causes pressure excursion leading to failure of the pipeline*. The pipeline is to be hydrotested at a minimum of 1.4 times the MAOP (maximum allowable operating pressure) and can operate against closed head (i.e. the main isolating valve at the entrance to the Facilities may be closed). There is 24hour monitoring of the lateral gas pipeline from the remote monitoring centre.

Whole Pipeline Overview

Flooding: A geotechnical study will be integrated into the design of the 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, earthquake or mining activity results in pipeline damage: Site is not affected by mine subsidence. Detailed geotechnical study will be performed and the outcomes of this study will be integrated into the design of the pipeline. Seismic review will be performed and the requirements will be incorporated into the design.

Aircraft, train or truck crash on gas delivery pipeline: The gas supply delivery 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 or road crossings. 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.

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 off-take point at the gas mainline), 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 Sydney 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.

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

Delta Electricity and EnergyAustralia both have a commitment to Occupational Health and Safety (OH&S) and has numerous policies and procedures to achieve a safe workplace. Written safety procedures would be established. An established incident reporting and response mechanism would be established, providing 24 hour coverage. Procedures specific to the pipeline and its environment would be incorporated into the safety system.

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 with these substances would be trained in their safe use and handling, and would be provided with all the relevant safety equipment.

Emergency procedures would be developed. All staff would need to be trained in these procedures and they would be incorporated in the facilities quality system.

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

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

Injury and incident management would be proceduralised and people would be trained in how to report incidents.

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 none of the material used, produced or handled are 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 9.

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

The rate at which a liquid leaks from a hole can be determined using a standard orifice flow equation:

$$\dot{m} = 0.8A\sqrt{(2\rho deltaP)}$$

For the case where two-phase flow occurs, the calculation technique is much more involved. An acceptable approximation is to divide the liquid flow rate determined in the equation by 3 to allow for two-phase flow.

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 10 minutes to isolate.

The approach used in this study for failure scenarios identified is to assume three possible event durations and to assign to each the same probability of occurrence. For this analysis, the three leak durations considered were 1 minute, 5 minutes and 10 minutes for manual responses to leaks.

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

[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.

impact of heat radiation on people is shown in Table 9 while Table 10 shows the effects of explosion overpressure.

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)
0.22 kg/s	5.5	88 kg/s	551 kg/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 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)	5	3	3
Intermediate leak (25 mm)	25	15	12
Massive leak (100 mm)	105	65	50
Full bore (guillotine)	260	160	115

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 10.

This data source has been chosen based on the extensive statistical significance of the data available (1,470,000 kilometre-years)[4] 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 11) over 250,000 km-yrs.

Table 14 - Equipment Failures and Associated Frequencies

Type of Failure	Failure Rate (pmpy)
GAS SUPPLY 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

[4] 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).

7.2 FAILURE OF AUTOMATIC PROTECTION

The automatic isolation valve would be positioned at the off-take from the gas mainline, closing automatically in case of a major leak of gas. While the design of the control system is not finalised, it is assumed that the protective systems will be designed to SIL 1 requirements (Reference 12).

Table 15 - Probability of Human Error

Safety Integrity Level (SIL)	Low Demand Mode of Operation (probability of failure to perform as intended on demand)
4	>=10^{-5} to < 10^{-4}
3	>=10^{-4} to < 10^{-3}
2	>=10^{-3} to < 10^{-2}
1	>=10^{-2} to < 10^{-1}

7.3 HUMAN ERROR

The following estimates of human error have been used as a guide for the purposes of determining human responses (Reference 13):

Table 16 - Probability of Human Error

ACTIVITY	Probability of error
Probability of failing to take correct action in high stress situations with one minute in which to act	0.9-1.0
Error in non-routine operation when other duties required	0.1
Error in routine operation where some care is needed	0.01
Error in routine simple operation	0.001

7.4 PROBABILITY OF FLAMMABLE OUTCOME

The probability of ignition if leak were based on the EGPIDG data (Reference14), as follows:

Table 17 – Ignition Probability

Leak size (mm)	Probability of ignition
<20mm	0.27

Table 17 – Ignition Probability

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

The probability of a delayed ignition is taken as 0.9M (in %), 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.

The probability of an explosion is very low for a natural gas leak out in the open and is not considered a credible event for a release of gas from the pipeline.

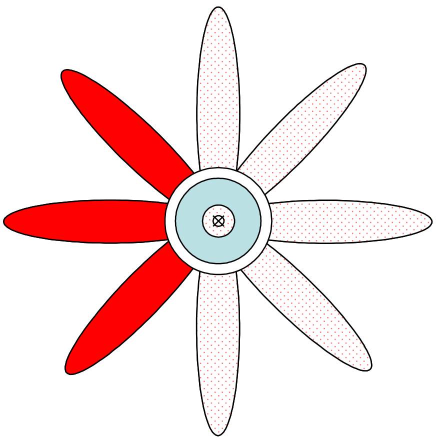
The probability of a jet fire was taken as:

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

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



7.5 RELATIONSHIP BETWEEN EXPOSURE AND EFFECT

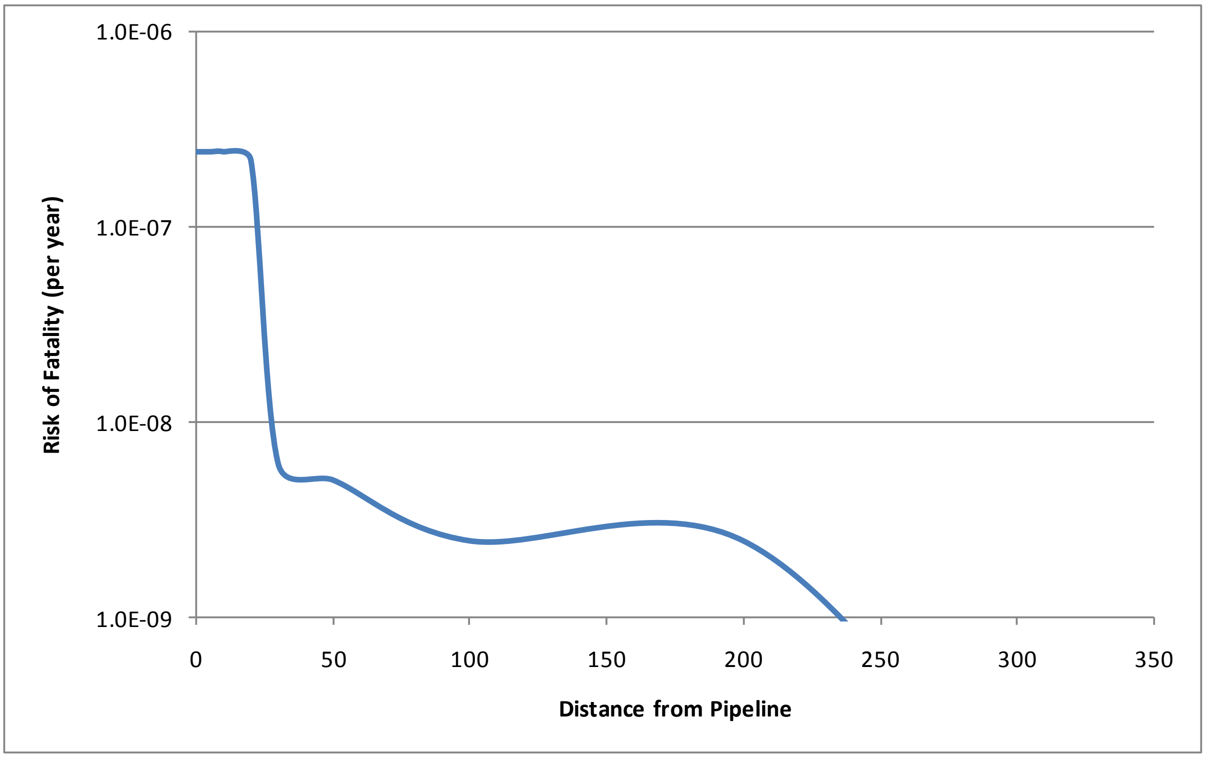
The relationship between exposure and effect was estimated based on the probit equation for heat radiation from jet fires. In the case of flash fires, 100% fatality was assumed for anyone engulfed within the flaming cloud, and 0% probability outside it.

8 RISK RESULTS AND COMPARISON WITH RISK CRITERIA

8.1 OVERALL INDIVIDUAL RISK OF FATALITY RISK

Figure 3 shows the risk-transect for individual fatality at the natural gas delivery pipeline. The risk criterion which is relevant for residential development (1 pmpy) is never reached. The pipeline does not travel next to any sensitive development (such as schools, hospitals etc.) where lower risk criteria would be relevant.

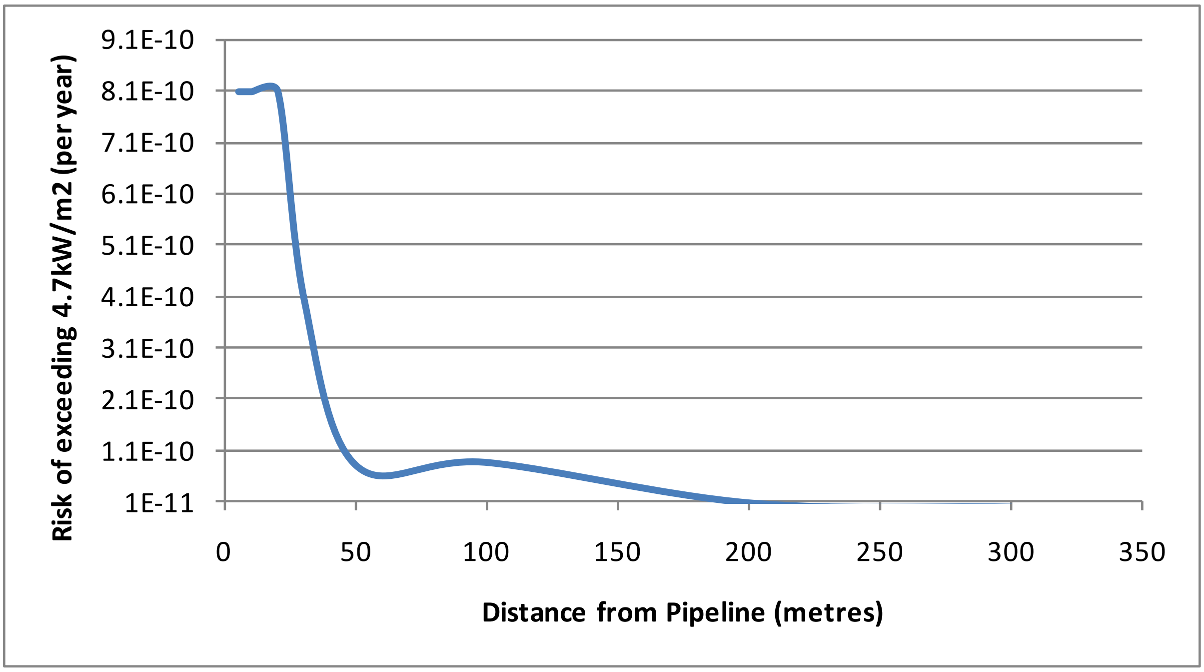
Figure 3 – Individual Risk Transects for the Gas Delivery Pipeline



8.2 INJURY RISK

Figure 4 shows the risk-transect for injury[5] at the natural gas delivery pipeline. The risk criterion ($50x10^{-6}$ per year) is never reached.

Figure 4 – Individual Risk Transects for the Gas Delivery Pipeline

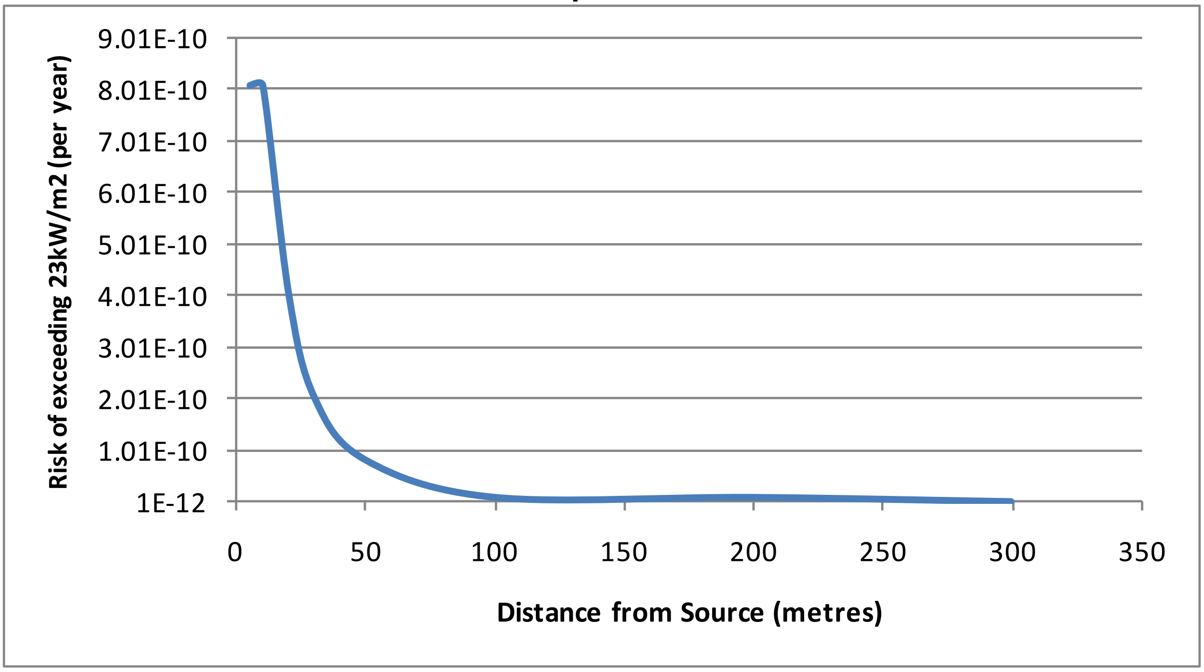


[5] Note that as explosion risk from the pipeline is considered negligible the injury risk relates to heat radiation exposure only

8.3 Propagation Risk

Figure 5 shows the risk-transect for propagation risk[6] at industrial developments at the natural gas delivery pipeline. The risk criterion (50×10^{-6} per year) is never reached.

Figure 5 – Individual Risk Transects for the Gas Delivery Pipeline



8.4 Adherence to Risk Criteria

The quantitative analysis showed that:

Individual Risk of Fatality: The risk of fatality associated with the gas delivery 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).

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[6] Note that as explosion risk from the pipeline is considered negligible the propagation risk relates to heat radiation exposure only

Propagation Risk: The risk of propagation of an incident at the gas delivery 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 CONCLUSION AND RECOMMENDATIONS

9.1 OVERVIEW OF RISK

The main hazard associated with the proposed gas delivery 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 leak. This 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

The detailed design has not been completed as yet for this development. A set of conservative assumptions as to the design and operation of the pipeline have therefore been made.

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

9.3 RECOMMENDATIONS

The risk assessment carried out in this study assumed that the gas delivery pipeline will be operated with appropriate consideration to safety and safety management at all stages.

The following recommendations emphasise the assumptions made in this risk assessment:

Recommendation 1: To ensure adequate safety of the operation of the delivery pipeline it is necessary to install an automatic emergency isolation valve at off take point at the gas mainline which would isolate natural gas supply from the gas mainline in case of a major leak at the gas delivery pipeline. In this risk assessment, the reliability of this automatic valve to close on demand is set as 95% (SIL1). A major leak is regarded as one which results in a mass flow through the hole in the pipe of 5 kg/s or more.

Recommendation 2: It is recommended that an assessment is carried out of the safety management system implemented and used as relevant to the gas delivery pipeline within the first year of operation.

Appendix 1

Risk Calculation Sheets

Report Risk Assessment of Natural Gas Delivery Pipeline to Delta and EnergyAustralia Facilities at Marulan, NSW

Appendix 1 – Risk Calculation Sheets

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 =	6.50E+06	Pa	Upstream of regulator

LATERAL GAS SUPPLY PIPELINE RISK ASSESSMENT

Leak size (m)	Cross section	Flow rate (kg/s)	
5.00E-03	1.96E-05	2.20E-01	Upstream of regulator
2.50E-02	4.91E-04	5.51E+00	Upstream of regulator
1.00E-01	7.85E-03	8.82E+01	Upstream of regulator
2.50E-01	4.91E-02	5.51E+02	Upstream of regulator

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

Leak size (m)	Frequency of failure (per km per year) for a pipe thickness of 9.7 mm	Probability of failure of automatic emergency isolation valve [-]	Probability of ignition	Freq. of flammable outcome (per km per year)	Mass in Flammable cloud (tonnes)
<20mm	2.70E-05	1.00E+00	0.027	7.29E-07	9.92E-01
20 to 100 mm	7.60E-05	5.00E-02	0.019	7.22E-08	1.59E+01
>100 mm	7.00E-07	5.00E-02	0.235	8.23E-09	9.92E+01
	Probability of flash fire if ignited [-]	**Freq. of flash fire (per km per year)**	**Freq. of jet fire (per km/yr)**	**Freq. of flash fire (per year, for the entire pipeline length)**	**Freq. of jet fire (per year, for the entire length of the pipeline)**
	8.93E-03	6.51E-09	7.22E-07	6.51E-08	7.22E-06
	1.43E-01	1.03E-08	6.19E-08	1.03E-07	6.19E-07
	8.93E-01	8.23E-09	0.00E+00	8.23E-08	0.00E+00
				2.50E-07	**7.84E-06**

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Consequence Calculation Sheets

JET FIRE - POINT SOURCE METHOD

Assume :

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

1 Mass burn rate = outflow rate

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame metres	Jet Fire: Distance to Heat Radiation (m) 4.7kW/m²	12.5kW/m	23.5kW/m²	Probit value $Y = -14.9 + 2.56 \ln(I^{1.333} t)$ 4.7kW/m²	12.5kW/m²	23.5kW/m²	Prol 4.7kW/m²
5.00E-03	Upstream of regulator	2.20E-01	1.65E+03	2.82	5.3	3.2	2.4	0.9	4.2	6.3	0
2.50E-02	Upstream of regulator	5.51E+00	4.13E+04	14.08	26.5	16.2	12.0	0.9	4.2	6.3	0
1.00E-01	Upstream of regulator	8.82E+01	6.61E+05	56.34	105.8	64.9	47.8	0.9	4.2	6.3	0
4.57E-01	Upstream of regulator	1.84E+03	1.38E+07	524.02	483.7	296.6	218.6	0.9	4.2	6.3	0

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
5.00E-03	Upstream of regulator	2.20E-01	1.65E+03	2.82	132	33	5	1	0	0	0
2.50E-02	Upstream of regulator	5.51E+00	4.13E+04	14.08	3290	823	132	33	8	4	1
1.00E-01	Upstream of regulator	8.82E+01	6.61E+05	56.34	52643	13161	2106	526	132	58	21
4.57E-01	Upstream of regulator	1.84E+03	1.38E+07	524.02	1099445	274861	43978	10994	2749	1222	440

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) (takes into a 1	2	5	10	20	30	50
5.00E-03	Upstream of regulator	2.20E-01	1.65E+03	2.82	2	3	6	11	21	31	51
2.50E-02	Upstream of regulator	5.51E+00	4.13E+04	14.08	8	9	12	17	27	37	57
1.00E-01	Upstream of regulator	8.82E+01	6.61E+05	56.34	29	30	33	38	48	58	78
4.57E-01	Upstream of regulator	1.84E+03	1.38E+07	524.02	263	264	267	272	282	292	312

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame metres	Probit 1	2	5	10	20	30	50
5.00E-03	Upstream of regulator	2.20E-01	1.65E+03	2.82	12	7	1	-3	-8	-11	-14
2.50E-02	Upstream of regulator	5.51E+00	4.13E+04	14.08	23	18	12	7	3	0	-3
1.00E-01	Upstream of regulator	8.82E+01	6.61E+05	56.34	33	28	22	17	12	9	6
4.57E-01	Upstream of regulator	1.84E+03	1.38E+07	524.02	43	38	32	27	23	20	16

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame	Probability of fatality						
5.00E-03	Upstream of regulator	2.20E-01	1.65E+03	2.82	1.00	0.98	0.00	0.00	0.00	0.00	0.00
2.50E-02	Upstream of regulator	5.51E+00	4.13E+04	14.08	1.00	1.00	1.00	0.98	0.02	0.00	0.00
1.00E-01	Upstream of regulator	8.82E+01	6.61E+05	56.34	1.00	1.00	1.00	1.00	1.00	1.00	0.83
4.57E-01	Upstream of regulator	1.84E+03	1.38E+07	524.02	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 4.7kW/m2						
5.00E-03	Upstream of regulator	2.20E-01	1.65E+03	2.82	1.00	1.00	1.00	0.00	0.00	0.00	0.00
2.50E-02	Upstream of regulator	5.51E+00	4.13E+04	14.08	1.00	1.00	1.00	1.00	1.00	1.00	0.00
1.00E-01	Upstream of regulator	8.82E+01	6.61E+05	56.34	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4.57E-01	Upstream of regulator	1.84E+03	1.38E+07	524.02	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	Upstream of regulator	2.20E-01	1.65E+03	2.82	1.00	1.00	0.00	0.00	0.00	0.00	0.00
2.50E-02	Upstream of regulator	5.51E+00	4.13E+04	14.08	1.00	1.00	1.00	1.00	0.00	1.00	0.00
1.00E-01	Upstream of regulator	8.82E+01	6.61E+05	56.34	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4.57E-01	Upstream of regulator	1.84E+03	1.38E+07	524.02	1.00	1.00	1.00	1.00	1.00	1.00	1.00

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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 ((kg)	M(TNT) (kg)	Scaled distance 5 m	10 m	20 m	30 m	50 m	100 m	200 m
5.00E-03	Upstream of regulator	2.20E-01	3.97E+01	1.72E+01	1.9	3.9	7.7	11.6	19.4	38.7	77.5
2.50E-02	Upstream of regulator	5.51E+00	9.92E+02	4.31E+02	0.7	1.3	2.7	4.0	6.6	13.3	26.5
1.00E-01	Upstream of regulator	8.82E+01	1.59E+04	6.90E+03	0.3	0.5	1.1	1.6	2.6	5.3	10.5
4.57E-01	Upstream of regulator	1.84E+03	3.31E+05	1.44E+05	0.1	0.2	0.4	0.6	1.0	1.9	3.8

Leak size(mm) (m)	Location	Burn rate (kg/s)	Mass in cloud ((kg)	M(TNT) (kg)	Overpresure (kPa) 5 m	10 m	20 m	30 m	50 m	100 m	200 m
5.00E-03	Upstream of regulator	2.20E-01	3.97E+01	1.72E+01	100	70.0	22.0	15.0	6.0	3.0	0.0
2.50E-02	Upstream of regulator	5.51E+00	9.92E+02	4.31E+02	100	100	85	70	30	10	4
1.00E-01	Upstream of regulator	8.82E+01	1.59E+04	6.90E+03	100	100	100	100	90	50	15
4.57E-01	Upstream of regulator	1.84E+03	3.31E+05	1.44E+05	100	100	100	100	100	100	70

Leak size(mm) (m)	Location	Burn rate (kg/s)	Mass in cloud ((kg)	M(TNT) (kg)	Probability of fatality 5 m	10 m	20 m	30 m	50 m	100 m	200 m
5.00E-03	Upstream of regulator	2.20E-01	3.97E+01	1.72E+01	1.00	1.00	0.15	0.10	0.04	0.02	0.00
2.50E-02	Upstream of regulator	5.51E+00	9.92E+02	4.31E+02	1.00	1.00	1.00	1.00	0.35	0.05	0.03
1.00E-01	Upstream of regulator	8.82E+01	1.59E+04	6.90E+03	1.00	1.00	1.00	1.00	1.00	1.00	0.10
4.57E-01	Upstream of regulator	1.84E+03	3.31E+05	1.44E+05	1.00	1.00	1.00	1.00	1.00	1.00	1.00

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 ((kg)	Flash fire danger zone (m)	Probability of Fatality 5 m	10 m	20 m	30 m	50 m	100 m	200 m
5.00E-03	Upstream of regulator	2.20E-01	3.97E+01	10	1.00	1.00	0.00	0.00	0.00	0.00	0.00
2.50E-02	Upstream of regulator	5.51E+00	9.92E+02	30	1.00	1.00	1.00	0.00	0.00	0.00	0.00
1.00E-01	Upstream of regulator	8.82E+01	1.59E+04	80	1.00	1.00	1.00	1.00	1.00	0.00	0.00
4.57E-01	Upstream of regulator	1.84E+03	3.31E+05	180	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Leak size(mm) (m)	Location	Burn rate (kg/s)	Mass in cloud ((kg)	Flash fire danger zone (m)	Probability of 4.7 kW/m2 5 m	10 m	20 m	30 m	50 m	100 m	200 m
5.00E-03	Upstream of regulator	2.20E-01	3.97E+01	10	1.00	1.00	1.00	0.00	0.00	0.00	0.00
2.50E-02	Upstream of regulator	5.51E+00	9.92E+02	30	1.00	1.00	1.00	1.00	0.00	1.00	0.00
1.00E-01	Upstream of regulator	8.82E+01	1.59E+04	80	1.00	1.00	1.00	1.00	1.00	1.00	0.00
4.57E-01	Upstream of regulator	1.84E+03	3.31E+05	180	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Leak size(mm) (m)	Location	Burn rate (kg/s)	Mass in cloud ((kg)	Flash fire danger zone (m)	Probability of 23 kW/m2 5 m	10 m	20 m	30 m	50 m	100 m	200 m
5.00E-03	Upstream of regulator	2.20E-01	3.97E+01	10	1.00	1.00	0.00	0.00	0.00	0.00	0.00
2.50E-02	Upstream of regulator	5.51E+00	9.92E+02	30	1.00	1.00	1.00	0.00	0.00	0.00	0.00
1.00E-01	Upstream of regulator	8.82E+01	1.59E+04	80	1.00	1.00	1.00	1.00	1.00	0.00	0.00
4.57E-01	Upstream of regulator	1.84E+03	3.31E+05	180	1.00	1.00	1.00	1.00	1.00	1.00	1.00

RISK ASSESSMENT GAS SUPPLY PIPELINE
UPSTREAM OF REGULATOR

	Frequency (per metre per year) Jet fire	Flash fire	Explosion
<20mm	7.22E-10	6.51E-12	0
20 to 100 mm	6.19E-11	1.03E-11	0
>100 mm	0.00E+00	8.23E-12	0

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	7.22E-10	7.22E-10	7.08E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20 to 100 mm	6.19E-11	6.19E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
>100 mm	0.00E+00	0.00E+00	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	6.51E-12	6.51E-12	6.51E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20 to 100 mm	1.03E-11	1.03E-11	1.03E-11	1.03E-11	1.03E-11	0.00E+00	0.00E+00	0.00E+00
>100 mm	8.23E-12	8.23E-12	8.23E-12	8.23E-12	8.23E-12	8.23E-12	8.23E-12	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	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20 to 100 mm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
>100 mm	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Total fatality (per m per yr)

	5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m
<20mm	7.3E-10	7.3E-10	7.1E-10	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
20 to 100 mm	7.2E-11	7.2E-11	1.0E-11	1.0E-11	1.0E-11	0.0E+00	0.0E+00	0.0E+00
>100 mm	8.2E-12	8.2E-12	8.2E-12	8.2E-12	8.2E-12	8.2E-12	8.2E-12	0.0E+00
Total risk of fatality (per metre per year)	**8.1E-10**	**8.1E-10**	**7.3E-10**	**2.0E-11**	**1.7E-11**	**8.2E-12**	**8.2E-12**	**0.0E+00**

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.

Total risk of fatality (per pipeline effect zone)		**2.4E-07**	**2.4E-07**	**2.2E-07**	**6.1E-09**	**5.1E-09**	**2.5E-09**	**2.5E-09**	**0.0E+00**
metres	**0**	**5**	**10**	**20**	**30**	**50**	**100**	**200**	**300**

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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
	7.29E-10	7.29E-10	7.29E-10	7.29E-10	0.00E+00	6.51E-12	0.00E+00	0.00E+00
	7.22E-11	7.22E-11	7.22E-11	7.22E-11	7.22E-11	7.22E-11	0.00E+00	0.00E+00
	8.23E-12	8.23E-12	8.23E-12	8.23E-12	8.23E-12	8.23E-12	8.23E-12	8.23E-12
Total	**8.09E-10**	**8.09E-10**	**8.09E-10**	**8.09E-10**	**8.04E-11**	**8.69E-11**	**8.23E-12**	**8.23E-12**

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
	7.29E-10	7.29E-10	6.51E-12	7.22E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7.22E-11	7.22E-11	7.22E-11	7.22E-11	7.22E-11	0.00E+00	0.00E+00	0.00E+00
	8.23E-12	8.23E-12	8.23E-12	8.23E-12	8.23E-12	8.23E-12	8.23E-12	8.23E-12
Total	**8.09E-10**	**8.09E-10**	**8.69E-11**	**8.03E-10**	**8.04E-11**	**8.23E-12**	**8.23E-12**	**8.23E-12**

10 REFERENCES

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