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AGL Dalton Power Project Environmental Assessment

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Appendix J

PHA

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PRELIMINARY HAZARD ANALYSIS OF AGL'S PROPOSED DALTON POWER STATION, NSW

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Preliminary Hazard Analysis of AGL's Proposed Dalton Power Plant, NSW

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C	24/02/2011	Final Report following changes to pipeline route	Karin Nilsson	Maarten Tentij	Karin Nilsson

CONTENTS

List of Figures

List of Tables

LIST OF APPENDICES

EXECUTIVE SUMMARY

E1 – General

To meet the rising demand for electricity in NSW, AGL Energy Limited (AGL) is proposing to build and operate a new gas fired power plant at Dalton, North West of Gunning in the Southern Tablelands of New South Wales. Due to the potentially hazardous nature and quantities of hazardous materials stored and utilised on site, the facility itself is classified as potentially hazardous.

The objective of this PHA is to present the hazards and risks associated with the proposed power plant. Through the evaluation of likelihood and consequence of the major hazards, the risks to the community associated with proposed power plant may be estimated and compared to NSW Department of Planning risk criteria.

The aim of the PHA is to:

- Identify and analyse the hazards and risks associated with all processes involved with the handling and transporting of potentially hazardous material which form part of the new development;
- Assess the findings against the risk criteria currently in use by NSW Department of Planning;
- Identify opportunities for risk reduction, and make recommendations as appropriate.

The risk assessment has quantitatively determined the risk of fatality and injury to the public associated with the handling and processing of potentially hazardous material at the proposed development.

The report assesses the risks from the following facilities:

- The power plant at Dalton: and
- The supply pipeline carrying natural gas from the AGL Moomba to Sydney supply line to the power plant.

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.

The risk assessment technique involves the following general steps:

- Identification of the hazards associated with the proposed project, including those which may potentially injure people off-site or damage the off-site environment;

- Identification of the proposed safeguards to mitigate the likelihood and consequences of the hazardous events;

- Estimation of the magnitude of the consequences of these incidents;

- Where the consequences may affect the land uses outside the site boundary, estimation of the probability with which these incidents may occur;

- Estimation of the risk by combining the frequency of the event occurring with the probability of an undesired consequence;

- Comparison of the risk estimated with the guidelines and criteria relevant to the proposal.

E2 Results

The main hazard associated with the proposed project is associated with the handling of natural gas, which is a flammable gas held under pressure.

Hazards may arise in fixed plant, storage, and pipelines. The failure modes assessed in the PHA derived from historical failures of similar facilities and equipment. For the facilities which form part of the development, 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), 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.

E3 Risk Assessment and Conclusions

E3.1 Power Plant

The risk 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).

- The 10×10^{-6} per year fatality risk contour (relevant for active open spaces) remains well within the site boundaries. The criterion for open spaces is therefore satisfied.

- The 50×10^{-6} per year fatality risk contour (relevant for industry and business) remains well within the site boundaries. The criterion for industrial and business zoning is 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.

- The risk associated with the transport of dangerous goods and potentially hazardous material to the site is negligible.

E3.2 Gas Pipeline

The risk analysis showed that:

- While the risk of fatality contour extends 22 meters on either side of the centreline of the pipeline, 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). The criterion for residential areas is therefore satisfied.

- The 10×10^{-6} per year fatality risk contour (relevant for active open spaces) is not achieved and the risk associated with the pipeline is less than the open space criterion at all points along the pipeline. The criterion for open spaces is therefore satisfied.

- The 50×10^{-6} per year fatality risk contour (relevant for industry and business) is not achieved and the risk associated with the pipeline is less than the industrial and business zoning criterion at all points along the pipeline. The criterion for industrial and business zoning is therefore satisfied.

E4 Recommendations

The risk assessment carried out in this study assumed that the facility 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. The recommendations are listed in the order in which they were listed in the study.

Recommendation 1: It is recommended that a safety management system be implemented and used at the site, specifically as it applies to the proposed hazardous materials handling, pipelining and storages.

Recommendation 2: High and low pressures of the natural gas pipe are to be monitored during (and, if applicable, outside) operation of the power plant. These conditions will need to be associated with an automatic trip / shut down of the pipeline at the metering station in case of a major failure of the natural gas pipeline within the site boundary (as assumed in this QRA).

Recommendation 3: The use of fusible tubing around above ground high risk natural gas piping to be investigated – such tubing would be linked to automatic shut down of the fuel source.

Recommendation 4: The detailed design of the turbine housing and associated equipment should clearly outline the basis of safety used to ensure that explosive situations do not arise (/the risk is rendered negligible). Reference should be made to European ATEX Directive (Ref 9) and the UK HSE PM84 (Ref 10) or other guidance / regulation of equivalent safety.

Recommendation 5: Fire protection inside the turbine housing to be determined, including use of explosion panels and use of fire retardant material if appropriate.

Recommendation 6: A system should be put in place to ensure that any removal of critical safety function (e.g. for repair or exchange) is subject to careful scrutiny by plant management (decisions on whether to shut down plan or a turbine if a critical safety function is removed need to be canvassed).

Recommendation 7: Rotating machines to be designed such that risk associated with projectile is minimised (gas pipelines protected or not in probable line of projectile, people protected etc.)

Recommendation 8: Loud alarm and visual indication (e.g. strobe light) to be installed within the turbine housing, alerting any persons within these housings of the pending discharge of asphyxiants and allowing escape.

GLOSSARY

AGL	Australian Gas Light Company
AGLGN	AGL Gas Networks Trunk Pipeline
DLN	Dry Low NO_x
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
NO_x	Nitrogen oxides
OH&S	Occupational Health and Safety
PHA	Preliminary Hazard Analysis
SCADA	Supervisory Control and Data Acquisition
SIL	Safety Integrity Level
UK	United Kingdom

REPORT

1 INTRODUCTION

1.1 BACKGROUND

To meet the rising demand for electricity in NSW, AGL Energy Limited (AGL) is proposing to build and operate a gas fired power plant at Dalton, North West of Gunning in the Southern Tablelands of New South Wales. Due to the potentially hazardous nature and quantities of hazardous materials stored and utilised on site, the facility itself is classified as potentially hazardous.

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* Ref 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* (Ref 2).

This document forms an appendix to the Environmental Assessment and provides details of the PHA undertaken for the proposed power plant.

1.2 SCOPE AND AIM OF STUDY

The objective of this PHA is to present the hazards and risks associated with the proposed peaking power plant and the lateral gas supply pipeline (connecting the site to the Main Trunkline (referred to as the *Moomba to Sydney Pipeline*).

Through the evaluation of likelihood and consequence of the major hazards, the risks to the community associated with proposed power plant may be estimated and compared to NSW 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 processes;
- 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;

- Where offsite effects are identified, 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 (Ref 2); and
- Identification of risk reduction measures as deemed necessary.

At the time this PHA was conducted, the design of the power plant and associated gas supply pipeline was in its preliminary stages. Detailed plant 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

A property has been acquired by AGL for this purpose 3km north of the town of Dalton in the NSW Southern Tablelands. The site is located between Goulburn and Yass and approximately 11 km from the town of Gunning. A location map is presented in Figure 1 below.

Under the Gunning Local Environment Plan (LEP) the zoning for the site is 1A Rural. Power generation facilities are permissible in the 1A Rural zone with consent of Council.

The Yass to Banaby 330kV transmission line passes through the property and the Moomba to Wilton natural gas pipeline is within approximately 4km of the property.

The AGL property is South of the Lachlan River and is surrounded by pastoral properties with varying degrees of residential development. To the West it is bounded by Walshs Road together with two adjacent properties.

A site selection study of the Dalton Site was undertaken by Aurecon, which recommended a specific location as being suitable for the development, which is indicated below in Figure 1.

2.2 PROJECT PHASING

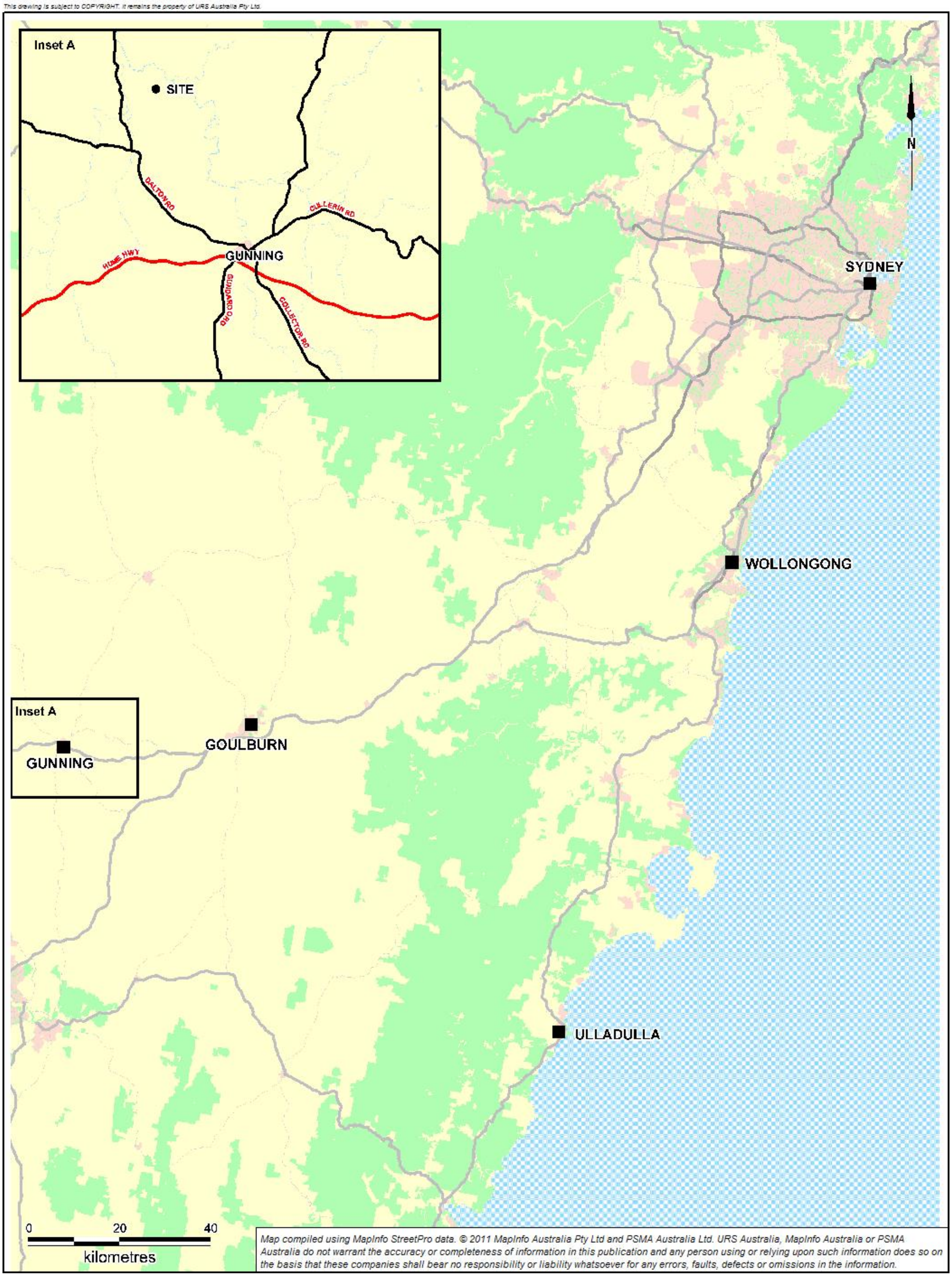
The power plant will be constructed in two stages and the final stage will include four to six turbines depending on the type of turbine selected. The types of turbines that may be used are listed in Table 1 below.

The power plant is to have an ultimate output of up to approximately 1500MW.

Table 1 - Open Cycle Turbine Units (examples)

Option	Type of Turbine	Stage 1	Stage 2 (total)
Option A	GE 9E (126 MW)	4 (504MW)	6 (756MW)
Option B	GE 9FA (255 MW)	3 (765MW)	4 (1020MW)
Option C	Alstom 13E2 (180 MW)	3 (540MW)	5 (900MW)
Option D	Siemens SGT5 2000E (168MW)	4 (672 MW)	6 (1008MW)

Figure 1 – Site Location



2.3 SITE LAYOUT

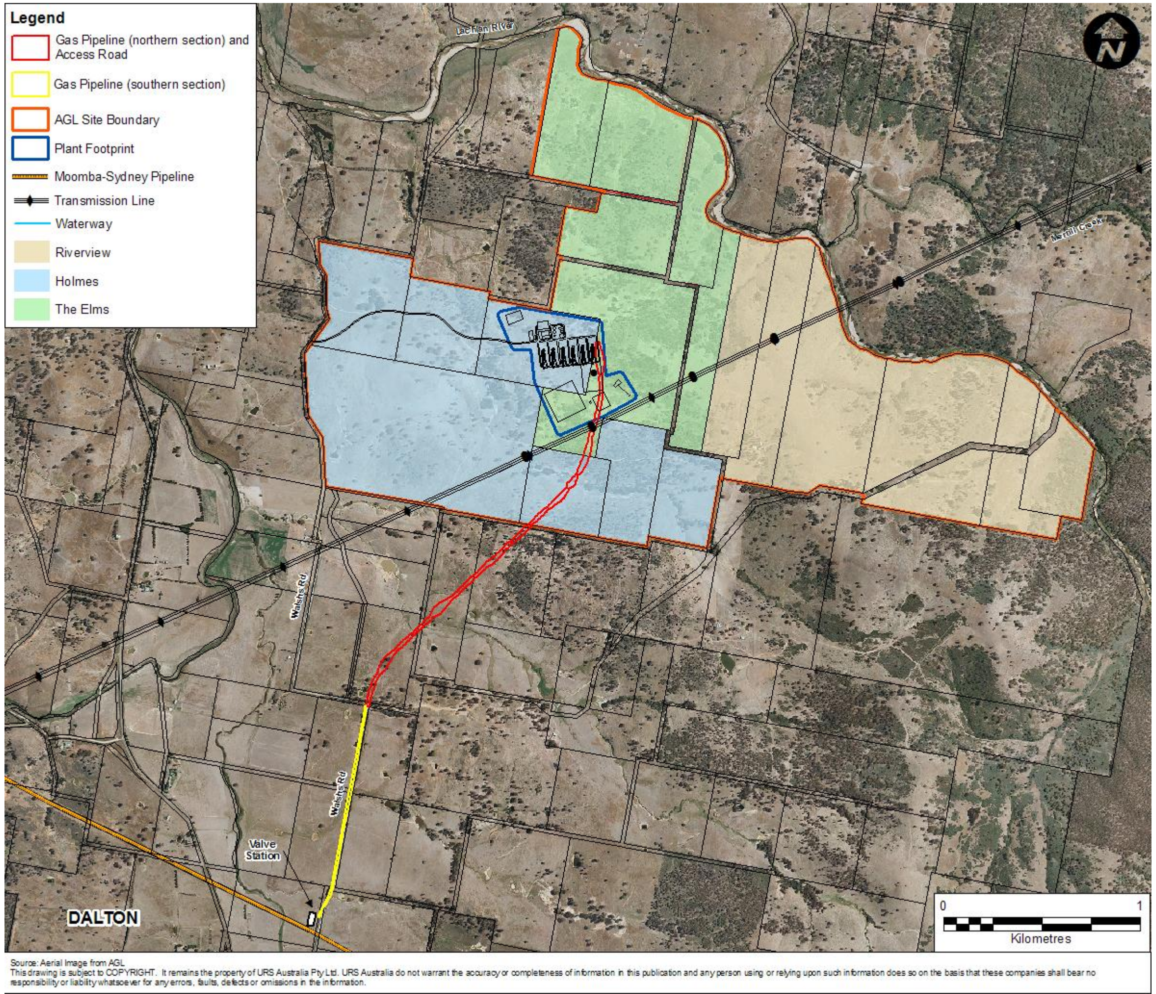
The site is serviced by existing energy infrastructure including the *Moomba to Sydney gas pipeline* supplying the gas to the site via a new lateral gas pipeline, as well as high voltage electricity transmission lines (which passes through the site).

The preliminary site and pipeline layout is presented in Figure 2 below.

Following completion of construction and commissioning, the major site features will include:

- The natural gas receiving station;
- Gas turbines (4 to 6 depending on the option taken, see above), air compressors and electricity generators inside turbine enclosures (“housings”);
- Generator transformers for each turbine;
- Exhaust stacks for each turbine;
- Inlet air evaporative cooler for each turbine;
- Demineralised and potable water storage tanks with associated pump(s);
- Raw and fire water storage tanks with associated pump(s);
- Evaporation pond;
- Stormwater pond (for surface water management);
- Water treatment plant;
- Service connections linked to the electricity transmission network, gas, compressed air and water supplies;

Figure 2 – Preliminary Site and Pipeline Layout



- Maintenance workshop building;
- Administration complex and control room with uncovered car park;
- Service roads;
- Fire pumps; and
- Gatehouse.

The switchyard will be located between the 330kV transmission lines, to which it will connect, and to the 330kV output from the power plant generator transformers. It is expected that the switchyard could be owned by Transgrid and a standalone yard is proposed. The area for the switchyard will include all the necessary facilities and will be independent from the power plant.

A gas supply pipeline easement will be developed to connect the site to the Moomba to Sydney Pipeline, as shown in Figure 2. The pipeline would run from a new off-take from the Moomba to Sydney Pipeline through a new valve station, along the western side of Walsh Road, and then north (within a new easement) connecting to the proposed power plant. A new access road would be incorporated into the new easement between Walsh Road and the power plant, as illustrated in Figure 2, allowing for maintenance access to the pipeline.

The gas supply pipeline would be located underground apart from the point where it leaves the Moomba to Sydney Pipeline and the point where it reaches the power plant.

2.4 Operating Hours and Staffing

Each phase of the proposed facility would be capable of operating for 24 hours per day. However, actual operational hours for each of the phases would be dependent upon periodic electricity demand and economic factors (the power plant is designed for peaking demand only, generally operating between 2 and 15% of the time.

It is expected that the facility would be staffed during day-shift only. 24-hour monitoring of the site may be provided from AGL's national control centre at Mt Beauty. Personnel could be called to the site at any time in case of a process upset.

This following risk assessment has conservatively assumed that the power plant is operational 100% of the time..

2.5 Security

The power plant, including the gas receiving and gas receiving stations, will be located within a fenced off area accessed through a security gate.

There will be a Gatehouse will be generally unmanned but have 24 hour communication with AGL's control centre at Mt Beauty.

2.6 ACCESS ROADS

As shown in Figure 2 above, the power plant will be accessed from Walshs Road using a purpose built access road north to the site. Internal access roads will be constructed on hard surface inside the power plant to allow vehicle and/or forklift access as required.

2.7 GAS TURBINE OPERATION

2.7.1 Theory

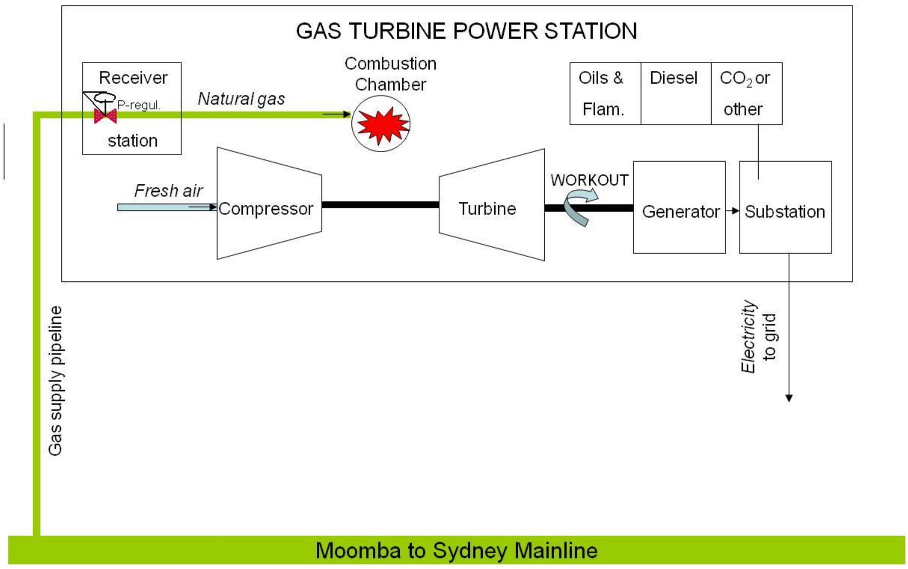
Gas turbines are rotary engines that extract energy from a flow of combustion gas (in this case natural gas). A gas turbine largely consists of an upstream air compressor coupled to a downstream gas turbine, and a combustion chamber in-between.

Energy is generated where air is mixed with the combustion gas and ignited in the combustion chamber. The heat produced by the burning fuel causes the air to expand and rush past the turbine causing it to spin.

Energy is extracted in the form of shaft power, compressed air and thrust and used to generate electricity in the transformer.

A block flow diagram of the gas turbine station and gas supply is shown in Figure 4 below. A view inside a typical gas turbine is shown in Figure 4.

Figure 3 – Block Flow Diagram of Turbine Plant and Gas Supply



2.8 DETAILS OF PLANT EQUIPMENT

Below is a brief explanation as to the operation of the equipment on site. Details of associated safeguards are presented in Section 5.2 below.

2.8.1 Gas turbines

The development will comprise four to six industrial gas turbines (depending on the option chosen) with the electricity generated fed into the 330 kV transmission network via a new switchyard on the site that will include high voltage transformers and circuit breakers. Natural gas for the turbines will be supplied by the Moomba to Sydney natural gas pipeline which runs approximately 4 km from the site.

The nature of the proposed power plant to meet peaking demand only largely determines the type of gas turbine selected. Required is a turbine that can handle intermittent operation, a high number of starts and stops and is reliable. As the plant will only run during high peak times, it is essential that multiple gas turbines are installed to increase reliability.

The gas turbines will already be largely assembled when they are transported to site. Each gas turbine generator unit consists mainly of three heavy lift items namely the gas turbine, electricity generator and high voltage transformer. In each gas turbine generator, air is drawn in through filters to remove particulate matter and is compressed. Following compression, the air flows into the combustion chambers where natural gas is injected and burnt, increasing the temperature to approximately 1100 – 1200 degrees Celsius.

The combustors feature Dry Low NO_x (DLN) technology to produce very low NO_x emissions. The combustion products from the combustion chambers enter the turbine area and expand to atmospheric pressure, reducing in temperature to around 550 degrees Celsius. As the gas expands, it drives each turbine, which in turn drives the compressor and an electrical generator. From the turbine, the heated exhaust gases pass through a silencer unit and are discharged through a stack.

2.8.2 Electrical generators

Attached to each gas turbine is an electrical generator that generates electricity when rotated by the turbine. The generators are large items of plant, assembled off site and delivered in one piece.

2.8.3 Transformers

The electrical transformer step the voltage from the generator at around 22 kilovolts to 330 kilovolts. The transformer(s) will be located adjacent to the existing 330 kilovolt lines running through the site with appropriate switchgear to ensure safe and reliable connection to the electricity network.

2.8.4 Gas Supply Pipeline (Lateral Pipeline)

Natural gas is the fuel for the gas turbines, sourced from the Moomba to Sydney pipeline. An approximately 4 kilometre lateral pipeline will transport the gas from the Moomba to Sydney pipeline to the gas receiving station at the entrance to the power plant.

The gas supply pipeline will deliver gas at a rate of about 140 tonnes per hour at a nominal maximum operating pressure of 8 MPa (MAOP of 12 MPa) up to the gas conditioning station where it will be reduced to 3.4 MPa prior to use by the gas turbine facility. This can be achieved using a pipeline of approximately 400 mm diameter.

The gas supply pipeline will be approximately 3.4km long, stretching approximately north to the power plant, as shown in Figure 2 above.

The gas supply to the plant will be controlled by the operator located remotely at one of AGL's national control room. Telemetered information will be received from the meter stations and the new valve station. All of this is recorded by a Supervisory Control and Data Acquisition (SCADA) system. The operator will be able to open and close the valve at the new vale station and control the flow rate through the pipeline. AGL maintains regular contact with the operator of the Moomba to Sydney natural gas pipeline. The operators of the Moomba to Sydney pipeline will also monitor and control the flow of gas to the power station.

The pipeline will be compliant with AS2885 (Ref 3). The detailed design of the gas supply pipelines is not completed and the assumptions as to the technical details made for this PHA are given in Table 2 below and further in the listing below the table.

Table 2 – Summary of Assumptions Made in the PHA for the Gas Supply Pipeline Design

Item	Pipeline Design
Pipe Diameter	400 mm NB (nominal bore)
Pipe Length	Approximately 3.4km
Design MAOP[1]	12 MPa
Operating pressure	Maximum 8MPa
Class Location to AS2885	R1 (broadly rural) with 40 hectare blocks
Pipe Thickness	12.7 mm
Depth of Cover	At least 750mm (or 450mm in rock)

[1] MAOP = maximum allowable operating pressure

- One valve station will be installed at the gas receiving station which is located at the Moomba to Sydney off-take. The valve station will include a remotely controlled slam shut valve (or other quick acting shut off device). The remote controlled shut off device will be fireproof.

- It is also assumed that there will be a bypass line around the valve station, which contains an isolation valve. This bypass is required for start-up and shutdown as well as for proof testing of the mainline valve while the pipeline is in operation.

- The pressure tapping points associated with the remotely operated valves are assumed to allow a drop in line pressure to be quickly ascertained. Closure of the valves at the entry to the power plant or at the Moomba to Sydney end of the line may be triggered automatically (to be determined in detailed design) by the sensor upon low pressure, or is manually initiated 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.

2.8.5 Gas Receiving Station and On-site Pipelines

The gas receiving station will be constructed inside the plant boundary. The power plant pipework will be 300 to 450 mm nominal diameter, with a pressure rating exceeding that of the operating pressure.

A remotely operable isolation valve will be installed at the pipeline within the gas receiving station, together with a non return valve, a pressure control valve and a quick acting, remotely controlled, emergency isolation valve.

The isolation valve will be fireproof.

There will be a bypass line around this valve station, which contains an isolation valve. This bypass is required for start-up and shutdown as well as for proof testing of the mainline valve while the pipeline is in operation.

Up to 500 metres of piping and up to 250 flanges are assumed associated with the gas receiving station and pipes used to transfer gas to the turbines. Both the length of pipework and the number of flanges is assumed to be highly conservative.

The article by Professor Michael Valenti for The American Society of Mechanical Engineers (Ref 4) provides an estimate of the complexity of the pipework and flange-systems inside the acoustic housing of the turbines. Prof Valenti states: *For example, a 250-megawatt turbine's pipework may have more than 200 flanges and 90 flexible joints*.

The following assumptions were made as to the design of the natural gas pipelines associated with the power plant – these assumptions are believed to be conservative.

Table 3 – Summary of Assumptions Made in the QRA for the Power Plant Natural Gas Pipeline

Feature	Assumption(s)
General – Overall Power Plant	
Percent operational	The power plant is expected to be operational for only a fraction of the time (less than 15% of the time). All data used in the present risk assessment are however for a plant operating 100% of the time. The quantitative risk results are valid, though highly conservative, for the plant under the expected operating conditions. They are also valid for a plant operating 100% of the time.
Gas Pipelines Inside Power Plant, including Gas Receiving Station	
Length	10 metres aboveground upstream of the pressure regulator. 500 metres (underground) and 60 meters (above ground, all turbines) downstream of the pressure regulator, stretching from the gas receiving station through to each turbine.
Diameter	450 mm nominal diameter.
Number of flanges	20 flanges upstream of the pressure regulator valve and 200 flanges after (up to the entry of the turbine enclosure).
Pressure	6 MPa up to the pressure regulator, then 3.5 MPa.
Temperature	25^{o}C
Features	Gas receiving station with pressure regulator, by-pass valves, non return valves, pressure indication, flow indication and transmitter. Remote controlled and automatic emergency isolation valve which closes on a high and low pressure (a low pressure may indicate a massive hole in the pipeline).
Gas Piping to Turbine Inside Turbine Enclosure	
Length	10 metres for each turbine
Number of flanges	200 flanges inside each turbine housing, 90 flexible joints (modelled in this QRA as flanges but with 3 times the failure rate compared with flanges)
Pressure	3.5 MPa
Temperature	25^{o}C

2.8.6 Ancillary equipment

To facilitate the extreme combustion conditions inside the combustion chambers associated with the turbines, air is compressed and cooled prior to entry into the combustion chamber of the gas turbine. This requires an air compressor attached to the turbine and an evaporative water cooling unit.

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*, Ref 1) and HIPAP No 4 (*Risk Criteria for Land Use Planning*, Ref 2). These documents describe the methodology and the criteria to be used in PHAs, as required by the NSW Department of Planning for major "potentially hazardous" development.

There are five stages in risk assessment (as per Ref 1):

Stage 1. Hazard Identification: The hazard identification includes a review of potential hazards associated with all dangerous and hazardous goods to be processed, used and handled at the power plant and associated pipelines and facilities. 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 facility 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 (HAZID) word diagram. The HAZID 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 HAZID 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 vessels and 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 calculations is shown in the form of risk contours overlaid on a map of the development area. For pipelines (as for other transport activities), the individual risk contours are best represented as risk transects, showing the risk as a function of the distance from the pipeline.

- Injury and irritation risk, i.e. the likelihood of injury to individuals at locations around the site 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 NSW Department of Planning (Ref 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. It is assumed that the person will 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* (Ref 2). The criteria for maximum tolerable individual risk from a new development are shown in Table 4 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 4 – Criteria for Tolerable Individual Risk From A New Development

Land Use	Maximum Tolerable Risk ($x10^{-6}$ per year[2])
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

Land Use		Maximum Tolerable Risk ($x10^{-6}$ per year[2])
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 5 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 5 – Risk to Individuals

Activity / Type of Risk	Published levels of risk (10^{-6} per year[2])
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

[2] 10^{-6} per year = per million per year

Activity / Type of Risk	Published levels of risk (10^{-6} per year[2])
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 (Ref 2), the criteria in the 1996 regional study of Port Botany by the Department of Planning[3] have been used for indicative purposes, as presented in Table 6 below.

Table 6 - 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 6 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.

[3] then the Department of Urban Affairs and Planning

- 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, the computer software tool ISORIS from the Warren Centre for Advanced Engineering (Ref 5) 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 4 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 plants 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 plants 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 plant". This hypothetical average plant 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 plant is significantly above average, the risk will probably be overestimated. However, it is extremely difficult to quantify the effect of software on plant 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 1: It is recommended that a safety management system be implemented and used at the site, specifically as it applies to the proposed hazardous materials handling, pipelining and storages.

4 HAZARD IDENTIFICATION

4.1 HAZARDOUS MATERIALS

A list of the types and storage quantities of materials that are likely to be found at the proposed site is included in the following table. Quantities are indicative only.

Table 7 - Typical Chemicals Stored Onsite

Plant Area / Use	Chemical/Product	Anticipated Storage Qty
Natural Gas supply	Natural gas	No storage on site unless the power plant is in shut down mode / not using any natural gas in which case the natural gas pipelines may be closed in. Approximately a total of 500 m long, 450 mm diameter, 3.4 MPa pressure, buried pipe (atmospheric temperature).
Backup generator	Diesel	10,000 L in fixed tank
Turbines, pumps, air compressor, lubrication	Turbine oils (combustible oil)	1,000 L in small IBC
Transformers	Insulating oil (non PCB)	1,000 L in small IBC
Fire protection	Oil for fire pump	600 L in small IBC
	Carbon dioxide and/or other proprietary fire protection gases such as Inergen and/or FM200	As required
Closed loop cooling system	Scale inhibitor	100 L
	Betz Foam-Trol	100 L
Chemicals for maintenance / repair work and clean-up	Carbon dioxide	As required for fuel line purging, in cylinders
	Nitrogen	As required for Gas line purging, in cylinders
	Acetone	100 L for miscellaneous cleaning

Note: Brand names are for example only

Natural gas is composed predominantly of methane gas. The composition of natural gas from Moomba is shown in Table 8 below.

Table 8 – Approximate Composition of Natural Gas (in Moomba to Sydney Pipeline)

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 9 below.

Table 9 - 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

The main hazard associated with the proposed site is related to a leak of flammable natural gas.

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:

- The pipelines, vessel or equipment 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 (for example within the gas turbine housing) 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 at the site, 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 operators of the facility (in accordance with NSW Occupational Health and Safety Act and its associated legislation (Ref 6)).

Other potential hazards are associated with the handling and use of diesel and other combustible liquids (i.e. the oils used for pumps, compressors, turbines etc.). Minor quantities of flammable acetone (used for cleaning) will also introduce a potential fire hazard.

A total of 16 hazards were identified at the power plant site, as listed in Table 10 below.

The *Hazard Identification Word Diagram* in Table 11 below details these hazards, their potential initiating events as well as their proposed controls.

Table 10 - Summary of Identified Hazards

Number	Hazardous Event Potential	Offsite Impact Potential	Assessed in Section
1	Leak of natural gas to atmosphere from gas pipes on-site (outside the turbine housings).	Y	5.2.1
2	Operational error of the pipeline causes leak.	Y	5.2.1
3	Venting of gas from process.	N	-
4	Explosion within piping or inside a vessel.	N	5.2.1
5	Leak of natural gas to inside the turbine housing from damage to pipe, corrosion, sabotage etc.	Y	5.2.3
6	Leak of natural gas to inside the turbine housing due to projectile.	N	5.2.3
7	Release of carbon dioxide (or of other fire quenching material to be used for fire protection)	N	5.2.4
8	Loss of containment of flammable or combustible liquid (including diesel, oils and acetone)	N	5.2.5
9	Fire at transformers	N	5.2.6
10	Flooding	N	5.2.6
11	Earthquake	N	5.2.6
12	Land subsidence due to mining activity	N	5.2.6
13	Aircraft crash on power plant site	N	5.2.6
14	Terrorist activity or vandalism to natural gas installation.	N	5.2.6
15	Transport of potentially hazardous material to the site (diesel, acetone)	N	0
16	Leak of natural gas from the gas supply pipelines	Y	5.2.1

4.3 HAZARD IDENTIFICATION WORD DIAGRAM

The Hazard Identification Word Diagram, included in Table 11 below, provides a summary of the hazardous incidents identified for the proposed site and their associated mitigating features. Each section of the power plant and associated pipelines was reviewed in turn in a workshop, to determine the potentially hazardous scenarios relevant to that section. The sections reviewed were:

- High pressure natural gas pipeline on-site up to the gas receiving station, including gas receiving station;

- Reduced pressure natural gas from the receiving station and on-site gas transport to the turbines at the power plant;
- Turbine enclosure;
- Carbon dioxide (or other asphyxiant fire quenching gas) storage;
- Storage and handling of combustible and flammable liquids (oils, diesel, acetone);
- Power generation;
- Potential hazards that could affect the whole site; and
- Natural gas supply pipeline from the Moomba to Sydney Pipeline to the power plant, including valve station at the connection with the main pipeline.

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 below.

Table 11 – Hazard Identification Word Diagram

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
SECTION OF PLANT: Gas Receiving Station and On-Site Gas Transport at the Power Plant			
1. Leak of natural gas to atmosphere from gas pipes on-site (outside the turbine housings).	Mechanical impact, weld failure, operational error corrosion, sabotage etc.	Release of odourised natural gas. If ignition source available (or if ignited at source due to static electricity), then flash fire or jet fire possible.	- Use of fully welded pipework wherever possible. Minimise pipe-runs (pipe lengths). Pipes of robust design. - Actuated isolation valve at receiving station inlet acting as under-pressure protection (connected to automatic closure of emergency isolation valve in case of major fault in downstream pipeline, see Recommendation 2. - Investigate the use of fusible tubing around high risk leak piping to be investigated, see Recommendation 3. - Data communication systems (SCADA or other). - Fire protection system to be installed. - NG disperses readily upwards, minimising chances of ignition. - Cathodic protection for external corrosion. Internal corrosion virtually absent with clean hydrocarbon. - Regular plant tours. Vegetation browning off around ground leak (lack of oxygen) aid detection. A small hole will be sonic – possible detection through high pitched sound. Icing up at leak point improves detection - Valve station contained on site. - Minimum number of flanges. Welded connections wherever possible. All welds are x-rayed (100%). **The risk associated with this scenario will be evaluated quantitatively.**

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
2. Operational error of the pipeline causes leak.	Operational error causes pressure excursion leading to failure of the pipeline.	Release of natural gas. If ignition, then possibility of fire.	- The pipelines are to be hydrotested at a minimum of 1.4 times the MAOP (maximum allowable operating pressure). - The pipeline can operate closed in (i.e. the main valve at the entrance to the site may be closed and the valve to the turbines may be shut). - Appropriate pressure relief designed to standards and codes. - Pressures of the natural gas supply will be monitored and if required emergency isolation can be initiated, see Recommendation 2. **The risk associated with this scenario will be evaluated quantitatively.**
3. Venting of gas from process.	Maintenance work, shutdown, flaring.	Release of flammable gas or heat to process area. Fire hazard.	- Releases to be piped to safe area (flare). Vents to elevated point. **Standard design practices to be applied. Vent points to be located as per code requirements. This scenario is not considered as credible and will not be investigated further.**
4. An explosion within piping or inside a vessel	Failure of maintenance activities creates ingress of air into natural gas piping and vessels and subsequent start-up without adequate purging.	Possible explosion. Due to the limited quantities of gas involved the effects of the explosion would however not be expected to pose a threat to nearby businesses or to any residential areas in the vicinity.	- This scenario is only theoretically possible during start-up, shut-down and maintenance operations; - Piping normally operated at a positive pressure, preventing ingress of air; - Prevention of ingress of air will be considered throughout the design and operation of the facility (for example in the preparation of start-up, shut-down and maintenance procedures). **This scenario does not appear credible for this site.**

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
SECTION OF PLANT: Turbine Enclosure			
5. Leak of natural gas to inside of turbine housing from damage to pipe, corrosion, sabotage etc.	Mechanical impact, weld failure, corrosion, sabotage etc.	Release of odourised natural gas (NG). If ignition source available (or if ignited at source), then flash fire or jet fire possible. If confinement sufficient then an explosion is possible with overpressure effects and projectiles. Due to the limited quantities of gas involved and the size of the site, the effects of the explosion would however not be expected to pose a threat to nearby businesses or to any residential areas in the vicinity.	- Control of ignition sources as per Australian Standard Hazardous Zone requirements. - The detailed design of the turbine housing and associated equipments need to demonstrate that explosive situations do not arise and need to clearly outline the basis of safety used to this end (see Recommendations 4 & 5). Generally, the basis of safety includes a combination of well controlled ventilation flows, flammable gas detection with automatic response, explosion relief and explosion suppression. - Preventative maintenance procedures and schedules will be developed. - Training of operators and maintenance workers. - System put in place to ensure removal of safety critical functions is subject to careful scrutiny (see Recommendation 6). - Permit to Work procedures, including for entry into Confined Space. - Emergency procedures and drills. **The risk associated with this scenario will be evaluated quantitatively.**

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
6. Leak of natural gas to inside of turbine housing due to projectile.	Violent mechanical failure of rotating machine (compressor, turbine) creates projectile.	Projectile would be ejected with high energy. Personnel hazard if in the vicinity. If a gas pipe is hit by the projectile or associated equipment / instrumentation then it may fail, causing gas release and fire / explosion if ignition source.	- Preventative maintenance of rotating machines. - Vibration monitoring. - Shut down of machine and repair if out of alignment. - Rotating machines to be designed such that risk associated with projectile is minimised (gas pipelines protected or not in probable line of projectile, people protected etc.), see Recommendation 7. - Buried pipeline is not at risk from such projectiles. - Plant layout to be such that above ground pipelines are not in line of projectiles. **The risk associated with this scenario does not appear credible provided proper design and maintenance is carried out. This scenario will not be evaluated further.**
SECTION OF PLANT: Carbon dioxide (or other asphyxiant fire quenching gas) Storage			
7. Release of carbon dioxide (or of other fire quenching material to be used for fire protection) into turbine housing.	Leaking cylinders, flanges, pipes into enclosed area.	Potential asphyxiation of person inside the enclosed area if concentrations reach hazardous levels.	- Small quantities, impact localised to enclosed area. - Permit to Work requirements.. - Alarm (visual and audible) inside enclosed area allowing personnel escape prior to offloading carbon dioxide / other fire quenching material, see Recommendation 8. **The consequences of this scenario are local only to the immediate vicinity of the release. No off-site consequences expected.**

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
SECTION OF PLANT: Storage and Handling of Combustible and Flammable Liquids (oils, diesel, acetone)			
8. Loss of containment of flammable or combustible liquid.	Mechanical failure, damage to packaging / vessel etc.	Release of flammable acetone (max 100L) or Release of combustible oil (max 1,000L each vessel (x3) or 10,000L diesel (x1 vessel). If source of ignition present then possibility of pool fire. Environmental pollution if spill not contained and/or not properly cleaned up / disposed off.	- Bunding requirements as per AS1940, i.e. 100% of the largest tank, with bunding design and construction as per Section 5.9.3 in AS1940. - Run-off from external (unbunded) areas would be captured in the *first flush* stormwater system which is designed to retain the first flush runoff from these areas. - Fire protection (fire extinguishers, hose reel requirements, separation distances etc) as per AS1940. - Design of ventilation of building as per AS1940 Section 4.4 with regards to flammable vapours. - Valving and piping associated with the storage as per AS1940 Section 7. - Control of ignition sources as per AS1940 Section 9.7.6. - Communication systems. **The credible event from this release is an environmental pollution if not contained on-site. Environmental management will be such that any run-off from the site will be captured in the sedimentation pond. Further, the consequences of this scenario are local only. No off-site consequences expected. This scenario will not be evaluated further.**

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
		Power Generation	
9. Fire at transformers	Faulty connection, internal fault in transformer.	Fire in switchyard. Material damage.	- Gravel around switchyard provides separation distance from neighbouring combustible material (grass, bush, etc.) and ensures any oil spill seeps into the gravel and does no pool. - Fire remains localised to switchyard. **The consequences of this scenario are local only to the immediate vicinity of the release. No off-site consequences expected. This scenario will not be evaluated further.**
		WHOLE SITE	
10. Flooding results in process upsets.	Uncontrolled flooding of site	Potential for damage to process / storage facilities resulting in release of hazardous material (particularly natural gas)	- Topography prevents flooding from any rivers or streams. **No off-site consequences expected. This scenario will not be evaluated further.**
11. Earthquake causes failure and subsequent leak of natural gas.	Earthquake creates failure of pipes / pipelines resulting in potential for rupture or massive leak. From the Dalton Siting Study (Ref 7): *The Dalton-Gunning Zone, only 60 km north of Canberra, has been assessed as one of the highest hazard earthquake areas in eastern Australia (Gaull and others, 1990).*	Release of natural gas. If ignition, then possibility of flash or jet fire.	- From the Dalton Siting Study (Ref 7): *The potential for heightened earthquake activity at the site can be accommodated in the design of the foundations for the proposed plant.* - Thick walled pipe and pipe grade can withstand considerable plastic deformation. - Structures and plant are designed to withstand earthquake effects using well-established procedures in accordance with relevant Australian or international standards. **The risk associated with this scenario will need to be rendered negligible through design (i.e. inherent safety to be incorporated into the detailed design). This scenario will not be evaluated further.**

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
12. Land subsidence causes failure and subsequent leak of natural gas.	Land subsiding due to mining activities in area other earth movement creates failure of pipes / pipelines resulting in potential for rupture or massive leak.	Release of natural gas. If ignition, then possibility of flash or jet fire.	- Thick walled pipe and pipe grade can withstand considerable plastic deformation. - Subsidence issue to be taken into account during detailed design, including requirements for thrust blocks on pipelines to be over-sized and prevented from separating from the pipe. Further, from the Dalton *Siting Study* (Ref 7): • *There is no evidence on any large scale landslides; and* • *There are no known major active volcanic or surface tectonic structures in the project area.* Further, a geotechnical investigation will be conducted for the site. **The risk associated with this scenario will need to be rendered negligible through design (i.e. inherent safety to be incorporated into the detailed design).**
13. Aircraft crash results in process upsets, potential damage to process / storage facilities resulting in hazardous releases	Aircraft crash	Potential damage to process / storage facilities resulting in hazardous releases, fire / explosion. Relatively small quantities of gas held within the power plant and very large site – effect unlikely to go off-site.	- Occupied site relatively small – aircraft crash unlikely. - Buried pipelines unlikely to be susceptible to aircraft crash. - Automatic emergency isolation valve (fire proof) at the gas receiving station. Also Non Return Valve.

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
14. Terrorist activity or vandalism to natural gas installation.	Terrorism / vandalism	Massive release of natural gas. If ignition, then possibility of flash or jet fire.	- Terrorism and severe vandalism currently unlikely in Australia. - Buried pipelines and no valve points at public areas. - Fenced power plant. - Security measures will include fencing, secure access, CCTV, and staffing - Regular and periodic surveillance. - See also scenario 1 above. **This scenario does not appear credible for this site.**
TRANSPORT RISKS			
15. Transport of potentially hazardous material to the site (diesel, acetone)	Transport accident causes release to the environment	Release of hazardous material onto the roadways and into the environment causing pollution. If ignition source then possibility of fire (note that diesel is not easily ignited).	- Oil and diesel transported to site in relatively small quantities. Diesel is used only for the occasional use of the stand-by emergency generator and oils are used to top up the gear boxes of the turbines, pumps, air compressors etc. - Very infrequent transport - It is expected that a maximum of 3 deliveries per year (conservative) will be sufficient for the operation of the site. - Access roads to site to be of adequate construction for the use and to be maintained / repaired. - General transport risks of such material are handled by transport company's safety requirements. Clean up and incident management as per transport company procedure.

Event	Cause/Comments	Possible Consequences	Prevention/ Protection
SECTION OF PLANT: Natural Gas Supply Pipelines (AGLGN Trunk / EGP to the Site Boundary)			
16. 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.	- Gas supply pipeline runs within AGL owned easement. - Signage along pipe route, including Dial Before You Dig information. Drawings available to Dial Before You Dig. - Resistance of pipelines to penetration through use of pipe thickness and low design factor. - Automatic shut down from low pressure trips if massive leak at pipeline prevents backflow from power plant and uncontrolled flow from Moomba to Sydney pipeline. Manual shut down (by isolating manually at the Moomba to Sydney pipeline off-take). - Natural gas disperses readily upwards, minimising chances of ignition. Explosion not credible in unconfined situation. **The risk associated with this scenario will be evaluated quantitatively.**

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 plant 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:

- NSW Occupational Health and Safety Act and its associated legislation including but not limited to the Dangerous Goods Regulations, Construction Safety Regulations, and the Factories Shops and Industries Regulations.
- NOHSC:1015(2001) - National Occupational Health & Safety Commission (NOHSC): Storage and Handling of Workplace Dangerous Goods.
- AS2885 - Pipelines – Gas and liquid petroleum, Parts 1, 2 and 3
- 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.
- AS3600 - Concrete Structures (for foundation and plinth).
- AS 1692 - Tanks for flammable and combustible liquids.
- API 620 - Design and construction of large welded low-pressure storage tanks.
- API 650 - Welded steel tanks for oil storage.
- AS1345 - Identification of the Contents of Pipes, Conduits and Ducts.

- ANSI Z 358.1 – For safety shower and eyewash facilities.
- AS 3780 – Storage and Handling of Corrosives.

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

5.2.1 Leak of Natural Gas from the Supply Pipeline

Australian Standard AS2885 (Ref 3) 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 the entire length of the run.

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 supply 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 11 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 (Ref 8). The data was collated covers a length-time of more than 970,000 km-yrs. Experience within Australia (APA Group, 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) and that the gas supply pipeline is located entirely within an AGL easement.

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 pipe thickness and low design factor.

In the very unlikely event of a damage to a pipeline which causes a leak, a vailve isolation would be activated at the power plant (preventing back flow from the plant and preventing uncontrolled flow from this pipeline. If the leak is less substantial, the activation would be manual. If the automatic trip is not activated then shut down would be manual by closing the slam shut valve(s).

Note also that natural gas disperses readily upwards, reducing chances of ignition. Explosion is not believed to be a credible in an unconfined situation such as for the pipeline.

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 valve stations 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 will 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) will be adopted as a minimum requirement for the design and construction of the pipelines. The pipeline will be constructed of seamless piping of 400 mm diameter (NB) and will be radiographed (including all welds).

  Factors such as the thickness of the pipe-wall, low pressure and temperature cycling and the material grade used makes this pipeline not susceptible to unzipping (Ref 3).

  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 gas supply pipeline will be coated with polyethylene (or other) coating. 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). In the present development, this potential is minimised through the fact that only one pipeline lays within the new easement. Further, 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. This scenario is further discussed in Section 5.2.6 below.

- *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. Icing up at leak point improves detection.

  - *Nearby explosion.* The potential for a domino incident due to an incident at the neighbouring Moomba to Sydney Pipeline or the ethane was canvassed. The preventative features for this type of incident include internal risk management procedures / systems in use by the natural gas / ethane pipeline owners and operators; the pipelines 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 ethane pipelines. Further, natural gas disperses readily upwards, minimising chances of ignition and making explosion not credible in unconfined situation; and the fact that all pipelines will be buried at a depth of at least 750mm (450mm in rock).

- *Terrorism / vandalism.* Terrorism and severe vandalism are currently unlikely in Australia and the pipeline is 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 power plant may be closed). There is 24hour monitoring of the Moomba to Sydney pipeline. Continuous observation of pressure of the gas supply pipeline from the plant Control Room.

Recommendation 2: High and low pressures of the natural gas supply to be monitored. If required (as defined in a detailed HAZOP study) these conditions may need to be associated with an automatic trip / shut down.

5.2.2 Gas Receiving Station and Gas Pipes Within the Power Plant

A. Pipeline / Vessel Leaks

Hazards at the gas treatment plant may arise in the following: fixed plant, storage, and pipelines. The failure modes are derived from historical failures of similar equipment and are described in the following sections.

- **Piping Failures:** Pressure piping may fail as a result of corrosion, erosion, mechanical impact damage, pressure surge ("water hammer") or operation outside design limitations of pressure and temperature. Pressure surge or significant deviations of pressure or temperature may cause a flanged joint to be overstressed, resulting in a small leak. Larger holes through to complete line fracture may conceivably result from mechanical impact or pressure surge.

- **Pressure Vessel Failures:** Storage and processing equipment in pressurised gas service will be operating at pressures of between 180 - 12,000 kPa (normal operating pressure at the turbines is 3,400 kPa). Vessels, such as the filter, may suffer from failure due to corrosion, erosion or mechanical impact. Major incidents involving the vessels include catastrophic failure and smaller leaks.

Corrosion and erosion caused failures usually result in small leaks which are detected early and corrected. Further, pressure surge or significant deviations of pressure or temperature may cause a flanged joint to be overstressed, resulting in a small leak.

Larger holes through to complete nozzle / pipe fracture may conceivably result from mechanical impact or pressure surge. These events are likely to be detected more rapidly, resulting in quicker isolation of the leak.

The potential to release natural gas will be minimised by:

- Use of fully welded pipework wherever possible;
- Minimizing pipe-runs (pipe lengths);
- Pipes of robust design (designed to comply with the requirements of Australian Standard AS4041 - Pressure piping);
- Detectors positioned strategically;
- Overpressure protection provided by three methods:
    - Rapid control valve closure under alarm conditions;
    - Emergency isolation valve installed at the inlet to the gas receiving station; and
    - Pressure relief valve.
- Control and communications equipment to provide remote monitoring and central control of system by operating staff.

Recommendation 3: The use of fusible tubing around above ground high risk natural gas piping to be investigated – such tubing would be linked to automatic shut down of the fuel source.

Also refer to recommendation 2.

A fire protection system will be installed in the facility. The fire control system will be developed to meet all requirements of Building Code of Australia and relevant Fire Authority. Elements of the system will include:

- Provision of water supply to the boundary of the site;
- Provision of booster pumps – duty and standby, if required, to meet the specified pressure objectives;
- Provision of permanent water storage, if required, to meet the supply volume objectives;
- Provision of a dedicated fire water ring main system through the facility; and
- Provision of fire hydrants and hose reels as nominated by above requirements.

B. Pipe / Vessel Internal Explosion

An explosion within piping or inside a vessel is theoretically possible during start-up, shut-down and maintenance operations. Due to the limited quantities of gas involved the effects of the explosion would however not be expected to pose a threat to nearby businesses or to any residential areas in the vicinity. Therefore, the probability of an explosion due to ignition of an explosive mixture within piping and vessels is considered negligible and will not be analysed further in this PHA. This conclusion is based on the following observations:

- All piping will normally operate at a positive pressure, thereby preventing ingress of air in the event of a pipe or other equipment failure;

- Prevention of ingress of air will be considered throughout the design and operation of the facility (for example in the preparation of start-up, shut-down and maintenance procedures).

5.2.3 Turbine Enclosure

A. Introduction and legislative framework

Despite the best efforts during design and management of the gas turbine power plant, natural gas turbines are not beyond mishap. Assuming that the gas turbines will be housed in acoustic chambers to reduce noise and permit turbine cooling by ventilation, a degree of confinement would be introduced. Ignition of fuels released into the turbine housing can cause fire and, because of the confinement, even explosions. Note that the explosive event is not credible in an unconfined scenario, where the turbines are not housed inside acoustic chambers.

Turbines typically rely on complex fuel supply pipes with multiple high-pressure joints to deliver the primary fuel, natural gas. *The large number of flanges and joints, combined with high pressures, presents an explosion hazard within the housing in the event of fuel leaks,* noted Mr Hunt, a chemical engineer at Eutech who led the risk assessment study[4] undertaken as a result of an explosion in a gas turbine acoustic housing at Teeside power plant, UK in 1996.

Since the Teeside explosion, guidelines and codes of practice have been developed, and are now in use, notably the European ATEX Directive (Ref 9) and the UK Health and Safety Executive's Guidance Note PM84: *Control of safety risks at gas turbines used for power generation* (Ref 10), both which are gaining wide acceptance in Australia.

The HSE Guidance Note PM84 covers the design and operation of gas turbine installations, making specific and practical recommendations with regard to

[4] At 12:25 a.m. on July 17, 1996, a fire and explosion occurred in the unit 106 turbine housing (enclosure) at the Teeside power plant.

operational functions such as alarm and engine trip conditions, and the maximum acceptable volume of clouds of explosive mixtures of gas and air.

Although it is not a specific legislative requirement to comply with these guidelines, they provide plant operators and legislators with a framework for assessing whether operation of a plant is satisfactory from a general Health and Safety standpoint (Ref 11). It is therefore appropriate for installations to adhere to the guidelines as far as is reasonably practicable, or other guidance / regulation of equivalent safety.

B. Basis of safety requirements

Basis of safety of turbine housings is generally achieved through a combination of:

- Elimination or control of sources of ignition as far as reasonably possible, following legislative requirements and Australian Standard requirement (e.g. for control of sources of ignition in potentially explosive atmosphere). Note that it may not be technically possible to reduce the temperature of all hot surfaces to eliminate the potential for an ignition of natural gas released into the turbine housing; and

- Limitation of the volume of the explosive atmosphere by the application of all or a combination of:

    - Dilution ventilation. Note that dilution ventilation reduces the size of any flammable cloud to below that which would result in a hazardous explosion if ignited. In order that the dilution ventilation ensures a negligible risk of an explosive atmosphere at all times, the ventilation system should have additional safety features such as e.g.: a 100% standby fan; an uninterruptible power supply to the ventilation fans; interlocks so that the gas turbine cannot start without sufficient ventilation; proven automatic isolation of fuel supply if ventilation fails;

    - Flammable gas detection combined with automatic shut-down of turbine and alarms;

    - Explosion relief,

    - Explosion suppression.

Preventative maintenance procedures and schedules will be developed for the proposed site, covering all critical safety functions such as leak detectors, ventilation fans, alarm systems etc. as appropriate.

Operators and maintenance workers at the plant will be trained to recognise the critical nature of critical safety functions (such as a leak detector, ventilation fan etc.).

Permit to Work systems will be put in place for work inside enclosed areas (including turbine housing).

Emergency procedures and drills for personnel will be developed.

A fire protection system will be installed in the facility, including inside the turbine hall, the generator transformers, as discussed under Section 5.2.1 above.

> **Recommendation 4:** The detailed design of the turbine housing and associated equipments should clearly outline the basis of safety used to ensure that explosive situations do not arise (/the risk is rendered negligible). Reference should be made to European ATEX Directive (Ref 9) and the UK HSE PM84 (Ref 10) or other guidance / regulation of equivalent safety.

> **Recommendation 5:** Fire protection inside the turbine housing to be determined, including use of explosion panels and use of fire retardant material if appropriate.

> **Recommendation 6:** A system should be put in place to ensure that any removal of critical safety function (e.g. for repair or exchange) is subject to careful scrutiny by plant management (decisions on whether to shut down a turbine if a critical safety function is removed need to be canvassed).

C. Assumptions Used for this PHA

It is assumed that the basis of safety design for the turbine will include:

- A highly reliable ventilation system, designed to remove even small leaks before lower flammable limits are reached,
- A number of gas detectors linked to automatic shut off of the gas supply,
- Automatic quenching using carbon dioxide or other if appropriate,
- Adequate separation distance between each turbine.

D. Other Hazards Associated with the Enclosure

Two other hazards associated with the enclosure were identified, namely:

- Violent mechanical failure of rotating machine (compressor, turbine) creates projectile(s).
- Release of carbon dioxide (or of other fire quenching material to be used for fire protection) into turbine housing creates risk of asphyxiation of person inside the enclosed area if concentrations reach hazardous levels.

The risk associated with the release of carbon dioxide is discussed under Section 5.2.4 below.

In case of a mechanical failure of the turbine, projectile may be ejected with high energy, creating a personnel hazard if in the vicinity. Further, if a gas pipe is hit by the projectile or associated equipment / instrumentation then it may fail, causing gas release and fire / explosion if an ignition source is present.

All rotating machines will be subject to regular and periodic preventative maintenance, including vibration monitoring. If any issues are identified, the machine would be shut down and repaired (as required).

Recommendation 7: Rotating machines to be designed such that risk associated with projectile is minimised (gas pipelines protected or not in probable line of projectile, people protected etc.).

Note that buried pipelines are not at risk from such projectiles.

5.2.4 Carbon dioxide Storage (or other asphyxiant fire quenching gas)

The turbine housings, electrical rooms and control rooms will contain fire suppressants, such as carbon dioxide or other fire quenching material.

Carbon dioxide is also anticipated to be required on site for purging purposes during maintenance work.

These materials may pose an asphyxiation hazard to people working within the housings. However, the quantities are relatively small, ensuring that any impact is localised to the enclosed area.

Permit to Work requirements will be established and adhered to when people are working inside the housings.

Recommendation 8: Loud alarm and visual indication (e.g. strobe light) to be installed within the housing, alerting any persons within these housings of the pending discharge of asphyxiants and allowing escape.

5.2.5 Storage and Handling of Combustible and Flammable Liquids (combustible diesel and oils or flammable acetone)

The following combustible and flammable liquids will be stored and handled on site:

- Diesel (10,000 L tank) used for the emergency backup generator;
- Combustible oils (3 x 1,000 litres) will be used in the pumps and turbines;
- Flammable acetone (100 litres) will be used for cleaning.

All the requirements for risk management of these flammable and combustible materials will be as per AS1940 (*Storage and handling of flammable and combustible liquids,* Ref 12), including:

- Bunding requirements as per AS1940, i.e. 100% of the largest tank, with bunding design and construction as per Section 5.9.3 in AS1940.

- Any valve controlling the drainage from the bunds is to be located outside the bund.
- Overflow line from all tanks is / will be open to atmosphere and directed to bund.
- Run-off from external (unbunded) areas would be captured in the first flush stormwater system which is designed to retain the first flush runoff from these areas.
- Fire protection (fire extinguishers, foam, hose reel requirements, separation distances etc) as per AS1940.
- Design of ventilation of building as per AS1940 Section 4.4 with regards to flammable vapours.
- Valving and piping associated with the storage as per AS1940 Section 7.
- Control of ignition sources as per AS1940 Section 9.7.6.
- Communication systems.
- Visual inspection of tanks, lines and equipment. Preventative maintenance program.
- Overflow line and vent line on top of diesel tank to minimise risk of ovepressurisation of tank.
- Foundations, supports, bearing etc. designed and constructed in accordance with AS1940. Tanks and associated equipment are protected from external impact by the bund wall (concrete) which is designed to comply with criteria in AS1940.
- Disposal of spills in accordance with established procedures.

Provided the requirements from AS1940 and the above recommendations are adhered to, the risk of an incident involving the combustible (and small quantities of flammable) material stored and handled is very small.

5.2.6 Whole Site

Flooding: The topography and design of the site prevents flooding from any rivers or streams.

Earthquake: A *Siting Study* was conducted in June 2009. This study looked at the suitability of the site in terms of earthquake hazards. While the study acknowledged the fact that the site is in a potential heightened earthquake zone it also concluded that: *The potential for heightened earthquake activity at the site can be accommodated in the design of the foundations for the proposed plant* (Ref 6). Such design measures will include use of suitable pipe and pipe grade which can withstand plastic deformation. Further, structures and plant will be designed to withstand earthquake effects using well-established procedures in accordance with relevant Australian or international standards (Note that geological stability has not been assessed as part of the present PHA).

Land Subsidence: The Dalton *Siting Study* (Ref 6) showed that there is no evidence on any large scale landslides; and that there are no known major active volcanic or surface tectonic structures in the project area.

Aircraft crash on Power Plant site: The gas supply pipelines, being buried, are unlikely to be damaged even in case of an aircraft crash. The preventative and protective features of this site makes the risk of an aircraft crash negligible. This scenario, while theoretically possible, does not appear credible for the present site.

Terrorism/vandalism: The site will be surrounded by fence and serviced by security cameras and IR (or other intrusions) detectors. The site will be staffed during normal working hours and monitored from Mt Beauty at all times.

Road Transport Risks: Once the site has been built and put into operation, the frequency of road transportation to the site of dangerous goods and potentially hazardous material will be minimal.

It is expected that one delivery (up to a maximum of three deliveries) per year will be sufficient for the operation of the site, consisting of the occasional diesel and oil top up and possibly the transport of some other material used for maintenance or cleaning (e.g. acetone). Note that oil and diesel will be transported to the site in relatively small quantities. Diesel is used only occasionally in the stand-by emergency generator (in case of a power failure, diesel is the fuel for the generator used to run the UPS - *Uninterrupted Power Supply*). Oils are used to top up the gear boxes of the turbines, pumps, air compressors etc.

General transport risks of these materials are handled by transport companies' internal safety requirements. Clean up and incident management will be as per the transport company's procedures.

The quantities and transport movement of potentially hazardous materials for this site are well below those listed in the *Transportation Screening Threshold* table (Table 2 in the guidelines on applying SEPP 33 (Ref 13)) as defined by the NSW Department of Planning.

The review of road transport risks concludes that the risk associated with the transport of dangerous goods and potentially hazardous material to the site is negligible.

5.3 SOFTWARE SAFEGUARDS

AGL and its operating entity have a commitment to Occupational Health and Safety (OH&S) and have numerous policies and procedures to achieve a safe workplace. There will be an active OH&S Committee responsible for the power plant. Written safety procedures will be established. An established incident reporting and response mechanism will be established, providing 24 hour coverage. The plant itself will develop procedures specific to the plant and its environment and they will be incorporated into the safety system.

The plant will need to comply with all codes and statutory requirements with respect to work conditions. 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 are trained in their safe use and handling, and are provided with all the relevant safety equipment.

Emergency procedures will be developed. All staff will need to be trained in these procedures and they will incorporated in the plant's quality system. The emergency procedures will include responses to emergency evacuation, injury, major asset damage or failure, critical power failure, spillages, major fire, and threats.

The site will have a manager with overall responsibility and who is supported by experienced personnel trained in the operation and support of the plant.

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

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

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

All persons on the premises will be provided with appropriate personal protective equipment suitable for use with the specific corrosive substances.

A first aid station will be provided comprising an appropriate first aid kit and first aid instructions, i.e. MSDSs, for all substances kept or handled on the premises. At least one person on the premises is trained in first aid; and a list of persons trained in, and designated as being responsible for the administering of, first aid is shown on the noticeboards on the premises. Further, the relevant and up-to-date MSDS will be kept in safe location next to the storage tanks.

Refer also recommendation 1.

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 Ref 14.

The explanation of the nomenclature used in the equations below is listed in Table 14 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 will 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 will 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.

Where automatic response has been designed into the plant (e.g. in the form of process trips) such response has been taken into account (with the relevant probability of failure of the trip etc.). The trips associated with the site, as relevant for the present PHA are the two trips actuated in case of a major leak at the supply pipeline or within the power plant.

Leak from vessels are assumed to last until the inventory of the vessel has been released, up to a maximum duration of one hour.

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 will either encounter a source of ignition within this time[5] 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

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

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 12 while Table 13 shows the effects of explosion overpressure.

Table 12 - 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 13 – 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 & plant 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

For jet flames and fireballs the effect of heat radiation is constant in every direction, hence they are omni-directional in effect. The probability of affecting a target at a location within the effect distance away from the location of the incident is equal in all directions.

The relationship between exposure and effect was estimated based on the probit equation for heat radiation. In the case of flash fires, 100% fatality was assumed for anyone engulfed within the flaming cloud, and 0% probability outside it. In the case of a Vapour Cloud Explosion, the relationship between overpressure and probability of fatality to people in a building as defined in the Orica course material in Ref 14 is taken as defining the lethal zone.

For the case of pipelines, the hazard must be treated as a linear hazard in the respect that it remains constant along the length of the route, and it only changes if there are special features in the pipeline such as valve stations. For a given location (at a distance **d** away from the fire), the heat radiation could exceed specified levels if **d** is less than, or equal to, the hazard range (or in this case the “effect distance”). Hence, this PHA has determined the hazard range of incident scenarios occurring anywhere along the interaction length of the pipeline.

Table 14 – 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

This initial outflow rates estimated for natural gas releases are shown in Table 15. 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 - this is a highly conservative approach.

Table 15 – Release Rates

Release rate [kg/s]	Hole Size					
	Small leak (5mm)	**Flange leak (13 m)**	**Interme-diate leak (25 mm)**	**Major leak (80 mm)**	**Massive leak (100 mm)**	**Full bore (guilo-tine)**
Upstream of the Pressure Regulator						
Instantaneous	0.2 kg/s	1.4 kg/s	5.1	52	81 kg/s	1,300 kg/s (first few seconds)
Downstream of the Pressure Regulator						
Instantaneous	0.2 kg/s	0.8 kg/s	3	30	47 kg/s	960 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 16 below.

Table 16 – Heat Radiation from Jet Fires

Hole size	Distance to Heat radiation (metres)		
	$4.7kW/m^2$	**$12.5kW/m^2$**	**$23.5kW/m^2$**
Upstream of the Pressure Regulator			
Small leak (5mm)	5	3	2
Intermediate leak (25 mm)	25	16	12
Massive leak (100 mm)	100	62	46
Full bore (guillotine)	405	250	185
Downstream of the Pressure Regulator			
Small leak (5mm)	4	2	1.5
Intermediate leak (25 mm)	20	12	9
Massive leak (100 mm)	80	50	35

Hole size	Distance to Heat radiation (metres)		
	4.7kW/m^2	**12.5kW/m^2**	**23.5kW/m^2**
Full bore (guillotine)	350	215	160

The distance to 100% chance of fatality from a jet fire is shown in Table 17 below.

Table 17 – Distance to 100% Chance of Fatality

Hole size	Distance to 100% Fatality (metres)		
	Jet Fire	**Flash Fire**	**Vapour Cloud Explosion**
Upstream of the Pressure Regulator			
Small leak (5mm)	3	10	10
Intermediate leak (25 mm)	10	30	30
Massive leak (100 mm)	30	50	50
Full bore (guillotine)	100	200	200
Downstream of the Pressure Regulator			
Small leak (5mm)	1	5	5
Intermediate leak (25 mm)	5	20	20
Massive leak (100 mm)	20	30	50
Full bore (guillotine)	100	50	100

7 FREQUENCY ANALYSIS

7.1 GENERIC EQUIPMENT FAILURES

A summary of all incident scenarios that are incorporated into the PHA are listed in Appendix 4. The frequency of each postulated equipment failure was determined using the data in the table below.

The frequencies used for fixed plant are those that have been in use by Orica Engineering for over 15 years of risk assessments in Australia. These frequencies are based on Orica Engineering's interpretation of published and unpublished (internal ICI and Orica) data.

The frequencies used for below ground gas piping installed as per AS2885 requirements (Ref 15) up to the gas receiving stations (for which the gas companies are responsible) are based on the data gathered by the European Gas pipeline Incident data Group (EGIG), (Ref 16) between 1988 and 1992. These figures have then been corrected to account for the approximate 30% reduction in incident risk associated with the pipelines, as presented in the EGIC report (Ref 17) showing a reduction in primary failure frequency of the natural gas pipeline from 1988-1992 compared with the latest figures of 2007. 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 (Ref 18) over 250,000 km-yrs.

Table 18 - Equipment Failures and Associated Frequencies

Type of Failure	Failure Rate ($\times 10^{-6}$ per year)
PIPELINES WITHIN FIXED PLANT (POWER PLANT)	
3 mm hole	9 / m
13 mm hole	3 / m
50 mm hole	0.3 / 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 believed to be further from the Australian standards than those in use in Europe (as included in the EGPIDG).

Type of Failure	Failure Rate (x10^{-6} per year)
3 mm gasket (13 mm hole equivalent)	5 / joint
Guillotine fracture (full bore):	
< 50 mm	0.6 / m
> 50 mm but < 100 mm	0.3 / m
> 100 mm	0.1 / m
VESSELS	
6 mm hole	24
13 mm hole	6
25 mm hole	3
50 mm hole	3
GAS SUPPLY PIPELINES (>100mm NB)	
<20 mm hole – steel pipeline	0.091 per meter
<80 mm hole – steel pipeline	0.127 per meter
Guillotine fracture (full bore) – steel pipeline up to 430mm diameter	0.044 per meter

7.2 Failure of Automatic Protection

Slam shut isolation valves will be positioned on either end of the supply pipelines. These valves will close automatically in case of a major leak at a pipeline. The following estimates of probabilities have been used as a guide for the purposes of determining the reliability of the automatic protection (Ref 19). While the design of the control system is not finalised, it is assumed that the protective systems will be designed to SIL 1 requirements.

Table 19 - Probability of Failure of Automatic Protection

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 (Ref 20):

Table 20 - 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 British Gas Corporation as reported in FP Lees (*Loss Prevention in the Process Industries*) (Ref 20) as follows:

Table 21 – Ignition Probability

Leak size (mm)	Probability of ignition
<20mm	0.2
20 to 100 mm	0.32
>100 mm	0.37

The probability of an explosion is virtually zero for a natural gas leak out in the open, such as for the gas supply pipeline. The probability of an explosion for the fixed plant (where there may be some confinement) is taken as 0.9M (in %), with M being the mass of flammable vapour in the cloud (Ref 21). This equation was used to determine the probability of a flash fire for the gas supply pipelines. This equation is believed to be highly conservative when used for natural gas plant because of the gas' propensity to rise high up in the air and disperse to below flammable limits without encountering an ignition source. 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 4.

8 RISK RESULTS AND COMPARISON WITH RISK CRITERIA

8.1 RISK CALCULATION – NATURAL GAS

Risk contours for the site are shown in the following figure:

- Figure 4 shows the individual fatality contours for risk associated with the power plant.
- Figure 5 shows the risk transect for individual fatality at the natural gas supply pipeline (from the off take at the Moomba to Sydney Pipeline up to the boundary of the new power plant.

Note that all data used in this risk assessment are for a plant and pipeline operating 100% of the time. The quantitative risk results are valid, though highly conservative, for the plant under the expected operating conditions, which are for a plant operating at a maximum 15% of the time.

As shown below, fatality, injury and propagation risk contours are contained well within the site boundary, as follows:

- The risk associated with natural gas pipelines after (downstream) the pressure reduction at the gas receiving facility is well below all criteria for fatality, injury and propagation risk at all locations within and outside of the power plant.
- The risk associated with natural gas pipelines before (upstream) of the pressure reduction at the gas receiving facility is well below all criteria for fatality, injury and propagation at the boundary of the Plant. The distance to the risk contours associated with NSW criteria of acceptable risk. These risk contours are all contained within the power plant.
- The individual risk of fatality associated with the gas supply pipeline is maximum $2x10^{-6}$ per year up to a distance of about 18 meters from the centre line of the pipeline. The $1x10^{-6}$ per year risk contour, relevant for residential development, reaches up to a distance of 22 meters from the centre line of the pipeline .

Figure 4 - Individual Fatality Risk Contours, Power Plant Site

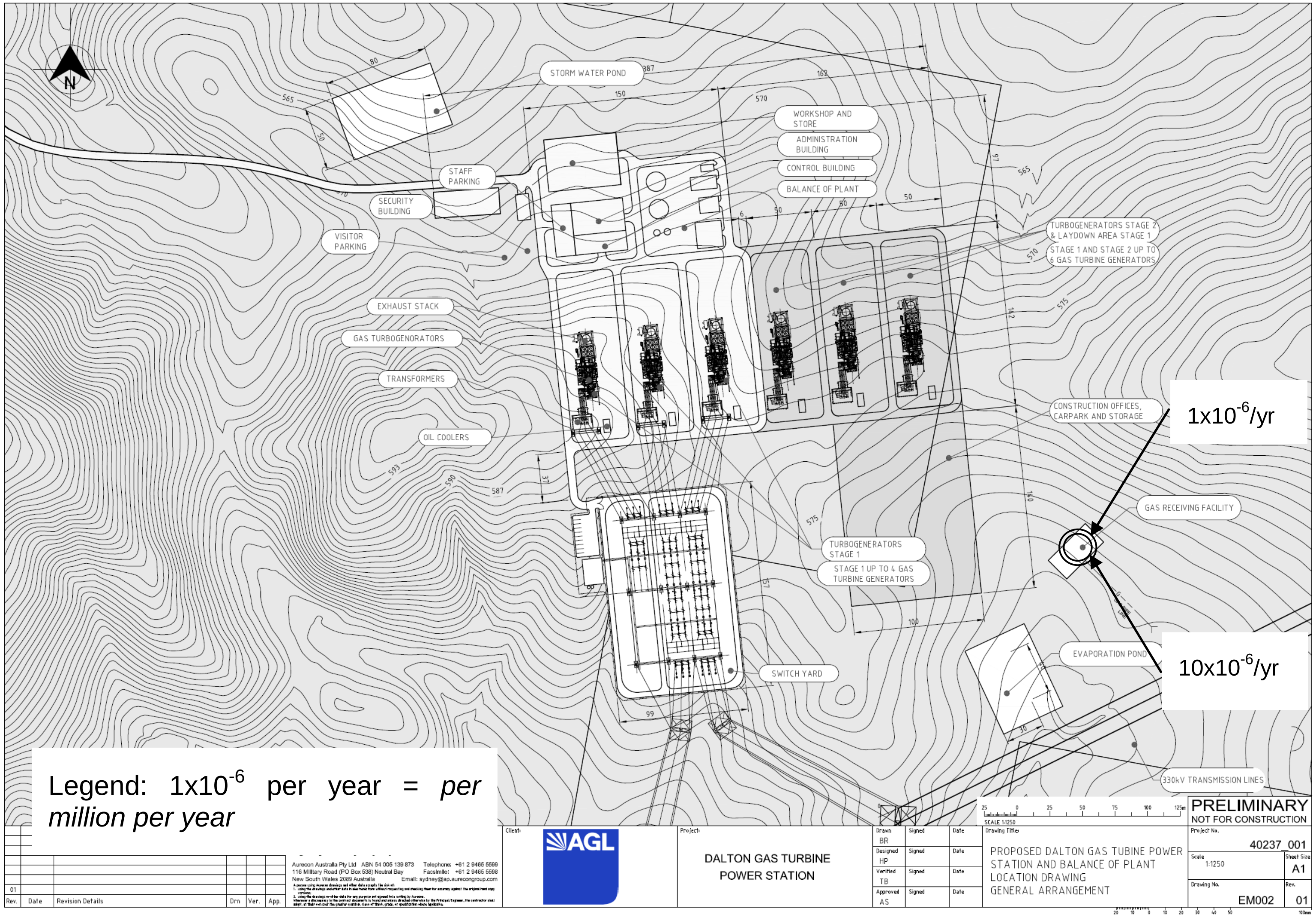


Figure 5 – Individual Risk Transects for the Gas Supply Pipeline

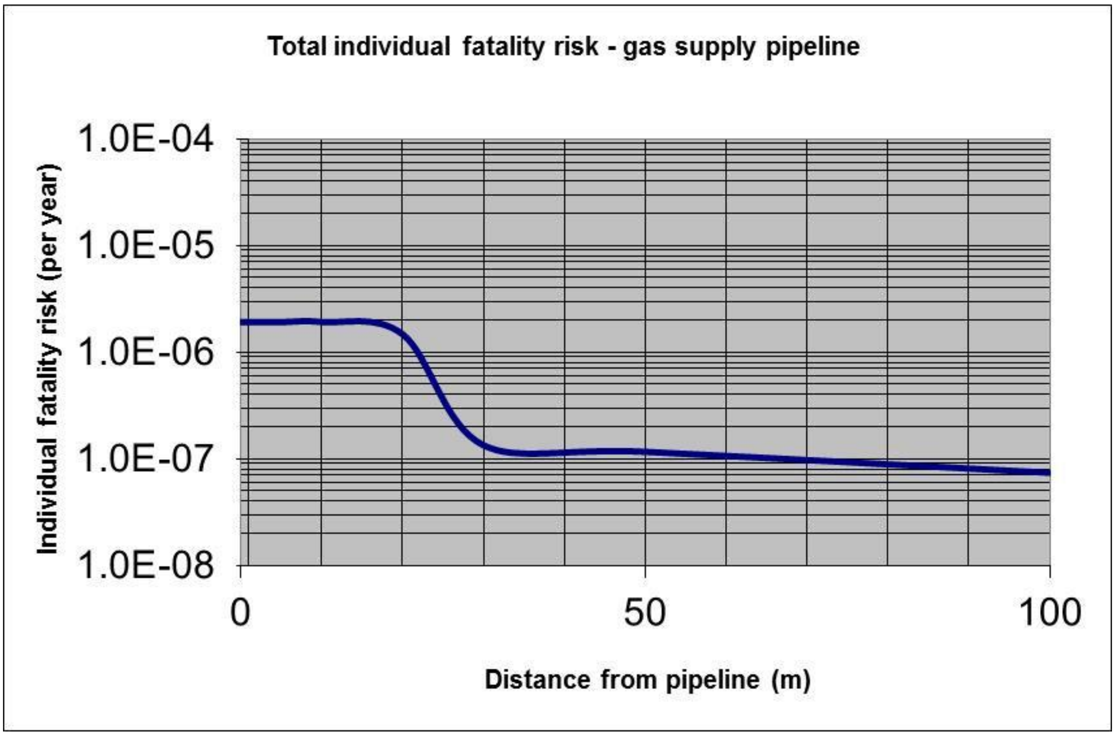


Table 22 – Distance to Risk Contours, Power Plant

Risk Contour	**Maximum Distance to Risk Contour from the Centre of Gas Receiving Facility (metres)**
Fatality Risk	
Individual Fatality Risk – 1 x10^{-6} per year[7]	10
Individual Fatality Risk – 10 x10^{-6} per year	7
Individual Fatality Risk – 50 x10^{-6} per year	< 5
Injury Risk	
Injury risk 4.7 kW/m^2 and 7 kPa – 50 x10^{-6} per year	< 5

[7] x10-6 per year – per million per year

Propagation risk	
Propagation risk 23 kW/m^2 and 14 kPa – 50 x10^{-6} per year	<5

Table 23 – Distance to Risk Contours, Gas Supply Pipeline

Risk Contour	Maximum Distance to Risk Contour from the Centre of the pipeline (metres)
Fatality Risk	
Individual Fatality Risk – 1 x10^{-6} per year[8]	22
Individual Fatality Risk – 10 x10^{-6} per year	Not achieved
Individual Fatality Risk – 50 x10^{-6} per year	Not achieved

The above criteria for individual risk do not necessarily reflect the overall risk associated with any proposal. In some cases for instance, where the 1 x10^{-6} per year contour approaches closely to residential areas or sensitive land uses, the potential may exist for multiple fatalities as the result of a single accident. One attempt to make comparative assessments of such cases involves the calculation of societal risk.

In this study the risk of fatality does not extend beyond the site boundaries or anywhere near the pipeline and is therefore well away from the residential areas. The concept of societal risk is therefore not applicable for the proposed development.

8.2 Risk of Natural Gas Explosion in Turbine Housing

The likelihood of a confined explosion inside the turbine housing was estimated taking into account that the basis of safety would include in the minimum (see Recommendations 4 and 5):

- Highly reliable ventilation fan system,
- Gas detection linked to automatic emergency shut down system,
- Prevention of ignition sources within the housing,
- Explosion panel (to minimize effect of confinement) and fire quenching (e.g. carbon dioxide), and
- Separation distances to nearby turbines and pressure piping.

[8] pmpy – pr million per year

The frequency of explosion inside the turbine housing can be estimated as follows:

> Explosion frequency = (Gas release frequency within housing) x (Ventilation fan failure probability) x (Gas detection and emergency shut down failure probability) x (Ignition probability of accumulated gas) x (Explosion if ignition probability).

With the following assumptions:

- Gas leak frequency = 1.4 x 10^{-3} t/yr (assuming equipment failure frequencies as per Table 18 and 290 flanges and flexible joints.

- Ventilation fan failure probability, allowing accumulation of gas = 0.1 (taken as the failure of one or the other of two automated protective systems of SIL 1, i.e. P = 0.05 + 0.05 = 0.1). This is believed to be a highly conservative assumption, particularly taking into account the requirement to provide reliable ventilation, see recommendation 4.

- Gas detection failure and failure of the emergency shut down = 0.05 per gas detector, assume two independent detectors [and that both have to fail or fail to pick up the leak]. Also, taken into account is a 0.0025 probability of common mode failure for gas detectors (e.g. due to maintenance failure affecting detector system).

- Ignition probability of accumulated gas = 0.1. Even though all equipment and instrumented protective equipment used in the housing need to be designed for the hazardous zone requirements, a gas turbine could have hot surfaces above the auto ignition temperature of the fluids used even in normal circumstances (operation under fault conditions may increase surface temperatures).

- Explosion if ignition probability = 1 (i.e. assuming that all ignitions of flammable gases inside the housing would lead to an explosion. This is highly conservative).

Calculations show:

Explosion frequency = (1.45 x 10^{-3}) x (0.1) x (0.05 x 0.05 + 0.0025) x (0.1) x (1) = 7.2 x 10^{-8} per year per housing.

With six turbines, the total frequency of explosion inside turbine housing is:

F(explosion in turbine housing) = 4.4 x 10^{-7} per year.

This frequency is very low.

A confined explosion may generate high over pressures which could damage neighbouring equipment and turbines. Further, the turbines will be located approximately 100 metres apart.

With proper design it is unlikely that an explosion at one turbine would have serious effect at a neighbouring turbine.

8.3 TRANSPORT RISK

The review of road transport risks concludes that the risk associated with the transport of dangerous goods and potentially hazardous material to the site is negligible.

8.4 ADHERENCE TO RISK CRITERIA

The quantitative analysis showed that:

8.4.1 Individual Risk of Fatality, Power Plant

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). The 1×10^{-6}/yr individual fatality risk for the power plant is contained well within the site boundaries.

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 side boundaries.

8.4.2 Individual Risk of Fatality, Supply Gas Pipeline

The 1×10^{-6}/yr individual fatality risk for the gas supply pipeline does not extend into any residential areas.

It should however be noted that the maximum tolerable risk for residential developments is exceeded for a distance of 22 meters of either side of the centreline of the gas supply pipeline for a pipeline designed to AS2885 requirements for rural development.

8.4.3 Injury Risk, Power Plant

The 50×10^{-6}/yr risk contour is contained within the site boundary. 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 50×10^{-6}/yr risk contour is contained within the site boundary. The risk of propagation of an incident at the power plant does not encroach into any other industrial areas.

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 current installation does not have a significant impact on societal risk.

Transport Risk: The risk associated with transport of potentially hazardous materials is low for this development.

9 CONCLUSION AND RECOMMENDATIONS

9.1 OVERVIEW OF RISK

The main hazard associated with the proposed project is associated with the production and handling of natural gas (predominantly composed of methane gas), which is a flammable gas held under pressure. Other, less significant hazards, are associated with the handling of flammable and combustible liquids.

Hazards may arise in fixed plant, storage, and 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 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), 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.

9.2 SUMMARY OF RISK RESULTS

The detailed design has not been completed as yet for this development. A set of very conservative assumptions as to the design and operation of the plant have been made, including a 100% on-line operation of the plant (despite the fact that it is expected that the plant will be operational for about 15% of the time only, with appropriate fire proof isolation valves separating the plant from pressurised gas supplies).

Despite the fact that many of the assumptions in this PHA are highly conservative, the results show that the risk associated with this development is very low. The most stringent risk criteria, as set by the NSW Department of Planning, are adhered to.

The results show that the 1 x 10^{-6} per year individual risk contour does not extend beyond the site boundary for the power station.

This risk contour does extend by 22 meters in either direction of the centreline of the pipeline, implying that future residential developments (if ever an option) would be restricted within this buffer.

9.3 RECOMMENDATIONS

The risk assessment carried out in this study assumed that the facility 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: It is recommended that a safety management system be implemented and used at the site, specifically as it applies to the proposed hazardous materials handling, pipelining and storages.

Recommendation 2: High and low pressures of the natural gas supply are to be monitored during (and, if applicable, outside) operation of the power plant. These conditions will need to be associated with an automatic trip / shut down of the pipeline at the metering station in case of a major failure of the natural gas pipeline within the site boundary (as assumed in this QRA).

Recommendation 3: The use of fusible tubing around above ground high risk natural gas piping to be investigated – such tubing would be linked to automatic shut down of the fuel source.

Recommendation 4: The detailed design of the turbine housing and associated equipment should clearly outline the basis of safety used to ensure that explosive situations do not arise (/the risk is rendered negligible). Reference should be made to European ATEX Directive (Ref 9) and the UK HSE PM84 (Ref 10) or other guidance / regulation of equivalent safety.

Recommendation 5: Fire protection inside the turbine housing to be determined, including use of explosion panels and use of fire retardant material if appropriate.

Recommendation 6: A system should be put in place to ensure that any removal of critical safety function (e.g. for repair or exchange) is subject to careful scrutiny by plant management (decisions on whether to shut down plan or a turbine if a critical safety function is removed need to be canvassed).

Recommendation 7: Rotating machines to be designed such that risk associated with projectile is minimised (gas pipelines protected or not in probable line of projectile, people protected etc.)

Recommendation 8: Loud alarm and visual indication (e.g. strobe light) to be installed within the turbine housing, alerting any persons within these housings of the pending discharge of asphyxiants and allowing escape.

Appendix 1

Release Scenarios

A. Input Data to Risk Assessment Program

Input data for ISORIS. Before using the data in the program, remove rows 1-22 as well as the following Columns: e, F, J, K, l, m						**Leak size (m)**	**Cross section**	**Flow rate (kg/s)**		**Prob of ignition**	
BATREG	Line from batterylimit to the pressure regulator					3.00E-03	7.07E-06	7.32E-02	Upstream of regulator	0.2	
REGTU1	Line from pressure regulator to the gas turbine 1					1.30E-02	1.33E-04	1.38E+00	Upstream of regulator	0.2	
REGTU2	Line from pressure regulator to the gas turbine 2					5.00E-02	1.96E-03	2.03E+01	Upstream of regulator	0.32	
REGTU3	Line from pressure regulator to the gas turbine 3					4.00E-01	1.26E-01	1.30E+03	Upstream of regulator	0.37	
REGTU4	Line from pressure regulator to the gas turbine 4					3.00E-03	7.07E-06	4.27E-02	Downstream of regulator	0.2	
						1.30E-02	1.33E-04	8.02E-01	Downstream of regulator	0.2	
TURBINE	Gas turbine					5.00E-02	1.96E-03	1.19E+01	Downstream of regulator	0.32	
	Gas flow rate = $0.8 \times A \times P \{M/zRT \times [(2/gamma + 1)^{0.5}]^{(gamma+1)(gamma-1)}\}^{0.5}$					4.50E-01	1.59E-01	9.61E+02	Downstream of regulator	0.37	
	R =	8.3		Leak frequency P/L:			Leak freq. vessels:		Duration:	600	s
	T =	293	K	3mm hole	9.00E-06	/m	6 mm hole	2.40E-05		300	s
	gamma =	1.1		13mm hole	3.00E-06	/m	13 mm hole	6.00E-06		60	s
	z =	1.1		50 mm hole	3.00E-07	/m	25 mm hole	3.00E-06	Prob of flash fire not jet fire		
	M =	18	g/mol	guilliotine>100mm	1.00E-07	/m	50 mm hole	3.00E-06		2.00E-01	
				guilliotine<50mm	6.00E-07	/m	cat rupture	1.00E-06			
	Duration of explosion of flash = $0.852M^{0.26}$		(Ref. TNO)	guilliotine50-100mm	3.00E-07	/m					
	M = mass fuel (kg)			flange	5.00E-06	/joint	Prob of trip switch functions failure:		Mass TNT = % efficiency x M_{vap} x H_c / 4600		
	t= duration (sec)			pump leak 23 mm	2.50E-03	pump / compressor		5.00E-02	% efficiency =	0.04	
				pump leak 11 mm	2.50E-03	pump / compressor	Prob of failure of EIVs		H_c =	50000	kJ/kg
				pump leak 2.5 mm	2.50E-03	pump / compressor		5.00E-02	Hc =	50000	kJ/kg
AGL DALTON PHA									rad effic =	0.15	

B. Release Scenarios

EQUIP-MENT	EAST	NORTH	TYPE	LENGTH metres	#JOINTS	TRIP	LEAK FREQ. /yr	FLASH FIRE FREQ. /yr	EXPL. FREQ. /yr	GAS PRES. Pa	DIAM ORIF. Metres	CROSS AREA m2	REL.HEIGHT m	LEAK RATE kg/s	MW (megawatts)	TNT 4%	CLOUD (KG)
BATREG	0	0	PI	10	20	NO	9.00E-05	1.80E-05	0.00E+00	6.00E+06	3.00E-03	7.07E-06	0.00E+00	7.32E-02	5.49E-01	2.39E-01	2.20E+01
BATREG	0	0	PI	10	20	NO	3.00E-05	6.00E-06	0.00E+00	6.00E+06	1.30E-02	1.33E-04	0.00E+00	1.38E+00	1.03E+01	4.48E+00	4.13E+02
BATREG	0	0	PI	10	20	YES	1.50E-07	3.00E-08	0.00E+00	6.00E+06	5.00E-02	1.96E-03	0.00E+00	2.03E+01	1.53E+02	6.63E+01	6.10E+03
BATREG	0	0	PI	10	20	YES	5.00E-08	1.00E-08	0.00E+00	6.00E+06	4.00E-01	1.26E-01	0.00E+00	1.30E+03	9.77E+03	4.25E+03	3.91E+05
BATREG	0	0	PI	10	20	NO	1.00E-04	2.00E-05	0.00E+00	6.00E+06	1.30E-02	7.07E-06	0.00E+00	1.38E+00	1.03E+01	4.48E+00	4.13E+02
REGTU1	0	50	PI	500	50	NO	4.50E-04	9.00E-05	0.00E+00	3.50E+06	3.00E-03	7.07E-06	0.00E+00	4.27E-02	3.20E-01	1.39E-01	1.28E+01
REGTU1	0	50	PI	500	50	NO	1.50E-03	3.00E-04	0.00E+00	3.50E+06	1.30E-02	1.33E-04	0.00E+00	8.02E-01	6.02E+00	2.62E+00	2.41E+02
REGTU1	0	50	PI	500	50	YES	7.50E-06	1.50E-06	0.00E+00	3.50E+06	5.00E-02	1.96E-03	0.00E+00	1.19E+01	8.90E+01	3.87E+01	3.56E+03
REGTU1	0	50	PI	500	50	YES	2.50E-06	5.00E-07	0.00E+00	3.50E+06	4.00E-01	1.26E-01	0.00E+00	9.61E+02	7.21E+03	3.13E+03	2.88E+05
REGTU1	0	50	PI	500	50	NO	1.50E-04	3.00E-05	0.00E+00	3.50E+06	1.30E-02	1.33E-04	0.00E+00	8.02E-01	6.02E+00	2.62E+00	2.41E+02
REGTU2	0	100	PI	500	50	NO	4.50E-04	9.00E-05	0.00E+00	3.50E+06	3.00E-03	7.07E-06	0.00E+00	4.27E-02	3.20E-01	1.39E-01	1.28E+01
REGTU2	0	100	PI	500	50	NO	1.50E-03	3.00E-04	0.00E+00	3.50E+06	1.30E-02	1.33E-04	0.00E+00	8.02E-01	6.02E+00	2.62E+00	2.41E+02
REGTU2	0	100	PI	500	50	YES	1.06E-09	2.12E-10	0.00E+00	3.50E+06	5.00E-02	1.96E-03	0.00E+00	1.19E+01	8.90E+01	3.87E+01	3.56E+03
REGTU2	0	100	PI	500	50	YES	3.53E-10	7.07E-11	0.00E+00	3.50E+06	4.00E-01	1.26E-01	0.00E+00	9.61E+02	7.21E+03	3.13E+03	2.88E+05
REGTU2	0	100	PI	500	50	NO	1.50E-04	3.00E-05	0.00E+00	3.50E+06	1.30E-02	1.33E-04	0.00E+00	8.02E-01	6.02E+00	2.62E+00	2.41E+02
REGTU3	0	150	PI	500	50	NO	4.50E-04	9.00E-05	0.00E+00	3.50E+06	3.00E-03	7.07E-06	0.00E+00	4.27E-02	3.20E-01	1.39E-01	1.28E+01
REGTU3	0	150	PI	500	50	NO	1.50E-03	3.00E-04	0.00E+00	3.50E+06	1.30E-02	1.33E-04	0.00E+00	8.02E-01	6.02E+00	2.62E+00	2.41E+02
REGTU3	0	150	PI	500	50	YES	1.06E-09	2.12E-10	0.00E+00	3.50E+06	5.00E-02	1.96E-03	0.00E+00	1.19E+01	8.90E+01	3.87E+01	3.56E+03
REGTU3	0	150	PI	500	50	YES	3.53E-10	7.07E-11	0.00E+00	3.50E+06	4.00E-01	1.26E-01	0.00E+00	9.61E+02	7.21E+03	3.13E+03	2.88E+05
REGTU3	0	150	PI	500	50	NO	1.50E-04	3.00E-05	0.00E+00	3.50E+06	1.30E-02	1.33E-04	0.00E+00	8.02E-01	6.02E+00	2.62E+00	2.41E+02
REGTU4	0	200	PI	500	50	NO	4.50E-04	9.00E-05	0.00E+00	3.50E+06	3.00E-03	7.07E-06	0.00E+00	4.27E-02	3.20E-01	1.39E-01	1.28E+01
REGTU4	0	200	PI	500	50	NO	1.50E-03	3.00E-04	0.00E+00	3.50E+06	1.30E-02	1.33E-04	0.00E+00	8.02E-01	6.02E+00	2.62E+00	2.41E+02
REGTU4	0	200	PI	500	50	YES	1.06E-09	2.12E-10	0.00E+00	3.50E+06	5.00E-02	1.96E-03	0.00E+00	1.19E+01	8.90E+01	3.87E+01	3.56E+03
REGTU4	0	200	PI	500	50	YES	3.53E-10	7.07E-11	0.00E+00	3.50E+06	4.00E-01	1.26E-01	0.00E+00	9.61E+02	7.21E+03	3.13E+03	2.88E+05
REGTU4	0	200	PI	500	50	NO	1.50E-04	3.00E-05	0.00E+00	3.50E+06	1.30E-02	1.33E-04	0.00E+00	8.02E-01	6.02E+00	2.62E+00	2.41E+02

PLANAGER
Risk Management Consulting

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				

1 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	Upstream of regulator	2.71E-01	2.03E+03	3.12	5.9	3.6	2.7	0.9	4.2	6.3	0	0.28	0.95
2.50E-02	Upstream of regulator	6.78E+00	5.09E+04	15.62	29.4	18.0	13.3	0.9	4.2	6.3	0	0.28	0.95
1.00E-01	Upstream of regulator	1.09E+02	8.14E+05	62.50	117.4	72.0	53.1	0.9	4.2	6.3	0	0.28	0.95
4.00E-01	Upstream of regulator	1.74E+03	1.30E+07	491.78	469.6	288.0	212.3	0.9	4.2	6.3	0	0.28	0.95
5.00E-03	Downstream of regulator	1.19E-01	8.90E+02	2.07	3.9	2.4	1.8	0.9	4.2	6.3	0	0.28	0.95
2.50E-02	Downstream of regulator	2.97E+00	2.23E+04	10.33	19.4	11.9	8.8	0.9	4.2	6.3	0	0.28	0.95
1.00E-01	Downstream of regulator	4.75E+01	3.56E+05	41.34	77.7	47.6	35.1	0.9	4.2	6.3	0	0.28	0.95
4.50E-01	Downstream of regulator	9.61E+02	7.21E+06	259.73	349.5	214.3	158.0	0.9	4.2	6.3	0	0.28	0.95

Heat radiation (kW/m2) at Distance from Centre of Flame (in metres).

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame (metres)	1	2	5	10	20	30	50	100	200	300
5.00E-03	Upstream of regulator	2.71E-01	2.03E+03	3.12	162	40	6	2	0	0	0	0	0	0
2.50E-02	Upstream of regulator	6.78E+00	5.09E+04	15.62	4049	1012	162	40	10	4	2	0	0	0
1.00E-01	Upstream of regulator	1.09E+02	8.14E+05	62.50	64791	16198	2592	648	162	72	26	6	2	1
4.00E-01	Upstream of regulator	1.74E+03	1.30E+07	491.78	1036663	259166	41467	10367	2592	1152	415	104	26	12
5.00E-03	Downstream of regulator	1.19E-01	8.90E+02	2.07	71	18	3	1	0	0	0	0	0	0
2.50E-02	Downstream of regulator	2.97E+00	2.23E+04	10.33	1772	443	71	18	4	2	1	0	0	0
1.00E-01	Downstream of regulator	4.75E+01	3.56E+05	41.34	28346	7087	1134	283	71	31	11	3	1	0
4.50E-01	Downstream of regulator	9.61E+02	7.21E+06	259.73	574012	143503	22960	5740	1435	638	230	57	14	6

Distance to this heat radiation from the source (in metres) (takes into account the length of the flame)

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame (metres)	1	2	5	10	20	30	50	100	200	300
5.00E-03	Upstream of regulator	2.71E-01	2.03E+03	3.12	3	4	7	12	22	32	52	102	202	302
2.50E-02	Upstream of regulator	6.78E+00	5.09E+04	15.62	9	10	13	18	28	38	58	108	208	308
1.00E-01	Upstream of regulator	1.09E+02	8.14E+05	62.50	32	33	36	41	51	61	81	131	231	331
4.00E-01	Upstream of regulator	1.74E+03	1.30E+07	491.78	247	248	251	256	266	276	296	346	446	546
5.00E-03	Downstream of regulator	1.19E-01	8.90E+02	2.07	2	3	6	11	21	31	51	101	201	301
2.50E-02	Downstream of regulator	2.97E+00	2.23E+04	10.33	6	7	10	15	25	35	55	105	205	305
1.00E-01	Downstream of regulator	4.75E+01	3.56E+05	41.34	22	23	26	31	41	51	71	121	221	321
4.50E-01	Downstream of regulator	9.61E+02	7.21E+06	259.73	131	132	135	140	150	160	180	230	330	430

Probit

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame (metres)	1	2	5	10	20	30	50	100	200	300
5.00E-03	Upstream of regulator	2.71E-01	2.03E+03	3.12	13	8	2	-3	-7	-10	-14	-18	-23	-26
2.50E-02	Upstream of regulator	6.78E+00	5.09E+04	15.62	24	19	13	8	3	1	-3	-7	-12	-15
1.00E-01	Upstream of regulator	1.09E+02	8.14E+05	62.50	33	29	22	18	13	10	7	2	-3	-6
4.00E-01	Upstream of regulator	1.74E+03	1.30E+07	491.78	43	38	32	27	22	20	16	11	7	4
5.00E-03	Downstream of regulator	1.19E-01	8.90E+02	2.07	10	5	-1	-6	-10	-13	-17	-21	-26	-29
2.50E-02	Downstream of regulator	2.97E+00	2.23E+04	10.33	21	16	10	5	1	-2	-6	-10	-15	-18
1.00E-01	Downstream of regulator	4.75E+01	3.56E+05	41.34	30	26	20	15	10	7	4	-1	-6	-8
4.50E-01	Downstream of regulator	9.61E+02	7.21E+06	259.73	41	36	30	25	20	18	14	9	5	2

Probability of fatality

Leak size(mm)	Location	Burn rate (kg/s)	Heat rad (kW)	Length of jet flame										
5.00E-03	Upstream of regulator	2.71E-01	2.03E+03	3.12	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.50E-02	Upstream of regulator	6.78E+00	5.09E+04	15.62	1.00	1.00	1.00	1.00	2.00	0.00	0.00	0.00	0.00	0.00
1.00E-01	Upstream of regulator	1.09E+02	8.14E+05	62.50	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.00	0.00	0.00
4.00E-01	Upstream of regulator	1.74E+03	1.30E+07	491.78	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.16
5.00E-03	Downstream of regulator	1.19E-01	8.90E+02	2.07	1.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.50E-02	Downstream of regulator	2.97E+00	2.23E+04	10.33	1.00	1.00	1.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00
1.00E-01	Downstream of regulator	4.75E+01	3.56E+05	41.34	1.00	1.00	1.00	1.00	1.00	0.98	0.16	0.00	0.00	0.00
4.50E-01	Downstream of regulator	9.61E+02	7.21E+06	259.73	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	0.00

PLANAGER
Risk Management Consulting

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
5.00E-03	Upstream of regulator	2.71E-01	4.88E+01	2.12E+01	1.8	**3.6**	**7.2**	10.8	18.1	36.2	72.3	108.5
2.50E-02	Upstream of regulator	6.78E+00	1.22E+03	5.31E+02	0.6	1.2	2.5	**3.7**	**6.2**	12.4	24.8	37.1
1.00E-01	Upstream of regulator	1.09E+02	1.95E+04	8.49E+03	0.2	0.5	1.0	1.5	2.5	**4.9**	9.8	14.7
4.00E-01	Upstream of regulator	1.74E+03	3.12E+05	1.36E+05	0.1	0.2	0.4	0.6	1.0	2.0	**3.9**	**5.9**
5.00E-03	Downstream of regulator	1.19E-01	2.14E+01	9.29E+00	**2.4**	**4.8**	9.5	14.3	23.8	47.6	95.2	142.8
2.50E-02	Downstream of regulator	2.97E+00	5.34E+02	2.32E+02	0.8	1.6	**3.3**	**4.9**	8.1	16.3	32.6	48.9
1.00E-01	Downstream of regulator	4.75E+01	8.54E+03	3.72E+03	0.3	0.6	1.3	1.9	**3.2**	**6.5**	12.9	19.4
4.50E-01	Downstream of regulator	9.61E+02	1.73E+05	7.52E+04	0.1	0.2	0.5	0.7	1.2	**2.4**	**4.8**	7.1

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
5.00E-03	Upstream of regulator	2.71E-01	4.88E+01	2.12E+01	100	60.0	17.0	10.0	4.1	1.8	0.0	0.0
2.50E-02	Upstream of regulator	6.78E+00	1.22E+03	5.31E+02	100	100	1	60	22	8	3	1
1.00E-01	Upstream of regulator	1.09E+02	1.95E+04	8.49E+03	100	100	100	100	90	35	10	8
4.00E-01	Upstream of regulator	1.74E+03	3.12E+05	1.36E+05	100	100	100	100	100	100	60	30
5.00E-03	Downstream of regulatc	1.19E-01	2.14E+01	9.29E+00	95	40.0	12.0	7.0	3.5	0.0	0.0	0.0
2.50E-02	Downstream of regulatc	2.97E+00	5.34E+02	2.32E+02	100	100	90	45	18	7	2	0
1.00E-01	Downstream of regulatc	4.75E+01	8.54E+03	3.72E+03	100	100	100	100	90	25	10	4
4.50E-01	Downstream of regulatc	9.61E+02	1.73E+05	7.52E+04	100	100	100	100	100	95	45	4

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
5.00E-03	Upstream of regulator	2.71E-01	4.88E+01	2.12E+01	1.00	1.00	0.10	0.05	0.01	0.00	0.00	0.00
2.50E-02	Upstream of regulator	6.78E+00	1.22E+03	5.31E+02	1.00	1.00	1.00	1.00	1.00	0.50	0.01	0.00
1.00E-01	Upstream of regulator	1.09E+02	1.95E+04	8.49E+03	1.00	1.00	1.00	1.00	1.00	0.50	0.05	0.05
4.00E-01	Upstream of regulator	1.74E+03	3.12E+05	1.36E+05	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.35
5.00E-03	Downstream of regulatc	1.19E-01	2.14E+01	9.29E+00	1.00	0.62	0.08	0.04	0.01	0.00	0.00	0.00
2.50E-02	Downstream of regulatc	2.97E+00	5.34E+02	2.32E+02	1.00	1.00	1.00	0.80	0.12	0.05	0.00	0.00
1.00E-01	Downstream of regulatc	4.75E+01	8.54E+03	3.72E+03	1.00	1.00	1.00	1.00	1.00	0.25	0.05	0.01
4.50E-01	Downstream of regulatc	9.61E+02	1.73E+05	7.52E+04	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.01

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
5.00E-03	Upstream of regulator	2.71E-01	4.88E+01	10	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
2.50E-02	Upstream of regulator	6.78E+00	1.22E+03	30	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00
1.00E-01	Upstream of regulator	1.09E+02	1.95E+04	80	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00
4.00E-01	Upstream of regulator	1.74E+03	3.12E+05	180	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
5.00E-03	Downstream of regulator	1.19E-01	2.14E+01	12	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.50E-02	Downstream of regulator	2.97E+00	5.34E+02	25	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
1.00E-01	Downstream of regulator	4.75E+01	8.54E+03	75	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00
4.50E-01	Downstream of regulator	9.61E+02	1.73E+05	170	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00

RISK ASSESSMENT GAS SUPPLY PIPELINE
UPSTREAM OF REGULATOR

Frequency (per metre per year)

	Jet fire	**Flash fire**	**Explosion**
<20mm	7.91E-09	8.79E-11	0
20 to 100 mm	9.89E-10	2.11E-10	0
>100 mm	0.00E+00	3.70E-10	0

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

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

	5 m	10 m	20 m	30 m	50 m	100 m	200 m	300 m
<20mm	7.91E-09	7.91E-09	7.91E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20 to 100 mm	9.89E-10	9.89E-10	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	8.79E-11	8.79E-11	8.79E-11	8.79E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20 to 100 mm	2.11E-10	2.11E-10	2.11E-10	2.11E-10	2.11E-10	0.00E+00	0.00E+00	0.00E+00
>100 mm	3.70E-10	3.70E-10	3.70E-10	3.70E-10	3.70E-10	3.70E-10	3.70E-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	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
	8.0E-09	8.0E-09	8.0E-09	8.8E-11	0.0E+00	0.0E+00	0.0E+00	0.0E+00
20 to 100 mm	1.2E-09	1.2E-09	2.1E-10	2.1E-10	2.1E-10	0.0E+00	0.0E+00	0.0E+00
>100 mm	3.7E-10	3.7E-10	3.7E-10	3.7E-10	3.7E-10	3.7E-10	3.7E-10	0.0E+00
Total risk of fatality (per metre per year)	**9.6E-09**	**9.6E-09**	**8.6E-09**	**6.7E-10**	**5.8E-10**	**3.7E-10**	**3.7E-10**	**0.0E+00**

not taking into account any overlapping effect

Divide pipeline into segments of 200 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)	**1.9E-06**	**1.9E-06**	**1.7E-06**	**1.3E-07**	**1.2E-07**	**7.4E-08**	**7.4E-08**	**0.0E+00**

C. Inside Turbine Housing – Calculation Sheet

Number flanges	2.00E+02	
Number flexible joints	9.00E+01	model as flanges
Total	2.90E+02	
Frequency of leak per flange	5.00E-06	per flange / joint
Leaks per enclosure	1.45E-03	
Probability of failure of fan, allowing accumulation of gas	1.00E-01	conservative
Failure to detect leak, each detector	5.00E-02	SIL4
Number of detectors	2.00E+00	
Common mode failure, gas detectors	2.50E-03	
Probability of ignition	1.00E-01	
Frequency if igniton (per enclosure)	**7.25E-08**	t/yr
Number of enclosures	6.00E+00	
Total frequency of ignition on site	4.35E-07	
Probability of explosion if igniton	1.00E+00	
Frequency of explosion inside one of the turbine enclosures	**4.35E-07**	**t/yr**

10 REFERENCES

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