PRELIMINARY
HAZARD ANALYSIS

TECHNICAL PAPER 6

WELLINGTON POWER PROJECT

GAS FIRED POWER STATION, PIPELINE AND TRANSMISSION INFRASTRUCTURE

PRELIMINARY HAZARD ANALYSIS

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Title: **Wellington Power Project** **Gas Fired Power Station, Pipeline and Transmission Infrastructure** **Preliminary Hazard Analysis**	**QA Verified:** P.JOHNSON **Date: 20 February 2008**

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ABBREVIATIONS

AS	Australian Standard
CWP	Central West Pipeline
DOC	Depth of Cover
DoP	NSW Department of Planning
EA	Environmental Assessment
ERM	ERM Power Pty Ltd
GIS	Geographic Information System
HIPAP	Hazardous Industry Planning Advisory Paper
IR	Infrared
kg/s	Kilograms per second
kW/m^2	Kilowatts per square metre
LFL	Lower Flammability Limit
MAOP	Maximum Allowable Operating Pressure
mm	millimetre
MLV	Main Line Valve
MPa (g)	Megapascal (gauge)
MW	Megawatt
NR	Not Reached
OCGT	Open Cycle Gas Turbine
PB	Parsons Brinckerhoff Australia Pty Ltd
PCV	Pressure Control Valve
PHA	Preliminary Hazard Analysis
QRA	Quantitative Risk Assessment
SCADA	Supervisory, Control and Data Acquisition
SCC	Stress Corrosion Cracking
Sm3	Standard cubic metres
UV	Ultraviolet
VCE	Vapour Cloud Explosion

1. SUMMARY

1.1. General

ERM Power Pty Ltd (ERM) proposes to construct a gas-fired power station near Wellington, NSW. The power station will comprise four gas-turbine generators with a power output up to 660MW. The power station will operate as a peak demand power station. The gas supply for the station is to be provided by a 100 km pipeline running from an offtake on the Central West Pipeline (CWP) near Parkes, NSW.

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

1.2. Individual Risk Results

Risk transects were generated for the pipeline and risk contours generated for the gas receival station and compressor station.

The following sections describe the results of the individual risk assessment.

1.2.1. Pipeline

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

- Case 1 (Base Case) – 750mm depth of cover (DOC), marker tape ,6.3mm wall thickness
- Case 2 – 900mm DOC, marker tape, 6.3mm wall thickness
- Case 3 - 1200mm DOC, marker tape, 6.3mm wall thickness
- Case 4 – 750mm depth of cover (DOC), 9.5mm wall thickness
- Case 5 – 900mm DOC, 9.5mm wall thickness
- Case 6 - 1200mm DOC, marker tape, 9.5mm wall thickness

For Case 1 (Base Case), the risk resulting the pipeline reaches an individual risk of fatality of 1 x 10^{-6} per year (the criteria for residential areas) at a distance of 118m from the pipeline. The assessment was repeated for the other sensitivity cases. The results of the assessment including the distances to the risk criteria levels required for other land uses are summarised in Table 1.1.

Table 1.1 shows the separation distances required for land uses near the pipeline route. Given that the nearest residential building is at least 150m from the pipeline then the DoP criteria for residential areas can be met. An appropriate level of safeguards may be selected depending on the separation distance to nearby landuses to meet the risk criteria of the DoP.

TABLE 1.1: DISTANCE TO INDIVIDUAL RISK LEVELS

Case	Distance to Individual Risk of Fatality (HIPAP No. 4) at Nearby Land Uses (m)				
	Sensitive Land Uses (0.5×10^{-7} per year)	**Residential (1×10^{-6} per year)**	**Commercial (5×10^{-6} per year)**	**Active Open Spaces (10×10^{-6} per year)**	**Industrial (10×10^{-6} per year)**
6.3mm wall thickness pipe					
1 (750mm DOC,marker tape)	141	118	NR	NR	NR
2 (900mm DOC,marker tape)	140	115	NR	NR	NR
3 (1200mm DOC,marker tape)	135	110	NR	NR	NR
9.5mm wall thickness pipe					
4 (750mm DOC,marker tape)	124	75	NR	NR	NR
5 (900mm DOC,marker tape)	121	65	NR	NR	NR
6 (1200mm DOC,marker tape)	117	8	NR	NR	NR

NR = Not reached at any distance from the pipeline

1.2.2. Power Station

Risk contours were generated for the power station site. The following were the results of the assessment of the risk contours:

- The risk contour for an individual risk of fatality of 1×10^{-6} per year (residential areas) extends past the boundary by at most 70m at the northern and western boundary of the site and does not extend to any residences.
- The risk contour for an individual risk of fatality of 10×10^{-6} per year (active open spaces) extends past the boundary by at most 20m at the northern boundary of the site and does not extend to any active open spaces.
- The risk contour for an individual risk of fatality of 50×10^{-6} per year (industrial areas) is not generated for the power station.
- There are no sensitive or commercial land uses near the power station.

Therefore, the risk resulting from the operation of the power station will meet the DoP criteria for individual risk.

1.2.3. Offtake and Compressor Station Facility

Risk contours were generated for the offtake and compressor station. The following were the results of the assessment of the risk contours:

- The risk contour for an individual risk of fatality of 1×10^{-6} per year (residential areas) extends past the boundary by at most 42m at the southern boundary of the site and does not extend to any residences.

- The risk contour for an individual risk of fatality of 10 x 10^{-6} per year (active open spaces) extends beyond the southern boundary by approximately 16m.
- The risk contour for an individual risk of fatality of 50 x 10^{-6} per year (industrial areas) is not generated for the site.
- There are no sensitive or commercial land uses near the delivery facility.

Therefore, the risk resulting from the operation of the station will meet the DoP criteria for individual risk.

1.3. Societal Risk Results

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

1.4. Environmental Risk Analysis

An assessment of the potential environmental hazards that could result from the construction and operation of the Wellington Power Project were identified. The type of risks include:

- Environmental impact on local flora and fauna
- Noise generation during operation of compressors and turbines
- Emissions of natural gas from station venting operations
- Emissions from turbine exhausts

The risks are of a routine nature which will be addressed in the Environmental Assessment (EA) for the project.

1.5. Conclusions

A PHA was undertaken for the Wellington Power Project. The risk resulting from the operation of the power station and associated infrastructure was assessed to determine the potential impact to local land uses.

Risk levels resulting from the gas supply pipeline were presented as risk transects for a number of sensitivity cases with various levels of pipeline safeguards. Distances to risk criteria levels for various land uses are summarised in Table 1.1. An appropriate level of safeguards may be selected from this table to meet the requirements of the DoP criteria for individual risk.

The assessment of risk for the stations showed that the risk levels resulting from the operation of the power station and the pipeline stations will meet the DoP criteria for individual risk.

1.6. Recommendations

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

2. Prior to the commencement of operation, the PHA would be updated to a final hazard analysis (FHA), where necessary. In the event of significant design changes occurring during the detailed design phase, this revision of the PHA would occur prior to the commencement of construction. This would be a likely requirement for the proposed gas pipeline and compressor station, as only preliminary designs were available at the time of the PHA, and the locations of the pipeline mainline stations were not known.
3. The enclosures for compressor and turbine units should be provided with appropriate gas detection (e.g. alarm on 20% LFL and shutdown on 40% LFL) and fire detectors (UV/IR) to detect lube oil fires.
4. The compressor and gas turbine units should be designed to minimise the number of potential leak sources in the enclosure (e.g. by placing flanged equipment outside the enclosure).
5. The AS2885:2007 guidelines for separation between station areas should be followed for the detailed design of the stations to minimise the potential for escalation.
6. The control room/ office, workshop/store and fire booster station at the power station should be relocated a minimum of 40m from the nearest turbine and also from the gas receival area. Alternatively, the spacing requirements in AS2885:2007 for station equipment should be followed.

2. INTRODUCTION

2.1. Background

ERM Power Pty Ltd (ERM) proposes to construct a gas-fired power station near Wellington, NSW. The power station will comprise four gas-turbine generators with a power output up to 660MW. The power station will operate as a peak demand power station. The gas supply for the station is to be provided by a 100 km pipeline running from an offtake on the Central West Pipeline near Parkes, NSW.

ERM commissioned Parsons Brinckerhoff Australia Pty Ltd (PB) to prepare the Environmental Assessment (EA) for the project. The power station project includes the following:

- a 100km pipeline with a nominal diameter of 356mm to deliver natural gas to the station,
- an open-cycle gas-turbine (OCGT) facility with gas receival facilities,
- a transmission line to connect to an existing substation near the proposed site.

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

This report summarises the objectives, scope of work, methodology and results of the PHA.

2.2. Objectives

The objectives of the study were to undertake a Preliminary Hazard Analysis of the Wellington Power Project and, in particular, to assess the hazard and risk impacts as given in the Director General's Requirements (Ref. 1), as follows:

*"**Hazards and Risk Impacts (All Project Components)***

The Environmental Assessment must include a screening of potential hazards on site (including new gas supply infrastructure) to determine the potential for off site impacts and any requirement for a Preliminary Hazard Analysis (PHA). The PHA, should potential off-site impacts be identified, must be prepared in accordance with the Department's Hazardous Industry Planning Advisory Paper No. 3, Hazardous Industry Planning Advisory Paper No. 6 and Multi-level Risk Assessment. Risk impacts associated with the transport of dangerous goods and hazardous materials must be documented with reference to the Department's draft 'Route Selection' guideline.

General Environmental Risk Analysis (All Project Components)

Not withstanding the above key assessment requirements, the Environmental Assessment must include an environmental risk analysis to identify potential environmental impacts associated with the project (construction and operation), *proposed mitigation measures and potentially significant residual environmental impacts after the application of proposed mitigation measures. Where additional key environmental impacts are identified through this environmental risk analysis, an appropriately detailed impact assessment of these additional key environmental impacts must be included in the Environmental Assessment.*

The detailed objectives of the study were to:

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

2.3. Scope

The scope of the assessment is the Wellington Power Project and associated infrastructure. The scope of the assessment includes the following:

- Gas supply pipeline and facilities (offtake/ compressor station)
- Power station site and facilities (gas receival station, turbines)
- Transmission line from power station to the sub-station

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

3. DESCRIPTION OF THE PROPOSED PIPELINE PROJECT

3.1. Power Station and Pipeline Project

The Wellington Power Project consists of the following facilities:

- an offtake and compressor station on the Central West Pipeline near Parkes, NSW (Figure 3.2),
- a 100km pipeline with a nominal diameter of 356mm from the offtake to the power station site,
- the power station near Wellington, NSW (Figure 3.1),
- a transmission line connecting the power station to the existing TransGrid substation (Figure 3.1).

3.1.1. Power Station Facilities

The power station will consist of a open-cycle gas-turbine plant of up to 660MW. The gas turbines will be four open-cycle units each with a capacity in the range 150MW to 165MW. The gas turbines will typically operate for 350 hours per year for peak demand requirements, depending on market conditions.

Design details of the power station are still preliminary but will likely consist of the following facilities:

- A scraper receiver station (the pipeline will have a facility for periodic launching of scrapers or ‘pigs’ which can be used to remove oil and condensate buildup and also to monitor the pipeline wall thickness via sensors and identify corrosion)
- Gas filtering, metering and pressure reduction facilities
- Gas heater

Associated power station facilities will include:

- Generator-transformers
- Demineralised water treatment plant
- Evaporation pond
- Startup and emergency diesel generator facility
- Demineralised water, firewater and raw water tank storage
- Office, workshop and control room buildings

No bulk storage of either gas or liquid fuels will be required for the power station operation. Water will be stored on site for potable use, amenities, firewater. Water will also be used for evaporative cooling for turbine operation. Water injection into the gas turbines may also be used for short term boosting of power output for a maximum of 100 hours per year.

Figure 3.1 shows the preliminary layout proposed for the power station.

3.1.2. Pipeline

The gas supply for the power station will be taken from the Central West Pipeline, which is in turn supplied from the Moomba-Sydney Gas Pipeline. A new pipeline will be constructed to transport gas from an offtake on the Central West Pipeline.

3.1.3. Offtake and Compressor Station

Limited design details of the proposed offtake and compressor station were available at the time of the assessment (December 2007). An assessment of typical equipment and layout from similar stations was undertaken. The following components were assumed for the assessment:

3.1.4. Offtake and Compressor Station

- An isolating valve
- Shutdown valves
- Filter Unit
- Flow meter
- Fuel gas regulating station (assumed let down to 4MPa)
- 2 x compressor units
- A scraper launcher unit

Figure 3.2 shows the preliminary layout proposed for the offtake and compressor station.

3.2. Power Station Site

The proposed site for the power station is located 2km north of Wellington on Goolma Road. An existing TransGrid substation is located near the site.

3.3. Pipeline Route

The proposed pipeline route is from an offtake station on the Central West Pipeline at Alectown near Parkes, proceeding in a south-east direction to the Parkes-Wellington road and then proceeds in a north-east direction. The pipeline route is within or adjacent to road reserve. A major crossing will be required at the Macquarie River. The proposed pipeline route is shown in Figure 3.3.

The total length of the pipeline is 100km. A spacing of 30km between main line valves (MLVs) will be required to meet the requirements of AS2885:2007 requirements for R2 areas. Details of the location and design of these stations have not been included in the preliminary design.

FIGURE 3.1: PRELIMINARY POWER STATION LAYOUT

FIGURE 3.2: PRELIMINARY LAYOUT FOR OFFTAKE AND COMPRESSOR STATION

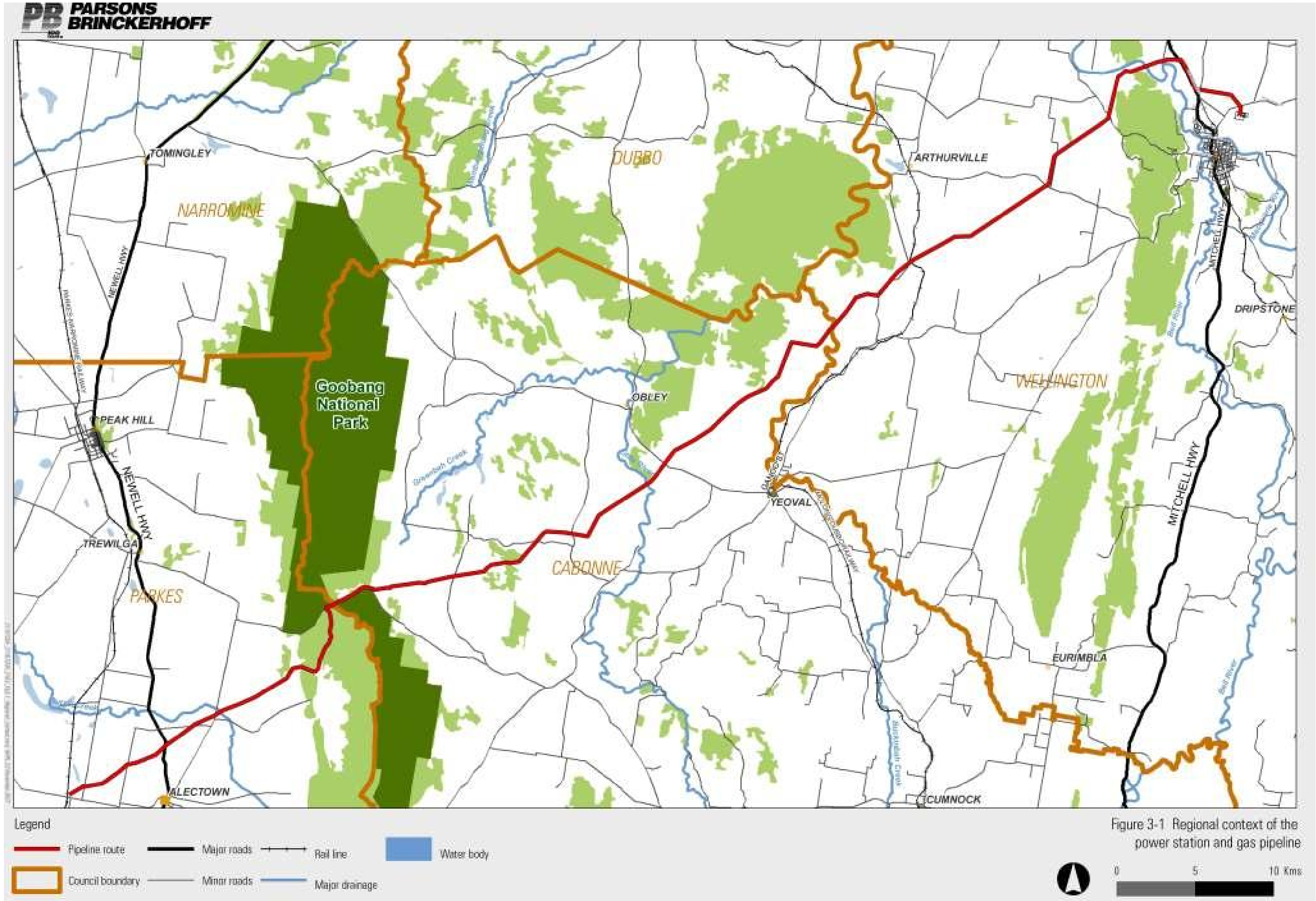


FIGURE 3.3: PIPELINE ROUTE

3.4. Pipeline Design

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

- 12 MPa Maximum Allowable Operating Pressure (MAOP)
- 356 mm pipeline diameter

3.5. Surrounding Land Use Categories

The pipeline will pass near a range of land uses including open rural areas. Generally zoning along the pipeline route is rural with limited buildup. A review of the aerial photography showed limited residential areas near the pipeline. The nearest houses appear to be about 150m to 200m from the centreline of the pipeline.

4. METHODOLOGY

The methodology undertaken for the risk assessment of the Wellington Power Project follows the guidelines of the following NSW Department of Planning documents:

- Hazardous Industry Planning Advisory Paper (HIPAP) No. 6, 'Guidelines for Hazard Analysis' (Ref. 3)
- HIPAP No.4, 'Risk Criteria for Land Use Safety Planning', (Ref. 4)
- HIPAP No. 3, 'Environmental Risk Impact Assessment Guidelines', (Ref. 5)
- 'Multi-Level Risk Assessment', (Ref. 6)
- 'Route Selection' (Ref. 7)

The hazard analysis process requires the identification of potential hazardous incidents which could occur as a result of the operation of the facility, including the identification of the following:

- the causes or failure mechanisms that initiate the hazardous event
- the proposed safeguards which reduce the consequence or likelihood of the incident

The outcome of the hazard identification is a number of scenarios which could potentially have an impact to land uses adjacent to the facility. These scenarios are carried forward to quantitative risk assessment, which involves the following steps (as summarised in Figure 4.1 (from HIPAP No. 10, Ref. 8).

- Consequence modelling to estimate the consequences (magnitude of impact) of the hazardous incident scenarios.
- Frequency assessment to estimate the frequency of the incident occurring.
- Assessment of the quantitative risk level by combining the results of the consequence and frequency assessment.
- Comparison of risk assessment results with relevant criteria for acceptable risk.
- Identification of risk reduction measures where the assessed risk levels exceed the criteria for acceptable risk.

The approach taken was to review the range of hazards that could occur and then to identify the significant risks. These were then carried forward for quantitative assessment. Resultant risk levels were compared with the criteria in HIPAP No. 4, summarised in Table 4.1.

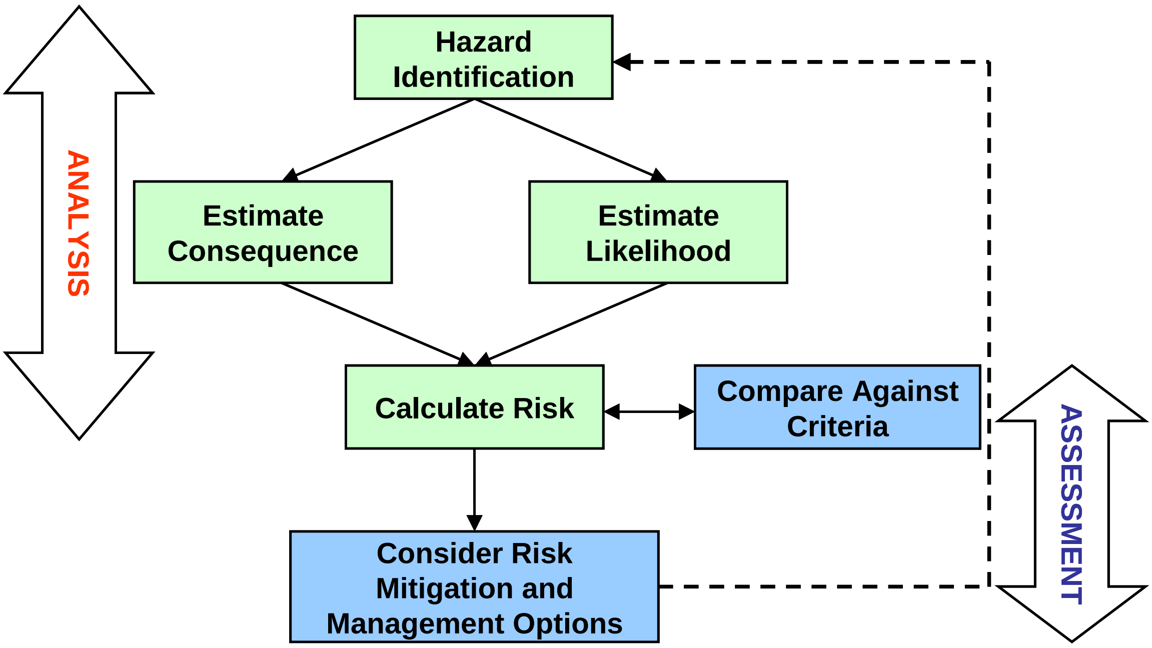


FIGURE 4.1: THE RISK ANALYSIS AND ASSESSMENT PROCESS (HIPAP NO. 10)

TABLE 4.1: RISK CRITERIA FOR LAND USE SAFETY PLANNING (HIPAP NO.4)

Land Use Category	Individual Risk Criteria (Chance of a Fatality per Million Years)
Sensitive developments (hospitals, schools, child care facilities, aged care housing)	0.5
Residential areas	1
Commercial areas (offices, retail centres, showrooms, restaurants etc)	5
Sporting complexes and active open spaces	10
Industrial facilities (reached at boundary)	50

4.1. Level of Assessment

The DoP document, ‘Multi-Level Risk Assessment’ (Ref. 6) provides guidelines for the level of analysis required for risk assessments. The assessment has shown that there is a potential for significant offsite consequences near the power station and pipeline facilities. As the expected frequencies of incidents indicates that risk levels may exceed DoP criteria, a Level 3 assessment was undertaken for the current study, i.e. full quantification of incidents with potential offsite impact.

5. HAZARD IDENTIFICATION

5.1. Hazardous Incidents

The hazard identification table for the power station and pipeline facilities is given in APPENDIX 1. The major hazards are discussed in further detail in the following sections. The hazard identification is used as a basis for identifying a list of scenarios for carrying forward to the quantitative risk assessment.

5.2. Releases from Pipeline

In summary, the incidents identified include the following:

- Loss of containment from the pipeline due to corrosion, third party impact, earth movement, subsidence, etc.
- Exposure of the pipeline due to erosion from flooding
- Vehicle loading
- AC induction effects from HV power lines enhancing corrosion
- Stress corrosion cracking
- Fatigue due to pressure cycling
- Weld and material defects
- Overpressure/ overtemperature

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

Ignited gas release from the pipeline could result in:

- Jet fires
- Flash fire
- Vapour Cloud Explosion (VCE)

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

If ignition was delayed, a vapour cloud could form, however as natural gas is buoyant, the potential for a significant cloud buildup is low. If the vapour cloud reached an ignition source a flash fire or a vapour cloud explosion could result.

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

A vapour cloud explosion could occur if there is a potential for buildup of natural gas in congested areas, which restricts the flame front and results in an explosive overpressure which will impact people in the area. As there are no major structures near the pipeline, there is a very low likelihood of congestion and resulting vapour cloud explosion.

From a literature review of gas pipeline failures, the main cause of pipeline leaks is external mechanical damage as a result of third party impact on the pipeline (Ref. 9). Australian industry sources indicate that pipeline failure modes are similar to overseas experience. Anecdotally, failures would appear to be less frequent in Australia compared to overseas experience. However, no compiled source of failure rates for pipelines within Australia is available and estimates of frequency based on reported incidents are therefore not considered reliable.

There are over 21,000km of major gas transmission pipeline in Australia. Very few incidents have been reported for major Australian pipelines. On this basis, generic European data was used for the frequency assessment as it provides a more statistically valid sample size.

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

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

5.2.1. Fatigue

The peak demand operation of the power station may result in pressure cycling from static to dynamic conditions as gas flow to the power station is turned on. As part of the detailed design, a fatigue assessment should be undertaken to ensure that the design of the pipeline will be capable of meeting the cycling demand as per the requirements of AS2885:2007 (Ref. 2).

Fatigue may result in fracture failure, leading to a pipeline rupture in the worst case. The potential for fatigue would be readily detected from the records of the operating history and maintenance inspections during the lifetime of the pipeline. If problems were detected, mitigation measures such as pressure restriction or reducing the design life of the pipeline would be implemented.

Given the effectiveness of the proposed safeguards and the conservative approach used for the assessment, no increase in the failure rate for the effect of fatigue was included in the analysis.

5.2.2. Stress Corrosion Cracking

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

Pipeline designers make allowance to minimise the impact of SCC by selecting an appropriate pipeline coating which will minimise the impact of external corrosion and by an appropriate design for the cathodic protection system. The protocols of the Pipeline Research Council International (PRCI) for the assessment of likelihood of SCC (Ref. 10) should also be followed in the detailed design.

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

5.3. Typical Pipeline Safeguards

The following engineered and procedural safeguards are typical of pipeline designs and would be implemented for the project.

5.3.1. Protection against External Damage

- Depth of Cover
- ‘One-Call‘/ ‘Dial-before-dig’ services
- Pipeline patrols
- Main line valve stations to isolate and limit release
- Marker tape
- Warning signs

5.3.2. Corrosion Protection

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

5.3.3. Ground Movement/Subsidence

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

5.4. Releases in Power Station and Offtake/ Compressor Station

In summary, the incidents identified include the following:

- Loss of containment from station pipework and equipment due to corrosion, mechanical damage, flange, gasket and fitting leaks, etc.
- External events including earthquake, flooding, lightning, bushfire, etc.
- Releases due to venting operations.
- Loss of containment during pigging operations.
- Failure of temperature and pressure control.
- Dispersion of natural gas from the stack during venting operations with the potential for ignition.

Similar to gas releases from the pipeline, loss of containment at the stations will result in jet fires, flash fires and VCE incidents. Releases in the open are unlikely to result in VCE. There is a potential for gas buildup in the enclosures for the compressors and gas turbines to result in an explosion in the event of ignition of gas. It is recommended that the enclosure be provided with appropriate gas detection as per industry practice (e.g. alarm on 20% LFL and shutdown on 40% LFL) and fire detectors (UV/IR) to detect lube oil fires. The compressor and gas turbine unit should be designed to minimise the number of potential leak sources in the enclosure (e.g. by placing flanged equipment outside the enclosure). Therefore the risk from the compressor and turbine equipment will be minimal.

5.5. Safeguards for Power Station and Offtake/ Compressor Station

The following safeguards have been included in the design of the proposed compressor station and delivery facility to prevent, control and mitigate fire incidents at the sites.

5.5.1. Leak Prevention/ Minimisation

- No free oxygen present in the natural gas (reducing the effect of corrosion)
- Painting of aboveground pipework
- Maintenance/inspection
- Spiral wound gaskets on HP flanged equipment
- Pressure control (PCV) and slam-shut valve on pressure regulating skid

- High fracture tough steel
- Permit to work system
- Security fencing
- Vehicle barriers
- Hydrostatic testing of equipment
- 100% radiography of all circumferential welds
- Security fence placed around the station outside the hazardous area classified by AS 2430 to minimise the risk of ignition sources
- Gravel or hardstand area inside the fenced site around gas filled equipment to minimise the risk of grass fires
- Lightning protection
- Maintenance procedures
- Operating procedures

5.5.2. Control

- Monitoring of pressure via SCADA system
- Remotely operated ESD valve at the station inlet
- Ignition control as per AS2430
- Slam shut valve operates if pressure increases above the set point
- Relieving of stress where ground movement stresses the pipeline.

5.5.3. Mitigation

- Separation distance between release point and site boundary (minimum 15m as per AS2885:2007)
- Emergency Response Procedures

5.6. Transmission Line Impact

Transmission lines will connect the turbine power output to an existing TransGrid sub-station located near the power station. The following potential impacts may result:

- Environmental impact to local flora and fauna and soil runoff during transmission construction
- Construction equipment and personnel contacting live power lines and equipment near the sub-station
- High voltage induction effects on construction personnel and equipment near live power lines

These hazards are typical of construction and operational impact of transmission lines. The environmental impacts of transmission line construction will be addressed in the EA. Safety aspects of construction near live transmission lines will be include in Construction Safety Plans for the project.

5.7. Environmental Risk Analysis

An assessment of the potential environmental hazards that could result from the construction and operation of the Wellington Power Project were identified. A environmental hazard identification table is included in Appendix 2.

The type of risks identified include:

- Environmental impact on local flora and fauna
- Noise generation during operation of compressors and turbines
- Emissions of natural gas from station venting operations
- Emissions from turbine exhausts

The risks are of a routine nature which will be addressed in the Environmental Assessment (EA) for the project.

5.8. Bushfire Risk

The proposed power station site has been identified as bush fire prone land. The Rural Fire Service advised that the development should meet the requirements of the NSW Rural Fire Service document ‘Planning for Bush Fire Protection’ (Ref. 11) and be addressed in the Environmental Assessment.

The typical design for the layout for gas pipeline facilities is to provide clearing of the area around the site fence as well as within the fenced area. The area around gas filled equipment will be either hardstand or gravel with open spaces within the boundary consisted of grassed areas only.

AS2885:2007 requires at least 15m spacing between fencing and compressor and turbine units to minimise the impact of external fires. The standard also requires open space to be provided around the site for firefighting purposes. A minimum separation of 4m is required between buildings. At least one site access point is to be wide enough for access for firefighting equipment. Firewater storage and fire booster stations have been included in the preliminary layout for the power stations. As well, liquid fuel storage will be required for the site.

Given the clearing within and around the power station site, the risk of external bushfires impacting plant is low. It is recommended that appropriate Australian standards (e.g. AS3959:1999, Construction of Buildings in Bush Fire-prone Areas) and the Building Code of Australia be referred to in the detailed design for the power station. A Fire Safety Study should also be prepared for the detailed design prior to construction.

5.9. Transport Risk

No transportation of significant quantities of flammable materials will be required for the power station as the turbines will only operate with natural gas fuel and no bulk storage of liquid fuel will be required. Approximately 4 tonnes in total of sulphuric acid and caustic soda will be delivered to site each year.

Sulphuric acid and caustic soda will be delivered to the power station site in intermediate bulk containers by an accredited carrier in accredited packaging. These hazardous substances would be handled in accordance with the Australian Code for the Transportation of Dangerous Goods by Road and Rail. The two substances (sulphuric acid and caustic soda) would be carried in separate vehicles at different times, as they are not compatible with each other. Specific handling procedures would be identified in a risk management and emergency response plan to be developed for the site.

The storage on site will be required to meet the requirements of AS3780-1994, ‘The Storage and Handling of Corrosive Substances’ (Ref. 12) and the NSW Occupational Health and Safety Amendment (Dangerous Goods) Regulation 2005 (Ref. 13). Given the small quantities stored on site, there will not be a significant risk from storage of acid and caustic.

Only minor quantities of other chemicals and dangerous goods would be stored at the power station site. These substances would generally be associated with day-to-day maintenance and house keeping activities, and would comprise small quantities of lubricant oils and cleaning chemicals. These substances would be stored within a designated bunded area within the administration building.

It is envisaged that the maintenance contractor would bring any materials required during major maintenance activities onto the facility and any waste materials would be taken off-site when the works were completed.

6. CONSEQUENCE ASSESSMENT

6.1. Releases

The Hazard Identification Table in Appendix 1 was reviewed to select a set of credible release scenarios and hole sizes to be carried forward to the Quantitative Risk Assessment (QRA). The following release scenarios and hole sizes were selected for the assessment:

- Gas Supply Pipeline
  - 6 mm holes, equivalent to pinhole leaks due to corrosion or defects
  - 25 mm, equivalent to punctures
  - Full Bore Rupture (356mm)
- Station Pipework
  - 6 mm holes, equivalent to pinhole leaks due to corrosion or defects
  - 25 mm, equivalent to punctures
- Station Valves
  - 10 mm holes, equivalent to valve body or gasket leaks
- Spiral Wound Gaskets
  - 3 mm holes, equivalent to pinhole leaks due to leaks from equipment flanges, manholes
- Fittings/Tapping points
  - 25 mm holes, equivalent to shearing of fitting / tapping point

6.2. Heat Radiation Effects

The probability of fatality corresponding to various heat radiation levels used for assessing heat radiations effects is shown in Table 6.1. These are conservatively based on exposure to an unprotected person with no means to escape (Ref. 4).

TABLE 6.1: PROBABILITY OF FATALITY FROM EXPOSURE TO HEAT RADIATION

Fire Heat Radiation (kW/m^2)	Probability of Fatality
4.7	Very Low, mainly burn injury
6	10%
10	50%
14	100%
23	Damage to Structures, potential for escalation

6.3. Release Rates

The release rates for equipment and pipeline failures were calculated using the Shell Global Solutions package, FRED Ver. 5 (Ref. 14).

6.3.1. Gas Supply Pipeline Releases

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

The analysis is summarised in Appendix 3. The release rates and resulting flame lengths are shown in Table 6.2. The release rates were calculated at the Maximum Allowable Operating Pressure (MAOP) of the pipeline (12 MPag).

6.3.2. Isolation of Pipeline Releases

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

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

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

6.3.3. Station Releases

The release rates for jet releases were modelled as continuous releases at the following pressures:

- 12 MPag for the offtake and compressor station
- 12 MPag for equipment upstream of the pressure regulation station
- 4 MPag for equipment downstream of the pressure regulation station

6.4. Jet Fire Heat Radiation Impact

6.4.1. Pipeline Releases

The assessment of the heat radiation effects from an ignited pipeline release are given in Appendix 3. The results are summarised in Table 6.2.

6.4.2. Station Releases

The distance to heat radiation levels of interest were calculated as detailed in Appendix 3. The results are summarised in Table 6.3.

TABLE 6.2: JET FIRES - CONSEQUENCE DISTANCES TO SPECIFIED HEAT RADIATION LEVELS

Release Scenario	Release Angle (from horiz.)	Hole Size (mm)	Pressure (MPag)	Release Rate (kg/s)	Flame Length (m)	Flame Width (m)	Distance to Heat Radiation Levels (m)				
							4.7kW/m^2	6kW/m^2	10kW/m^2	14kW/m^2	23kW/m^2
Gas Supply Pipeline Releases (Lateral)											
Pinhole (corrosion)	45º	6	12	0.63	10	1	13	12	11	10	9
Puncture (puncture)	45º	25	12	11	31	5	44	41	35	33	29
Rupture - Isolation	45º	355	12	862	178	41	266	246	213	195	174
Rupture - No Isolation	45º	355	12	2210	260	70	398	369	319	292	259
Gas Supply Pipeline Releases (Vertical)											
Pinhole (corrosion)	90º	6	12	0.63	9	1	9	8	7	6	4
Puncture (puncture)	90º	25	12	11	30	5	32	29	23	20	16
Rupture - Isolation	90º	355	12	862	166	41	196	176	141	121	97
Rupture - No Isolation	90º	355	12	2210	243	70	297	267	215	186	150
Station Releases (12 MPa, Horizontal)											
Gasket leak	0º	3	12	0.16	5.9	0.6	7.8	7.5	7.0	6.8	6.5
Valve/ gland leak	0º	10	12	1.75	15.5	2.0	21.9	20.9	19.2	18.5	17.7
Fitting Failure	0º	25	12	11.0	32.3	4.9	47.6	45.3	41.4	39.8	37.9
Station Releases (4 MPa, Horizontal)											
Gasket leak	0º	3	4	0.05	3.6	0.3	4.6	4.4	4.1	4.0	3.9
Valve/ gland leak	0º	10	4	0.51	9.4	1.0	12.0	12.1	11.2	10.9	10.5
Fitting Failure	0º	25	4	3.2	19.6	2.5	27.6	26.4	24.2	23.4	22.4

TABLE 6.3: FLASH FIRES – CLOUD DIMENSIONS AND CONSEQUENCE DISTANCES

Release Scenario	Release Angle (from horiz.)	Hole Size (mm)	Pressure (MPag)	Release Rate (kg/s)	Flash Fire Dimensions (D5 Conditions)		Flash Fire Dimensions (F2 Conditions)	
					Downwind Distance (m)	Width (m)	Downwind Distance (m)	Width (m)
Gas Supply Pipeline Releases (Lateral)								
Pinhole (corrosion)	45º	6	12	0.63	1.4	0.6	1.3	0.5
Puncture (puncture)	45º	25	12	11	1.4	0.8	1.4	0.8
Rupture - Isolation	45º	355	12	862	2.8	2.7	2.8	2.7
Rupture - No Isolation	45º	355	12	2210	3.4	0.002	5.0	0.002
Gas Supply Pipeline Releases (Vertical)								
Pinhole (corrosion)	45º	6	12	0.63	0.4	0.1	0.4	0.01
Puncture (puncture)	45º	25	12	11	0.6	0.02	0.6	0.003
Rupture - Isolation	45º	355	12	862	2.4	0.008	3.2	0.006
Rupture - No Isolation	45º	355	12	2210	3.4	0.002	5.0	0.002
Station Releases (12 MPa, Horizontal)								
Gasket leak	0º	3	12	0.16	5.0	0.6	6.0	0.7
Valve/ gland leak	0º	10	12	1.75	18.0	2.0	20.0	2.4
Fitting Failure	0º	25	12	11.0	50.0	8.0	46.9	8.6
Station Releases (4 MPa, Horizontal)								
Gasket leak	0º	0.05	4	0.05	2.5	0.3	3.0	0.3
Valve/ gland leak	0º	0.51	4	0.51	8.5	1.0	10.0	1.1
Fitting Failure	0º	3.2	4	3.2	23.0	3.2	21.0	3.6

6.5. Incidents Carried Forward to QRA

Table 6.4 summarises the scenarios with offsite consequences which have been carried forward to the QRA.

TABLE 6.4: SCENARIOS CARRIED FORWARD TO QRA

Release Scenario	Hole Size (mm)	Release Rate (kg/s)	Offsite Jet Fire Consequences	Offsite Flash Fire Consequences
Gas Supply Pipeline Releases (Lateral)				
Pinhole (corrosion) release (45º)	6	0.63	Carried Forward	Not Carried Forward
Medium (puncture) release (45º)	25	11	Carried Forward	Not Carried Forward
Rupture followed by isolation (45º)	355	862	Carried Forward	Not Carried Forward
Unisolated rupture (45º)	355	2210	Carried Forward	Not Carried Forward
Gas Supply Pipeline Releases (Vertical)				
Pinhole (corrosion) release (45º)	6	0.63	Carried Forward	Not Carried Forward
Medium (puncture) release (45º)	25	11	Carried Forward	Not Carried Forward
Rupture followed by isolation (45º)	355	862	Carried Forward	Not Carried Forward
Unisolated rupture (45º)	355	2210	Carried Forward	Not Carried Forward
Station Releases (12 MPa, Horizontal)				
Gasket leak	3	0.16	Carried Forward	Carried Forward
Valve/ gland leak	10	1.75	Carried Forward	Carried Forward
Fitting Failure	25	11.0	Carried Forward	Carried Forward
Station Releases (4 MPa, Horizontal)				
Gasket leak	3	0.05	Not Carried Forward	Not Carried Forward
Valve/ gland leak	10	0.51	Not Carried Forward	Not Carried Forward
Fitting Failure	25	3.2	Not Carried Forward	Not Carried Forward

7. FREQUENCY ANALYSIS

7.1. Gas Supply Pipeline Incident Frequencies

Frequencies for pipeline releases and jet fires were derived from published historical records of pipeline incidents. Details of the frequency analysis for pipeline incidents is given in Appendix 4. The frequencies of jet fire and flash fire incidents were estimated based on:

- The frequency of the initiating leak
- The probability of immediate ignition for jet fires
- The probability of delayed ignition for flash fires

7.1.1. Pipeline Safeguards

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

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

Heavy wall thickness pipe may also be provided at locations where there is an increased risk of external interference. Heavy wall pipe will also reduce the likelihood of corrosion resulting in pipeline releases. The specification proposed for the gas supply pipework has not been nominated in the preliminary design.

For general cross-country locations, pipe with a specification of API 5l X65 or X70 would be used. For an operating pressure of 12 MPa and a pipeline diameter of 356mm, the wall thickness for X70 pipe will be 6.3mm, equivalent to a design factor of about 0.70.

By comparison, for an operating pressure of 12 MPa and a pipeline diameter of 356mm, the minimum wall thickness will be about 9.5mm, equivalent to a design factor of about 0.77 for API 5l X42 pipe which has a specified minimum yield strength (SMYS) of 290MPa. (Generally, a maximum design factor of 0.8 applies for pipelines). As no pipewall thickness was specified in the preliminary design, two wall thickness cases were assumed:

- A wall thickness of 6.3mm
- A wall thickness of 9.5mm

Marker tape is an additional safeguard typically applied above the buried pipeline to indicate the presence of high pressure pipelines.

As the safeguards proposed for the current pipeline have not nominated, a number of cases with different levels of typical industry safeguards were considered. These are:

- Case 1 (Base Case) – 750mm depth of cover (DOC), marker tape, 6.3mm wall thickness
- Case 2 – 900mm DOC, marker tape, 6.3mm wall thickness
- Case 3 - 1200mm DOC, marker tape, 6.3mm wall thickness
- Case 4 – 750mm depth of cover (DOC), 9.5mm wall thickness
- Case 5 – 900mm DOC, 9.5mm wall thickness
- Case 6 - 1200mm DOC, marker tape, 9.5mm wall thickness

7.2. Station Incident Frequencies

Details of the frequency assessment for the power station site and the offtake and compressor station are given in Appendix 4. The frequency of jet fire incidents was estimated based on:

- generic failure rates for component releases
- the probability of ignition of the release (which is dependent on the release rate)

A parts count of components was undertaken to determine the total release frequency at each location within the stations.

8. QUANTITIVE RISK ASSESSMENT

8.1. Overview

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

The quantitative risk levels for a facility such as the stations are usually presented as risk contours. Contours of equal risk level around each site are produced. The contours indicate the risk level at any point around the facility.

8.2. Individual Risk

The calculation of risk is assessed by combining the consequence of the event (in this case the distance to heat radiation levels estimated in Section 5.6) with the frequency of occurrence (from Section 7). The risk for all incidents is accumulated to show the total risk to an individual at any point near the pipeline and facilities.

8.2.1. Gas Supply Pipeline

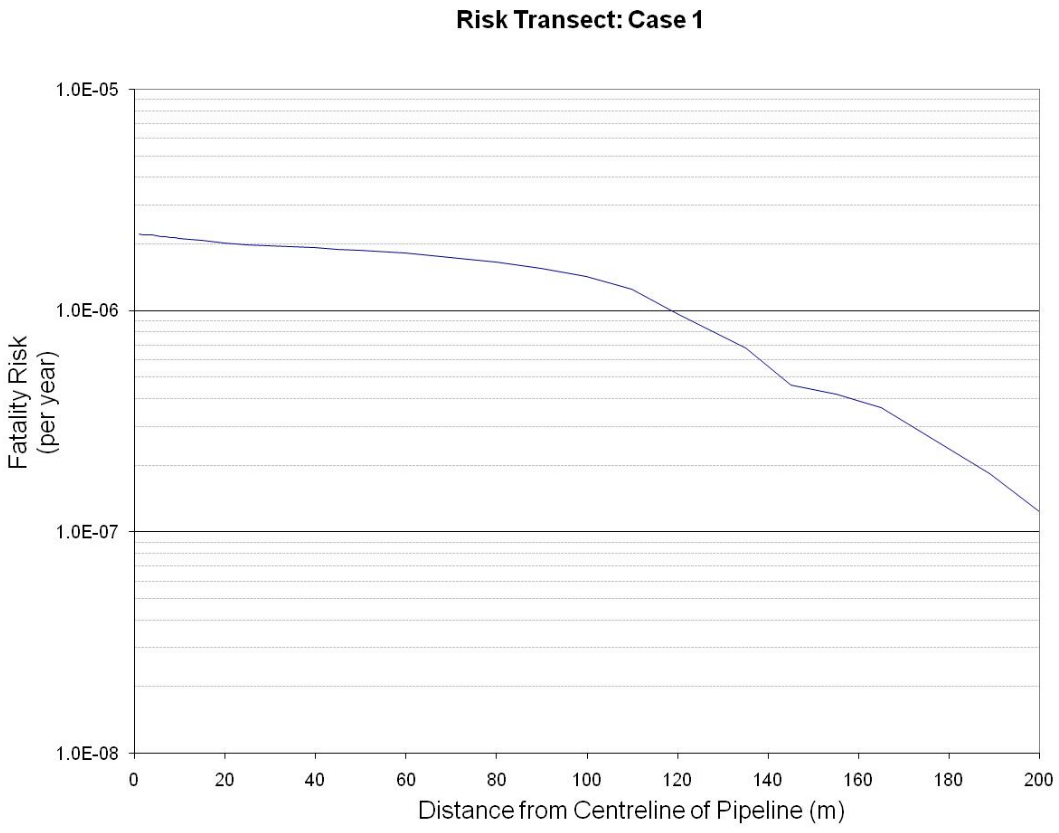
The risk transect for the pipeline with the safeguards proposed for Case 1 (750mm DOC) is shown in Figure 8.1. This shows that the risk resulting the pipeline reaches an individual risk of fatality of 1 x 10^{-6} per year (the criteria for residential areas) at a distance of 110m from the pipeline. The assessment was repeated for the other sensitivity cases. The results of the assessment are summarised in Table 8.1. Table 8.1 also summarises the distances to the risk criteria levels required for other land uses.

Table 8.1 shows the separation distances required for land uses near the pipeline route. Given that the nearest residential building is at least 150m from the pipeline then the DoP criteria for residential areas can be met. An appropriate level of safeguards may be selected depending on the separation distance to nearby landuses to meet the risk criteria of the DoP.

TABLE 8.1: DISTANCE TO INDIVIDUAL RISK LEVELS

Case	Distance to Individual Risk of Fatality (HIPAP No. 4) at Nearby Land Uses (m)				
	Sensitive Land Uses (0.5 x 10^{-7} per year)	Residential (1 x 10^{-6} per year)	Commercial (5 x 10^{-6} per year)	Active Open Spaces (10 x 10^{-6} per year)	Industrial (10 x 10^{-6} per year)
6.3mm wall thickness pipe					
1 (750mm DOC,marker tape)	141	118	NR	NR	NR
2 (900mm DOC,marker tape)	140	115	NR	NR	NR
3 (1200mm DOC,marker tape)	135	110	NR	NR	NR
9.5mm wall thickness pipe					
4 (750mm DOC,marker tape)	124	75	NR	NR	NR
5 (900mm DOC,marker tape)	121	65	NR	NR	NR
6 (1200mm DOC,marker tape)	117	8	NR	NR	NR

NR = Not reached at any distance from the pipeline



Risk Transect: Case 1

FIGURE 8.1: PIPELINE RISK TRANSECT – CASE 1 (750 MM DEPTH OF COVER, 6.3MM WT, MARKER TAPE)

8.2.2. Power Station

Figure 8.2 shows the risk contours that were generated for the power station site. The following were the results of the assessment of the risk contours:

- The risk contour for an individual risk of fatality of 1 x 10^{-6} per year (residential areas) extends past the boundary by at most 70m at the northern and western boundary of the site and does not extend to any residences.
- The risk contour for an individual risk of fatality of 10 x 10^{-6} per year (active open spaces) extends past the boundary by at most 20m at the northern boundary of the site and does not extend to any active open spaces.
- The risk contour for an individual risk of fatality of 50 x 10^{-6} per year (industrial areas) is not generated for the power station.
- There are no sensitive or commercial land uses near the power station.

Therefore, the risk resulting from the operation of the power station will meet the DoP criteria for individual risk.

FIGURE 8.2: INDIVIDUAL FATALITY RISK CONTOURS AT THE POWER STATION

FIGURE 8.3: INDIVIDUAL FATALITY RISK CONTOURS FOR THE OFFTAKE AND COMPRESSOR STATION

8.2.3. Offtake and Compressor Station Facility

Figure 8.3 shows the risk contours that were generated for the offtake and compressor station. The following were the results of the assessment of the risk contours:

- The risk contour for an individual risk of fatality of 1 x 10^{-6} per year (residential areas) extends past the boundary by at most 42m at the southern boundary of the site and does not extend to any residences.
- The risk contour for an individual risk of fatality of 10 x 10^{-6} per year (active open spaces) extends beyond the southern boundary by approximately 16m.
- The risk contour for an individual risk of fatality of 50 x 10^{-6} per year (industrial areas) is not generated for the site.
- There are no sensitive or commercial land uses near the delivery facility.

Therefore, the risk resulting from the operation of the stations will meet the DoP criteria for individual risk.

8.2.4. Main Line Valves

Risk contours were not generated for the main line valves as the locations have not been identified. The risk for these stations will generally be less than for the compressor and delivery stations as there will be less equipment at the MLVs. Therefore the extent of the risk contours for the MLV stations will be less than the other aboveground stations.

8.3. Societal Risk

Societal risk is a measure of society’s concerns for risks which result in multiple fatalities. For example, people may be concerned with the risks of aircraft crashes, based on reporting of incidents with high casualty figures. By comparison, people may be less concerned with the risks of motor vehicle accidents which occur on a daily basis and do not receive the same level of public attention.

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

8.4. Escalation

The potential for escalation between facilities was assessed by considering the consequence distances for heat radiation levels of 23 kW/m^2 (impact on structures) resulting from jet fire incidents. Flash fire incidents have a very short duration and will not result in significant potential for escalation to onsite equipment. The following escalation incidents were considered. A maximum hole size of 25mm was assumed for assessing escalation, as larger hole sizes will have a very low likelihood of occurrence.

For releases from equipment at a pressure of 12MPa, the distance to a heat radiation level was shown to be about 40m.

It is recommended that the AS2885:2007 guidelines for separation between station areas be followed for the detailed design of the stations.

8.4.1. Escalation from Compressor Station

The compressor units are located about 50m from the inlet to the compressor station. In the event of a major incident at the compressor station, the compressors would be shut down and the compressor station isolated via the shutdown valves. Therefore, the risk of escalation to the compressor station inlet is unlikely to impede shutdown of the station.

The station buildings (office, control room, etc) are also located about 50m from the compressors. Therefore, there the risk of escalation to the control room is unlikely to impede remote operation and local control in the event of an emergency.

The offtake is located about 100m from the compressor station. Therefore, there is a low risk of compressor station incidents escalating to impede controlled shutdown of the gas supply offtake to the proposed pipeline.

8.4.2. Escalation from Power Station

The turbine units are located about 100m from the inlet facilities at the power station. In the event of a incident at the turbines, individual turbines would be shut down and isolated via the shutdown valves. If the incident was serious enough, the station would be isolated by shutdown valves on the gas receival unit. The risk of escalation from turbine units to the shutdown valves at the station inlet is unlikely to impede shutdown of the station.

The control room is currently shown as being located about 30m from the nearest turbine unit. The workshop area and the firewater booster station is also shown as being located about 20m from the nearest turbine. It is recommended that the control room/ office, workshop/store and fire booster station be relocated a minimum of 40m from the nearest turbine and also from the gas receival area. Alternatively, the spacing requirements in AS2885:2007 for station equipment should be followed.

8.5. Conclusions

A PHA was undertaken for the Wellington Power Project. The risk resulting from the operation of the power station and associated infrastructure was assessed to determine the potential impact to local land uses.

Risk levels resulting from the gas supply pipeline were presented as risk transects for a number of sensitivity cases with various levels of pipeline safeguards. Distances to risk criteria levels for various land uses are summarised in Table 8.1. As the nearest residential building is at least 150m from the pipeline then the DoP criteria for residential areas can be met. An appropriate level of safeguards may be selected from this table to meet the requirements of the DoP criteria for individual risk.

The assessment of risk for the stations showed that the risk levels resulting from the operation of the power station and the pipeline stations will also meet the DoP criteria for individual risk.

8.6. Recommendations

1. A number of issues (stress corrosion cracking, fatigue due to pressure cycling,) have been identified which will need to be addressed in the detailed design of the gas pipeline.
2. Prior to the commencement of operation, the PHA would be updated to a final hazard analysis (FHA), where necessary. In the event of significant design changes occurring during the detailed design phase, this revision of the PHA would occur prior to the commencement of construction. This would be a likely requirement for the proposed gas pipeline and compressor station, as only preliminary designs were available at the time of the PHA, and the locations of the pipeline mainline stations were not known.
3. The enclosures for compressor and turbine units should be provided with appropriate gas detection (e.g. alarm on 20% LFL and shutdown on 40% LFL) and fire detectors (UV/IR) to detect lube oil fires.
4. The compressor and gas turbine units should be designed to minimise the number of potential leak sources in the enclosure (e.g. by placing flanged equipment outside the enclosure).
5. The AS2885:2007 guidelines for separation between station areas should be followed for the detailed design of the stations to minimise the potential for escalation.
6. The control room/ office, workshop/store and fire booster station at the power station should be relocated a minimum of 40m from the nearest turbine and also from the gas receival area. Alternatively, the spacing requirements in AS2885:2007 for station equipment should be followed.

9. ASSUMPTIONS

The following major assumptions were made during the risk assessment.

9.1. Gas Supply Pipeline

The following key assumptions were made during the quantitative risk assessment.

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

9.2. Power Station, Offtake and Compressor Station

- The assessed risk was based on the parts count given in Appendix 4, based on the parts count for similar facilities.
- The likelihood of vapour cloud explosions is negligible as natural gas will tend to disperse readily in the open air and there are no congested areas which could result in unburnt gas building up.
- The direction of jet fire releases from station equipment was assumed to be horizontal.

APPENDIX 1. HAZARD IDENTIFICATION TABLE

A 1.1. Hazard Identification

Table A1.1 shows the hazard identification that was undertaken for the Wellington Power Project.

TABLE A1.1 HAZARD IDENTIFICATION TABLE

ID	Area/ Equipment	Hazardous Event	Cause	Consequence	Prevention	Control	Mitigation	Carried Forward?
Gas Supply Pipeline								
1.1	Pipeline	Scouring/ erosion at watercourses/ drains	• Flooding	• Potential impact on exposed pipeline	• Depth of cover • Extra wall thickness at waterways/ drain crossings • Concrete slabbing/ coating where required	• Pipeline patrols	• Restoration	No
1.2	Pipeline	High pipeline stress	• Vehicle Loading at road/ rail crossings	• Potential impact on pipeline • Gas release • Jet fire if ignited • Potential injury/ fatality	• Depth of cover at road/ rail crossings • Pipeline design to take account of additional stresses	-	-	No
1.3	Pipeline	Corrosion	• Stray currents • Damaged protection coating on pipeline	• Pinhole leaks • Jet fire if ignited • Potential injury/ fatality	• Cathodic protection • 'Holiday' testing of coating integrity	• Intelligent pigging •	• Inspection and maintenance	Yes
1.4	Pipeline	Stress corrosion cracking	• Corrosive soil conditions combined with high temperature and pressure cycling	• Gas release • Jet fire if ignited • Potential injury/ fatality	• Coolers on compressor outlet • Pipeline coating • Cathodic protection	• Intelligent pigging	• Inspection and maintenance	No
1.5	Pipeline	Gas release	• Material/ weld defects	• Gas release • Jet fire if ignited • Potential injury/ fatality	• Welding procedures • Material certificates • Radiography • Hydrostatic testing	• QA/QC • Intelligent pigging	• Inspection and maintenance	Yes

ID	Area/ Equipment	Hazardous Event	Cause	Consequence	Prevention	Control	Mitigation	Carried Forward?
1.6	Pipeline	Overpressure	• Control Failure	• Pipeline/ equipment damage	• Pipeline designed to full MAOP (12MPa)	• Monitoring of system pressure	• -Slam-shut valve	No
1.7	Pipeline	Overtemperature	• Compressor cooler failure	• Pipeline/ equipment damage	• Temperature rating of pipeline and equipment	• Monitoring of compressor outlet temperature	• Compressor shutdown	No
1.8	Pipeline	AC induction impact near pipelines	• Pipeline route near HV power lines	• Pinhole leaks • Jet fire if ignited • Potential injury/ fatality	• AC induction safeguards • Route Selection	• -Cathodic protection	• Inspection and maintenance	No
1.9	Pipeline	Pipe lifting due to soil conditions	• Pipeline route passing near 'black soil' country	• Exposed pipe • Pipe stress	• Route selection	• Weighted pipe	• Pipeline patrols	No
Station Equipment								
2.1	Station pipework	Pinhole/ small leak	• External corrosion • Internal corrosion • Stress Corrosion Cracking • Material/ construction defects	• Gas release • Jet fire if ignited	• No free oxygen present in the natural gas • Painting of aboveground pipework • Cathodic protection and coating on underground pipework • Aftercoolers on compressor outlet • Hydrostatic testing	• Remotely operated ESD valve at the station inlet • Ignition control as per AS2430. • Site inspection	• Separation distance between release point and site boundary.	Yes

ID	Area/ Equipment	Hazardous Event	Cause	Consequence	Prevention	Control	Mitigation	Carried Forward?
2.2	Station pipework	Medium/ Large Leak	• External damage by third party interference • Vehicle impact • Maintenance impact	• Gas release • Jet fire if ignited	• High fracture tough steel • Permit to work system • Security Fencing • Vehicle Barriers • QA, welding inspection • Equipment located entirely within MacGen property.	• Remotely operated ESD valve at the station inlet. • Ignition control as per AS2430.	• Separation distance between release point and site boundary.	Yes
2.3	Station pipework	Rupture	• Ground movement	• Gas release • Jet fire if ignited	• Inherent flexibility and strength of gas transmission pipelines and equipment • Design basis accounts for local seismic activity (to AS 1170). • Most equipment is located aboveground	• Regular site patrols • Relieving of stress where ground movement stresses the pipeline • Remotely operated ESD valve at the station inlet	-	No
2.4	Station pipework	Rupture	• Construction or material defects • Third party interference • Vehicle impact • Maintenance impact	• Gas release • Jet fire if ignited	• Hydrostatic testing of equipment • Radiography of circumferential welds/ Ultrasonic on pipelines • Equipment located entirely within MacGen property.	• Monitoring of pressure via SCADA system • Remotely operated ESD valve at the station inlet • Ignition control as per AS2430.	-	Yes

ID	Area/ Equipment	Hazardous Event	Cause	Consequence	Prevention	Control	Mitigation	Carried Forward?
2.5	Station equipment	Small leak	• Flange/ gasket leak due to overpressurisation	• Gas Release • Jet fire if ignited	• Maintenance/inspection • Spiral wound gaskets on HP flanged equipment	• Remotely operated ESD valve at the station inlet • Ignition control as per AS2430. • Site inspection	• Separation distance between release point and site boundary.	Yes
2.6	Station equipment	Medium leak	• Valve body/gland leaks • Instrument tapping point/ small bore pipework failure	• Gas Release • Jet fire if ignited	• Maintenance/inspection	• Remotely operated ESD valve at the station inlet • Ignition control as per AS2430. • Site inspection	• Separation distance between release point and site boundary.	Yes
2.7	Station Equipment	Valve leaks	• Leaks from gland, body	• Gas Release • Jet fire if ignited	• Appropriate selection of valves for application • Regular inspection of valves • Low corrosion potential due to dry gas • Valves welded into line • Routine maintenance.	-	-	Yes
2.8	Station Equipment	Venting releases during normal operations and maintenance	• Maintenance work on equipment	• Gas Release • Jet fire if ignited	• Permit to work system	• Operating procedures and monitoring	• Small quantities released	No

ID	Area/ Equipment	Hazardous Event	Cause	Consequence	Prevention	Control	Mitigation	Carried Forward?
Scraper Receiver								
3.1	Scraper Receiver	Releases during pigging operations	• Equipment failure	• Gas Release • Jet fire if ignited	• Permit to work system	• Pigging procedures • Trained/ Certified operators	-	No
Inlet Filter and Compressor								
4.1	Inlet Filter	Filter Blockage	• Debris in intake line	• Reduced throughput • Impact on production • No safety impact	• Minimal particles in gas supply	• Differential pressure monitoring	-	No
4.2	Compressor	Overtemperature	• Mechanical / Fan Failure • Interstage / After Cooler failure	• High output temperature	• Maintenance/ Inspection	• Temperature monitoring • Compressor protection	• Compressor shutdown	No
4.3	Compressor	Overpressure	• Compressor control failure	• Equipment damage	• Maintenance/ Inspection	• Compressor overpressure protection	• Compressor shutdown	No
Gas Pre-Heater and Pre-Filter								
5.1	Pre-Heater	Overtemperature	• Heater control failure	• Impact to equipment	• Pipeline/ equipment design temperature range	• Temperature monitoring	• Heater shutdown	No
5.2	Pre-Heater	Low temperature	• Heater control failure • Loss of fuel gas	• Impact to equipment	• Pipeline/ equipment design temperature range	• Temperature monitoring • Heater controls	• Heater shutdown	No

ID	Area/ Equipment	Hazardous Event	Cause	Consequence	Prevention	Control	Mitigation	Carried Forward?
Pressure Regulator								
6.1	Pressure regulator	Overpressure	• Regulator failure	• Overpressure downstream system • Pipe/ equipment damage	• Dual active and monitor regulators	• Pressure monitoring	• Slam shut valve	No
Miscellaneous								
7.1	Station gas pipework and equipment	Impact from external event	• Bushfire / grassfire	• Damage to surface facilities • Possible escalation to leak and ignition to jet fire	• Vegetation well cleared around above-ground facility • Security fence placed around the station • Gravel or hardstand area inside the fenced site around gas filled equipment	• Equipment materials and low thermal radiation impact will limit the damage. • It is unlikely that loss of containment would result.	-	No
7.2	Station gas pipework and equipment	Impact from external event	• Lightning	• Damage to surface facilities • Loss of power supply • Damage to electrical/control equipment • Possible escalation to leak and ignition to jet fire	• Lightning protection to AS1768 • Surge diverters	• Surge protection on electrical/ control equipment	-	No
7.3	Chemical storage	Spillage of caustic soda and sulphuric acid	• Handling • Mechanical damage	• Injury • Contamination	• Storage to comply with AS3780	• Storage and handling procedures		No

APPENDIX 2. ENVIRONMENTAL RISK ANALYSIS

A 2.1. Environmental Hazard Identification

Table A2.1 shows the hazard identification that was undertaken for the potential environmental impacts from the construction and operation of the Wellington Power Project.

TABLE A2.2 ENVIRONMENTAL HAZARD IDENTIFICATION TABLE

ID	Area/ Equipment	Hazardous Event	Cause	Consequence	Prevention/ Control/ Mitigation	Comment/ Action
Station and Pipeline Construction						
1.1	Station/ Pipeline Construction	Damage to flora and fauna during construction work (e.g. native grasses)	• Trenching • Impact on endangered species	• Environmental impact	• Construction Environmental Management Plan	Ecological and environmental studies undertaken as part of EA
1.2	Station/ Pipeline Construction	Soil runoff	• Excavation for trenching	• Sedimentation reaching watercourses	• Construction Environmental Management Plan • Trenching procedures • Spoil management	Soil management and environmental studies undertaken as part of EA
1.3	Station/ Pipeline Construction	Construction vehicle impact	• Transportation of construction personnel, materials and equipment	• Noise • Dust generation	• Construction Environmental Management Plan • Transport Management Plan	Transport study undertaken as part of EA
1.4	Pipeline Construction	Impact on Stock Routes	• Trenching • Vehicle impact	• Damage to condition of Stock Route • Reduced feed capacity	• Construction Environmental Management Plan • Transport Management Plan	Ecological and transport studies undertaken as part of EA
1.5	Pipeline Construction	Sourcing and disposal of hydrotest water	• Pipeline commissioning	• Environmental impact	• Environmental Management Plan	EMP to identify suitable sources and identify disposal methods
1.6	Pipeline construction	Electrical hazards near powerlines	• Construction near power line easements	• Potential contact with live lines • AC induction effects	• Construction safety plan • ESAA procedures for work near powerlines	-

ID	Area/ Equipment	Hazardous Event	Cause	Consequence	Prevention/ Control/ Mitigation	Comment/ Action
Power Station, Offtake and Compressor Station Operation						
2.1	Compressor/ Power Station	Noise generation	• Compressor operation • Turbine operation • Venting operations	• Local amenity affected	• Compressor/ turbines in enclosure • Venting released at height • Routine operations managed by designed mitigation	Noise studies undertaken as part of EA
2.2	Compressor/ Power Station	Releases of natural gas, vapours	• Venting operations • Turbine exhaust emission	• Environmental impact of emission	• Turbines using low emission technology • Venting released at height • Routine operations managed by designed mitigation measures	Air quality studies undertaken as part of EA

APPENDIX 3. CONSEQUENCE ASSESSMENT

A 3.1. Introduction

This appendix documents the consequence assessment for the Wellington Power Project. The following activities undertaken for the consequence analysis are described:

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

A 3.2. Release Rate Scenarios

The leak scenarios and representative hole sizes selected for the analysis are summarised in the following table.

TABLE A3.1: RELEASE SCENARIOS AND HOLE SIZES

Process Equipment	Release Scenario	Representative Hole Size
Gas Supply Pipeline	Small pipework release, due to corrosion or defects	6mm
	Medium size release (for example, punctures)	25mm
	Full Bore Rupture	356mm
Power Station/ Offtake/. Compressor Station	Gasket / flange leaks	6mm
	Valve body leaks	10mm
	Instrument leaks; pipeline punctures	25mm

A 3.3. Consequence Assessment Approach – Jet fires

The consequence modelling for the jet fire and flash fire scenarios was undertaken using Shell FRED 5, which was developed by Shell Global Solutions (Ref. 14). The following sections summarise the modelling approach.

A 3.3.1. Jet Flame Model

The heat radiation impact from jet fire incidents is modelled in Shell FRED as a view factor model with the jet flame geometry modelled as a frustrum of a cone.

Figure A3.1 shows the top view of a typical jet fire model showing the distances to heat radiation levels of interest.

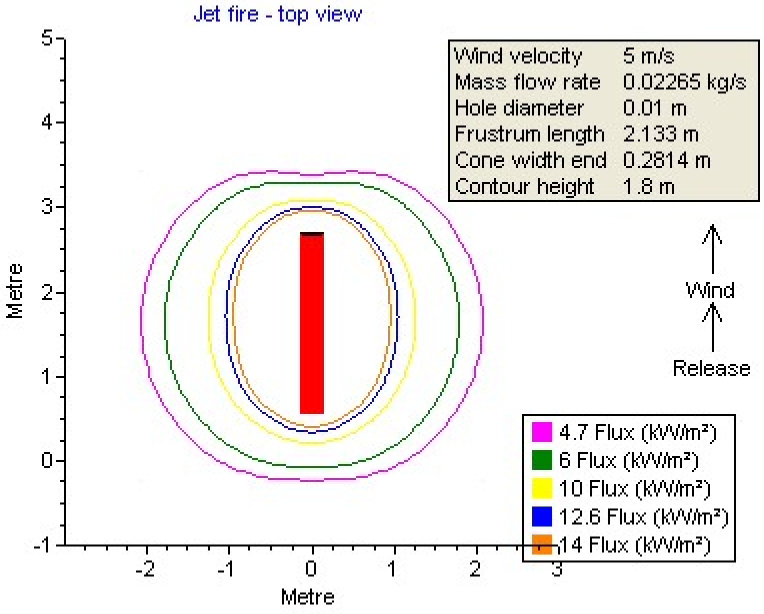


FIGURE A3.1: TYPICAL JET FIRE MODEL OUTPUT RESULTS

A 3.3.2. Flash Fire Model

The impact from flash fire incidents is modelled in Shell FRED as the dispersion distance to half the lower flammable limit (LFL). It is assumed that in a flash fire there is a 100% chance of fatality occurring within the fireball. A typical dispersion model is shown in Figure A3.2.

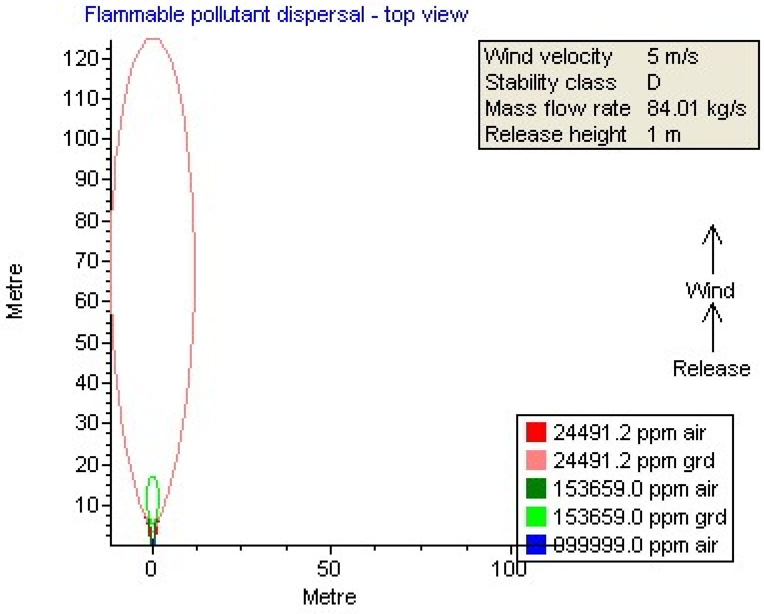


FIGURE A3.2: TYPICAL FLASH FIRE MODEL OUTPUT RESULTS

A 3.3.3. Meteorological Conditions

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

- 5m/s wind speed
- "D" Pasquill stability class
- 20oC ambient temperature
- 70% relative humidity

Gas dispersion modelling for flash fire was also undertaken for Pasquill stability class "F" and 2 m/s.

A 3.3.4. Orientation of Release

The angle of release from the gas supply pipeline was modelled as follows:

- Vertical where the release is 90 degrees to the horizontal plane. Releases due to third party impact will tend to occur on the top of the pipeline.
- Horizontal releases will tend to scour the ground around the pipeline resulting in a crater which will deflect the jet upwards. The release is modelled as a jet flame at 45 degrees to the horizontal plane.

Releases within the power station and pipeline stations facility were modeled as a horizontal release. The pipework within stations is typically located aboveground, and hence external impact is not limited to the top of the pipe. Similarly, fitting releases could occur in any direction, depending on the leak location and the placement of the fitting. Horizontal releases result in the furthest impact distances and would give the worse case results for releases from the station.

A 3.4. Gas Supply Pipeline Release Rates

The release rates for jet fires were modelled assuming the release occurs at the Maximum Allowable Operating Pressure (MAOP) of the pipeline (12 MPag). Releases from 6mm, 25mm holes and full bore rupture (unisolated) were modelled as continuous releases. A depressuring curve was undertaken to model the isolated case for full bore rupture.

To determine the pressure drop, a depressuring curve was determined using Shell FRED. This curve was calculated using a line pressure of 12.MPa and a pipe length of 30km. An average of the release rate and the release rate 60 seconds after isolation was used as the release rate for the isolated rupture case.

A 3.5. Release Rates for Station Releases

The release rates for gas release were modeled as continuous releases. A summary of the release pressures used are given in the following table.

TABLE A3.2: PRESSURES USED FOR STATION RELEASES

Location	Pressure Modeled	Basis
Offtake and Compressor Station	12MPag	MAOP of Gas supply line to Wellington Power Station
Power Station		
Upstream of Regulator	12MPag	MAOP of Gas supply line to Wellington Power Station
Regulator and gas delivery to Power Station	4MPag	Assumed delivery pressure to turbines

A 3.6. Summary of Release Rates

The results of the release rate calculations are shown in Table A3.3.

TABLE A3.3: RELEASE RATES

Release Scenario	Release Angle (from horiz.)	Hole Size (mm)	Pressure (MPag)	Release Rate (kg/s)
Gas Supply Pipeline Releases (Lateral)				
6mm pinhole release	45°	6	12	0.63
25mm puncture	45°	25	12	11
Full Bore Rupture – Isolated Case	45°	356	12	862
Full Bore Rupture – Failure of Isolation	45°	356	12	2210
Gas Supply Pipeline Releases (Vertical)				
10mm pinhole release	90°	6	12	0.63
50mm puncture	90°	25	12	11
Full Bore Rupture – Isolated Case	90°	356	12	862
Full Bore Rupture – Failure of Isolation	90°	356	12	2210
Station Releases (12 MPag)				
3mm release - gasket leaks	0	3	12	0.16
10mm release – valve body leaks	0	10	12	1.75
25mm fitting and pipeline release (70bar)	0	25	12	11.0
Station Releases (12 MPag)				
3mm release - gasket leaks	0	3	4	0.05
10mm release – valve body leaks	0	10	4	0.51
25mm fitting and pipeline release (70bar)	0	25	4	3.2

A 3.7. Heat Radiation Effects

Table A3.4 shows the consequence distances to relevant heat radiation levels calculated for each release scenario for jet fires. Table A2.5 shows the dimension for flash fire incidents

TABLE A3.4: JET FIRES - CONSEQUENCE DISTANCES TO SPECIFIED HEAT RADIATION LEVELS

Release Scenario	Release Angle (from horiz.)	Hole Size (mm)	Pressure (MPag)	Release Rate (kg/s)	Flame Length (m)	Flame Width (m)	Distance to Heat Radiation Levels (m)				
							$4.7kW/m^2$	$6kW/m^2$	$10kW/m^2$	$14kW/m^2$	$23kW/m^2$
Gas Supply Pipeline Releases (Lateral)											
Pinhole (corrosion)	45º	6	12	0.63	10	1	13	12	11	10	9
Puncture (puncture)	45º	25	12	11	31	5	44	41	35	33	29
Rupture - Isolation	45º	355	12	862	178	41	266	246	213	195	174
Rupture - No Isolation	45º	355	12	2210	260	70	398	369	319	292	259
Gas Supply Pipeline Releases (Vertical)											
Pinhole (corrosion)	90º	6	12	0.63	9	1	9	8	7	6	4
Puncture (puncture)	90º	25	12	11	30	5	32	29	23	20	16
Rupture - Isolation	90º	355	12	862	166	41	196	176	141	121	97
Rupture - No Isolation	90º	355	12	2210	243	70	297	267	215	186	150
Station Releases (12 MPa, Horizontal)											
Gasket leak	0º	3	12	0.16	5.9	0.6	7.8	7.5	7.0	6.8	6.5
Valve/ gland leak	0º	10	12	1.75	15.5	2.0	21.9	20.9	19.2	18.5	17.7
Fitting Failure	0º	25	12	11.0	32.3	4.9	47.6	45.3	41.4	39.8	37.9
Station Releases (4 MPa, Horizontal)											
Gasket leak	0º	3	4	0.05	3.6	0.3	4.6	4.4	4.1	4.0	3.9
Valve/ gland leak	0º	10	4	0.51	9.4	1.0	12.0	12.1	11.2	10.9	10.5
Fitting Failure	0º	25	4	3.2	19.6	2.5	27.6	26.4	24.2	23.4	22.4

TABLE A3.5: FLASH FIRES – CLOUD DIMENSIONS AND CONSEQUENCE DISTANCES

Release Scenario	Release Angle (from horiz.)	Hole Size (mm)	Pressure (MPag)	Release Rate (kg/s)	Flash Fire Dimensions (D5 Conditions)		Flash Fire Dimensions (F2 Conditions)	
					Downwind Distance (m)	Width (m)	Downwind Distance (m)	Width (m)
Gas Supply Pipeline Releases (Lateral)								
Pinhole (corrosion)	45º	6	12	0.63	1.4	0.6	1.3	0.5
Puncture (puncture)	45º	25	12	11	1.4	0.8	1.4	0.8
Rupture - Isolation	45º	355	12	862	2.8	2.7	2.8	2.7
Rupture - No Isolation	45º	355	12	2210	3.4	0.002	5.0	0.002
Gas Supply Pipeline Releases (Vertical)								
Pinhole (corrosion)	45º	6	12	0.63	0.4	0.1	0.4	0.01
Puncture (puncture)	45º	25	12	11	0.6	0.02	0.6	0.003
Rupture - Isolation	45º	355	12	862	2.4	0.008	3.2	0.006
Rupture - No Isolation	45º	355	12	2210	3.4	0.002	5.0	0.002
Station Releases (12 MPa, Horizontal)								
Gasket leak	0º	3	12	0.16	5.0	0.6	6.0	0.7
Valve/ gland leak	0º	10	12	1.75	18.0	2.0	20.0	2.4
Fitting Failure	0º	25	12	11.0	50.0	8.0	46.9	8.6
Station Releases (4 MPa, Horizontal)								
Gasket leak	0º	0.05	4	0.05	2.5	0.3	3.0	0.3
Valve/ gland leak	0º	0.51	4	0.51	8.5	1.0	10.0	1.1
Fitting Failure	0º	3.2	4	3.2	23.0	3.2	21.0	3.6

APPENDIX 4. FREQUENCY ANALYSIS

A 4.1. Pipeline Release Frequencies

A 4.1.1. Generic Pipeline Failure Data

The failure rate data used for the assessment of the frequency of pipeline releases was derived from the European Gas Pipeline Incident Data Group (EGIG, Ref. 9). The European data are useful because of the significant exposure in terms of kilometre years experienced which gives a statistically significant basis for estimating release frequencies. The data also give the frequency of different causes of failure. Also included are factors such as wall thickness, depth of cover, probability of ignition, etc.

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

AS2885-2007 is a risk based standard which emphasises the protection of pipelines from external interference. It has been previously noted that the reported failure frequency of pipeline incidents is significantly lower than that experienced in Europe, however the causes for this difference are unclear (Ref. 15). It is believed that low population densities and relatively young pipelines result in the low incident frequencies (about 150 incidents reported since 1965).

Differences between design, construction and operational standards from different geographical areas have been noted; however it is difficult to then conclude decisively which are the significant factors that determine expected incident frequencies.The overall failure frequency reported by EGIG for the period 1970-2004 was 0.41 incidents per 1000 km-yr compared with a failure frequency of 0.17 incidents per 1000 km-yr for the years 2000-2004.

A 4.1.2. Base Failure Frequencies

Table A4.1 summarises the data derived from the EGIG report for the period 1970-2004. The data are categorised by the identified cause of the incident and show the relative frequency of each cause. The most frequent cause of pipeline failures is due to external interference (52%) with the next most likely causes being construction/ material defects (18%) and corrosion (17%).

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

TABLE A4.1: BASE FREQUENCY OF PIPELINE FAILURES

Cause	**Pipeline Base Frequency by Cause and Hole Size (per 1000 km-yr)**		
	Pinhole-Crack (d<10mm)	**Hole (10mm < d<50mm)**	**Maximum Hole Size (d>50mm)**
External Interference	0.05	0.12	0.03
Construction/Material	0.045	0.02	0.005
Corrosion	0.06	0.004	0
Ground Movement	0.008	0.008	0.001
Hot tap error	0	0	0
Other/Unknown	0.025	0.003	0
Total	**0.188**	**0.155**	**0.036**

A 4.1.3. Additional Safeguards

The base frequencies given in Table A4.1 were then adjusted to take account of the additional safeguards including:

- Marker tape
- Depth of cover (750mm minimum depth of cover)
- Wall thickness (9.5 mm minimum wall thickness)

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

A 4.1.4. Marker Tape

Corder (Ref. 16) has reported that a damage reduction factor of 1.67 was achieved when marker tape is provided above pipelines based on experimental data derived from testing undertaken by British Gas. This factor was used to reduce the frequency of impacts resulting from external interference.

A 4.1.5. Depth of Cover

Table A4.2 summarises the risk reduction factors from the testing reported by Corder (Ref.16). Note that a reduction factor of 1.0 resulted for depths of cover of 1.11m and that lower depths of cover result in a reduction factor greater than 1, i.e. there is an increase of the relative frequency of external impact.

TABLE A4.2: REDUCTION FACTORS FOR DEPTH OF COVER

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

A 4.1.6. Final Pipeline Failure Frequencies

The revised failure frequencies incorporating risk reduction factors for the base case frequency assessment are summarised in Table A4.3.

TABLE A4.3: SUMMARY OF FINAL PIPELINE FAILURE FREQUENCIES (INCLUDING REDUCTION FOR ADDITIONAL SAFEGUARDS- BASE CASE)

Cause	Pipeline Base Frequency by Cause and Hole Size (per 1000 km-yr)		
	Pinhole-Crack (d<10mm)	**Hole (10mm < d<50mm)**	**Rupture (d>50mm)**
External Interference	0.034	0.081	0.020
Construction/Material	0.045	0.020	0.005
Corrosion	0.030	0.004	0.000
Ground Movement	0.008	0.008	0.001
Hot tap error	0.000	0.000	0.000
Other/Unknown	0.025	0.003	0.000
Total	**0.142**	**0.116**	**0.026**

A 4.1.7. Pipeline Ignition Probabilities

The probability of ignition used in the frequency assessment was based on the EGIG 2005 Report.

TABLE A3.4: PROBABILITY OF IGNITION FOLLOWING PIPELINE GAS RELEASE

Hole Size	Ignition Probability
Pinhole (10mm)	3.2%
Hole (50mm)	2.1%
Rupture	25%

A 4.1.8. Probability of Leak Detection

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

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

In the case of pipeline rupture, depressuring of the line would occur rapidly if the loss of pressure is detected and the isolation valve is remotely operated by the operator.

The shutdown will fail if pressure detection fails or if the operator fails to close the shutoff valve. The probability of failure to detect a leak and isolate the pipeline following a rupture has been calculated using a fault tree as shown in Figure D.1. The data used for equipment failure rates and human error probabilities is shown in Table A4.5.

TABLE A4.5: FAILURE RATE DATA FOR FAULT TREE ANALYSIS OF SHUTDOWN FAILURE

Component Failure	Source Reference	Failure Rate (x 10^{-6} per year)	Testing Frequency	Failure Probability (per demand)
Pressure Switch fails to function on pressure drop	CCPS 2.1.4.1.3 (Ref. 17)	0.4	Annual	1.8 x 10^{-3}
Isolation valve fails to close	CCPS 3.5.3.3	-	-	2.2 x 10^{-3}
Failure of SCADA System to send signal	OREDA (Ref. 18)	1.05	Monthly	0.044
Human Error – Operator Fails to Initiate Shutdown	HEART - Type E (Ref. 19)	-	-	.02

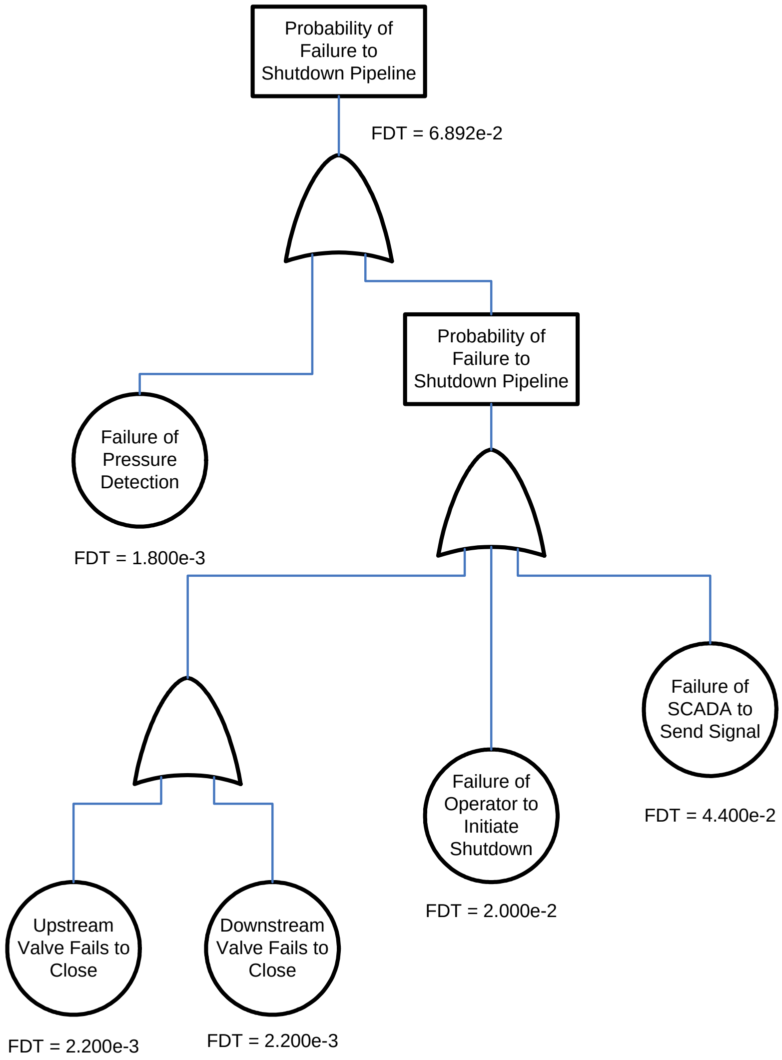


FIGURE A4.1: FAULT TREE FOR PROABABILITY OF FAILURE OF PIPELINE SHUTEDOWN

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

A 4.2. Station Release Frequencies

A 4.2.1. Probability of Ignition in Stations

Release frequencies were derived for the following equipment failures:

- Gasket leaks
- Valve body leaks
- Instrument fitting leaks
- Pipework leaks

The release frequency data used for the QRA is summarised in Table A4.6. The basis of these figures is explained further below.

TABLE A4.6: RELEASE FREQUENCIES

Equipment	Release Frequency (x 10^{-6} per year)
Gasket/Flange Leaks	
6mm spiral wound gasket leak	50.00 per flange
Valve body leak	
10mm gland leak	170.00 per valve
Instrument Fitting	
25mm leak	100.00 per fitting
Pipework	
3mm hole (corrosion pitting)	3.00 per m
25mm hole	0.30 per m

Valves

The Health and Safety Executive (Ref. 20) reports the frequency of valve failures. The report showed that the frequency of valve leaks (10mm or less) to be 1.7 x 10^{-4} per year and the associated flange leak frequency was 5.0 x 10^{-5} per year.

Instrument Fitting

For tapping point failures, the failure rate for pipework as per Cox, Lees and Ang (Ref. 21) was used, i.e. 1 x 10^{-4} per year.

A 4.2.2. Probability of Ignition in Stations

Cox, Lees and Ang (Ref. 21) estimates the probability of ignition of leaks of flammable gas in plants as shown in Table A4.7, which is applicable to aboveground facilities.

TABLE A4.7: PROBABILITY OF IGNITION FOLLOWING STATION GAS RELEASE

Mass Flow rate	Ignition Probability (Gas or Mixture)	Conditional Probability of Explosion (given ignition)	Explosion Probability (Gas or Mixture)	Jet Fire Probability (Gas or Mixture)
<1 kg/s	0.01	0.04	0.0004	0.0096
1 - 50 kg/s	0.07	0.12	0.0084	0.0616
>50 kg/s	0.3	0.3	0.09	0.21

A 4.2.3. Parts Count

The parts count for the Compressor and Delivery Station are shown in Table A4.8.

TABLE A4.8: STATIONS PARTS COUNT

Plant Area	Parts Count		
	Flanges	Valves	Instrument Fittings
Offtake Station			
Station Inlet	-	1	-
Shutdown Valve	4	5	2
Filter Skid	12	9	5
Meter Skid	4	8	1
Compressor Station			
Station Inlet	-	1	-
Shutdown Valve	4	4	2
Filter Skid	12	9	5
Regulator Skid – HP End	4	3	1
Station Outlet	-	1	-
Power Station			
Receiving Station	12	12	12
Regulator Skid – HP End	7	4	1

A 4.2.4. Jet Fire Frequency

The jet fire frequencies for the stations are shown in Table A4.9.

TABLE A4.9: STATION JET FIRE FREQUENCY RESULTS

Plant Area	Parts Count		
	Flanges	Valves	Instrument Fittings
Offtake Station			
Station Inlet	0.00E+00	1.05E-05	0.00E+00
Shutdown Valve	1.92E-06	4.19E-05	1.23E-05
Filter Skid	5.76E-06	9.42E-05	3.08E-05
Meter Skid	3.84E-06	4.19E-05	6.16E-06
Compressor Station			
Station Inlet	0.00E+00	1.05E-05	0.00E+00
Shutdown Valve	1.92E-06	4.19E-05	1.23E-05
Filter Skid	5.76E-06	9.42E-05	3.08E-05
Regulator Skid – HP End	1.92E-06	3.14E-05	6.16E-06
Station Outlet	0.00E+00	1.05E-05	0.00E+00
Scraper Launcher	9.60E-07	3.14E-05	1.23E-05
Power Station			
Receiving Station	5.76E-06	1.26E-04	7.39E-05
Regulator Skid – HP End	3.36E-06	4.19E-05	6.16E-06

A 4.2.5. Flash Fire Frequency

The flash fire frequencies for the stations are shown in Table A4.10.

TABLE A4.10: STATION FLASH FIRE FREQUENCY RESULTS

Plant Area	**Parts Count**		
	Flanges	**Valves**	**Instrument Fittings**
Offtake Station			
Station Inlet	0.00E+00	1.43E-06	0.00E+00
Shutdown Valve	8.00E-08	5.71E-06	1.68E-06
Filter Skid	2.40E-07	1.29E-05	4.20E-06
Meter Skid	1.60E-07	5.71E-06	8.40E-07
Compressor Station			
Station Inlet	0.00E+00	1.43E-06	0.00E+00
Shutdown Valve	8.00E-08	5.71E-06	1.68E-06
Filter Skid	2.40E-07	1.29E-05	4.20E-06
Regulator Skid – HP End	8.00E-08	4.28E-06	8.40E-07
Station Outlet	0.00E+00	1.43E-06	0.00E+00
Scraper Launcher	4.00E-08	4.28E-06	1.68E-06
Power Station			
Receiving Station	2.40E-07	1.71E-05	1.01E-05
Regulator Skid – HP End	1.40E-07	5.71E-06	8.40E-07

APPENDIX 5. REFERENCES

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