JEMENA

Port Kembla Gas Terminal to Eastern Gas Pipeline

Final Hazard Analysis

Document no. Rev 0: 411010-00484-SR-REP-0001
21 October 2021

Jemena Document No. GAS-599-RP-RM-001

Level 12, 333 Collins Street
Melbourne VIC 3000
Australia

T: +61 3 8676 3500
Worley Services Pty Ltd
ABN 61 001 279 812

Disclaimer

This report has been prepared on behalf of and for the exclusive use of Jemena, and is subject to and issued in accordance with the agreement between Jemena and Worley Services Pty Ltd. Worley Services Pty Ltd accepts no liability or responsibility whatsoever for it in respect of any use of or reliance upon this report by any third party. Copying this report without the permission of Jemena or Worley Services Pty Ltd is not permitted.

The information contained in these documents is protected by the General Data Protection Regulation (GDPR). Worley complies with the provisions of the Regulation and the information is disclosed on the condition that the Recipient also complies with the provisions of the (GDPR). In particular, all of the resumes and the information contained therein, must be kept securely, must be used only for the purposes of assessing the suitability of the individuals to perform the tasks proposed and/or assessing the overall capabilities of Worley to undertake the Work proposed and must be destroyed upon completion of those purposes.

Details on how personal information provided to Worley is processed can be found at https://www.worley.com/site-services/privacy

COVID-19

Worley is committed to providing the proposed Services to you in a timely and professional manner. Worley is also committed to ensuring the health and safety of everyone, including our people and our customers. In some cases, the COVID-19 pandemic has caused us to modify our working practices. Worley employees and collaborators may therefore provide some or all of the proposed Services from offices within their homes. In addition, the ability to travel for attendance to business meetings or site may be affected.

Worley will take reasonable steps to mitigate any delays associated with the measures necessary to keep everyone safe and comply with all government regulations and proclamations regarding the COVID-19 pandemic. Customers will be informed if there is any foreseeable impact on providing the proposed Services.

PROJECT 411010-00484-SR-REP-0001 - Port Kembla Gas Terminal to Eastern Gas Pipeline - Final Hazard Analysis

Rev	Description	Originator	Reviewer	Worley Approver	Revision Date	Customer Approver	Approval Date
Rev A	Issued for Review	Y. Lee	T. Millen	F. Losty	21 September 2021		
Rev 0	Issued for Use	Y. Lee	T. Millen	F. Losty	21 October 2021		

Table of contents

Appendices

Appendix A. Parts Count

Appendix B. Summary of Release Scenarios

Appendix C. Jet Fire & Flash Fire Impacts

List of tables

List of figures

1. Executive Summary

Jemena is currently planning to upgrade capacity between Port Kembla and the Eastern Gas Pipeline through construction of a new ~11.5km pipeline (Port Kembla Pipeline, PKP) from Port Kembla, through to a new meter station (Kembla Grange Meter Station, KGMS) in the vicinity of Jemena's existing MLB/Lateral Offtake facility. Sections of the PKP will run parallel to the existing Port Kembla Lateral (PKL).

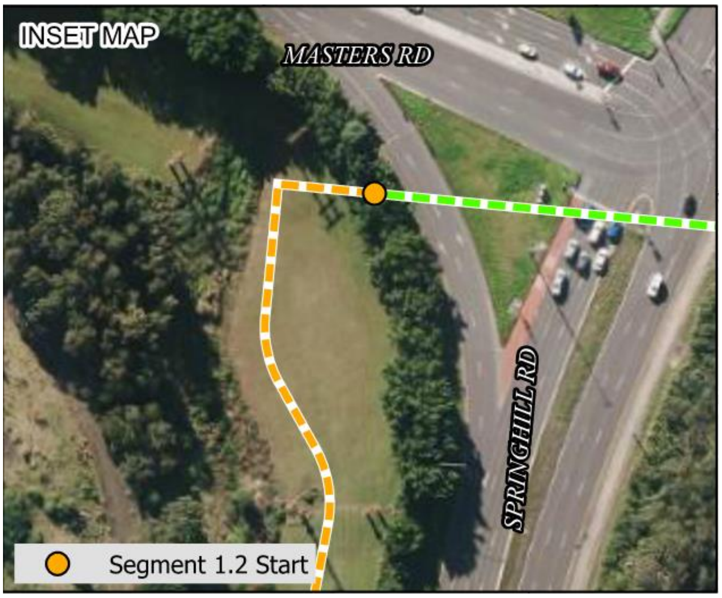
The pipeline will have a nominal diameter of 450mm, and is designed for future operation up to a Maximum Allowable Operating Pressure (MAOP) of 16.55MPa.

As part of the approvals process for the PKP, Jemena was required to complete a Level 2 (Semi Quantitative) Preliminary Hazard Analysis (PHA). The Department of Planning, Industry & Environment (DPIE) guideline "Multi-Level Risk Assessment" requires that incidents that have potential significant consequences beyond the site boundary must be quantified and demonstrated to be below the appropriate criteria. The study [1] demonstrated that life safety risk consequences associated with the PKP and the KGMS were within the tolerable limits specified by HIPAP-4 [2]. As part of the process, Jemena are required to submit a Final Hazard Analysis (FHA) at least one month prior to commencement of construction.

Since the submission of the PHA, there have been a number of changes to the overall project, in terms of transfer of pipeline ownership, and modifications to both the Cringila nitrogen facility and the KGMS.

The first 4.3 km of the pipeline (Segment 1.1) will be owned and operated by the Australian Industrial Energy (AIE), with the transfer of ownership between AIE and Jemena located near the intersection of Masters Road and Springhill Road.

Figure 1-1: AIE to Jemena Interface



Segment 1.2 will be owned and operated by Jemena, and runs approximately 2.5km from the AIE/Jemena interface to Cringila, where nitrogen is injected as required to meet Wobbe index specification. Whilst located within BOC property, the nitrogen facility will be part of Jemena pipeline license PL26.

Pipeline Segment 2 runs approximately 5.5 km from Cringila to Kembla Grange, where gas is metered and enters the Eastern Gas Pipeline via a hot tap connection.

The FHA has been completed as a Quantitative Risk Assessment (QRA), considering the following Jemena owned and operated scope:

- Pipeline Segment 1.2, from the AIE/Jemena interface to Cringila
- Pipeline Segment 2, from Cringila to the Kembla Grange Meter Station
- Kembla Grange Meter Station

Location specific individual risk (LSIR) contours for the entire pipeline length, inclusive of the facilities is shown in Figure 1-2, with magnified views for Kembla Grange and Cringila in Figure 1-3 and Figure 1-4 respectively.

The results of the QRA modelling undertaken indicate that risk exposure associated with the PKP and the associated KGMS will be below the fatality risk criteria specified in HIPAP-4, with no risks recorded above 5E-05 per annum (limit for commercially developed land), and no risk above 5E-07 per annum (sensitive land use) impacting on residential areas. Due to the application of a higher probability of ignition model, the Cringila injection facility shows a slightly higher risk than the KGMS, with a localized area showing risk in excess of 5E-06 per annum.

Note along the pipeline length, risk was measured to be <5E-07 per annum, and risk contours of 3E-07 per annum have therefore been recorded to show risk in these locations.

Figure 1-2: Location Specific Individual Risk Contours

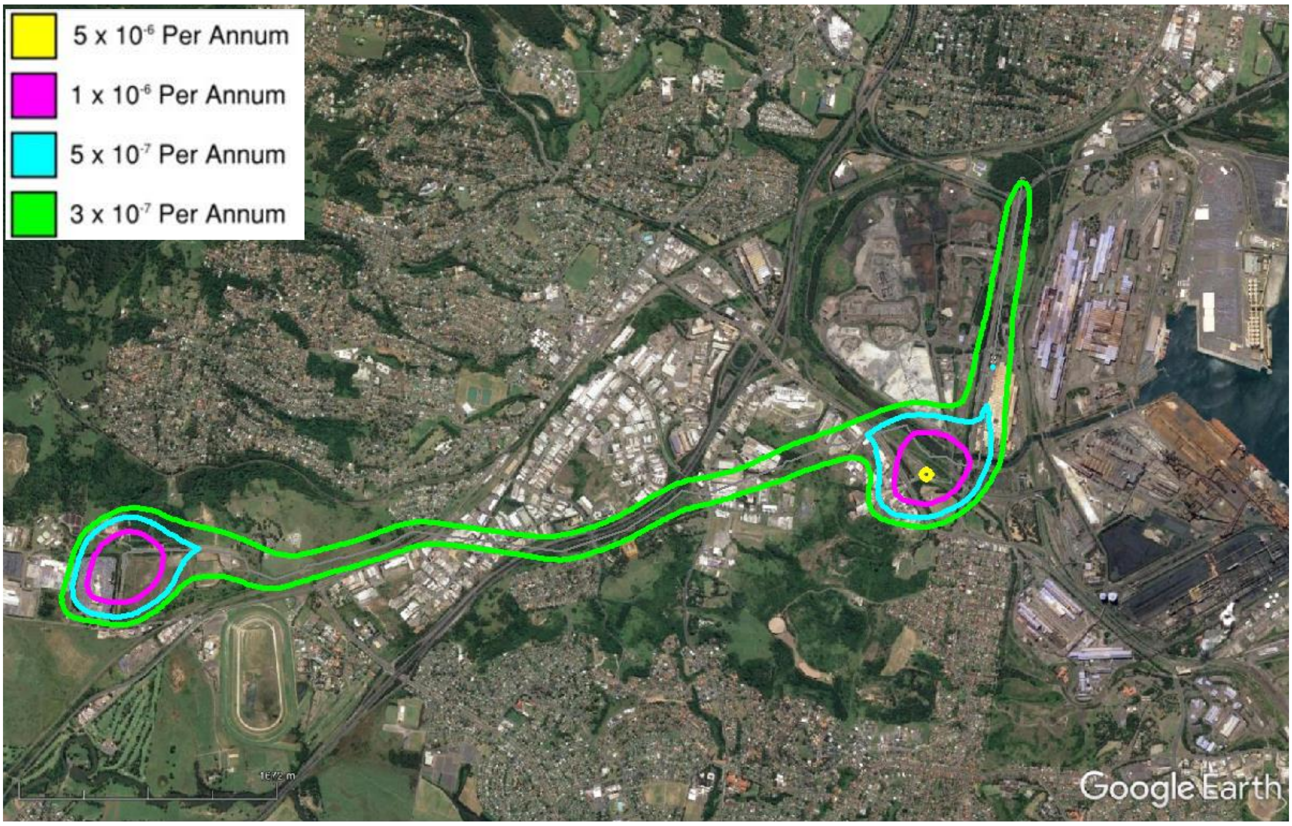


Figure 1-3: Location Specific Individual Risk Contours – KGMS

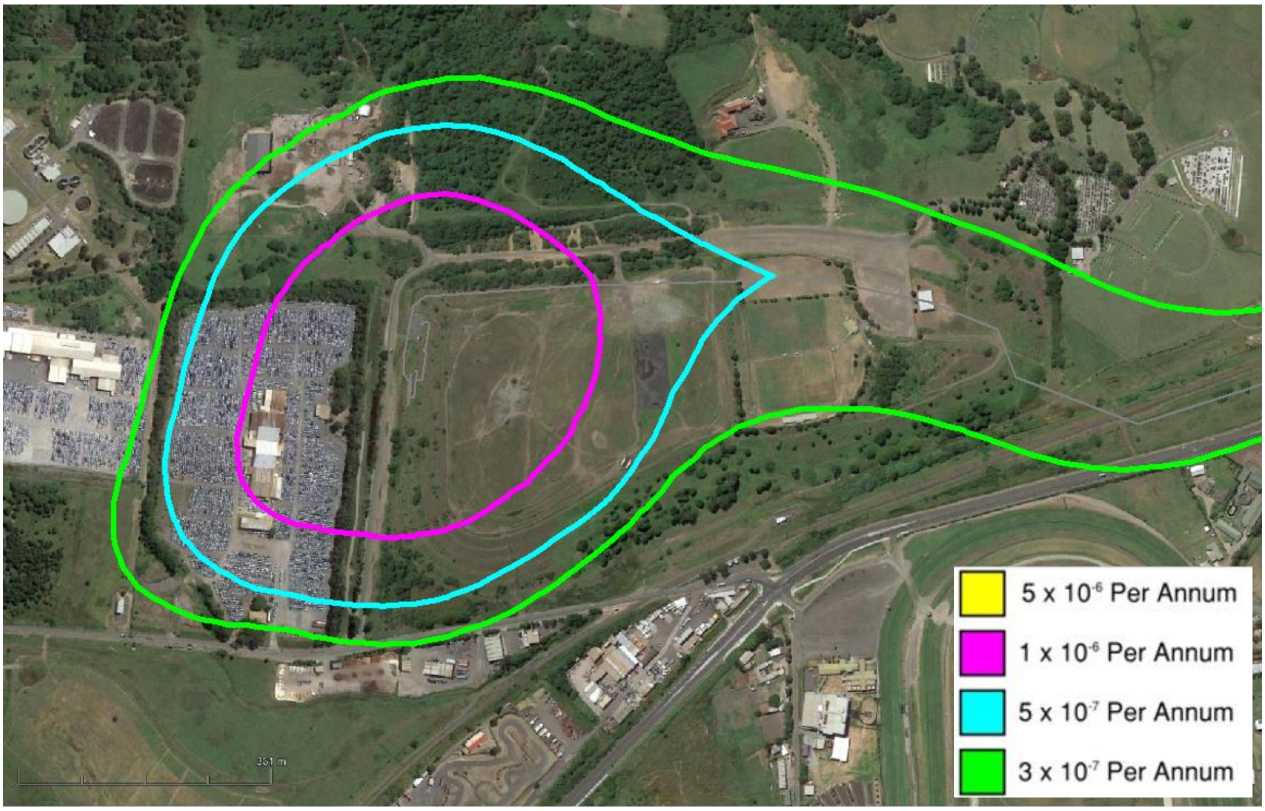
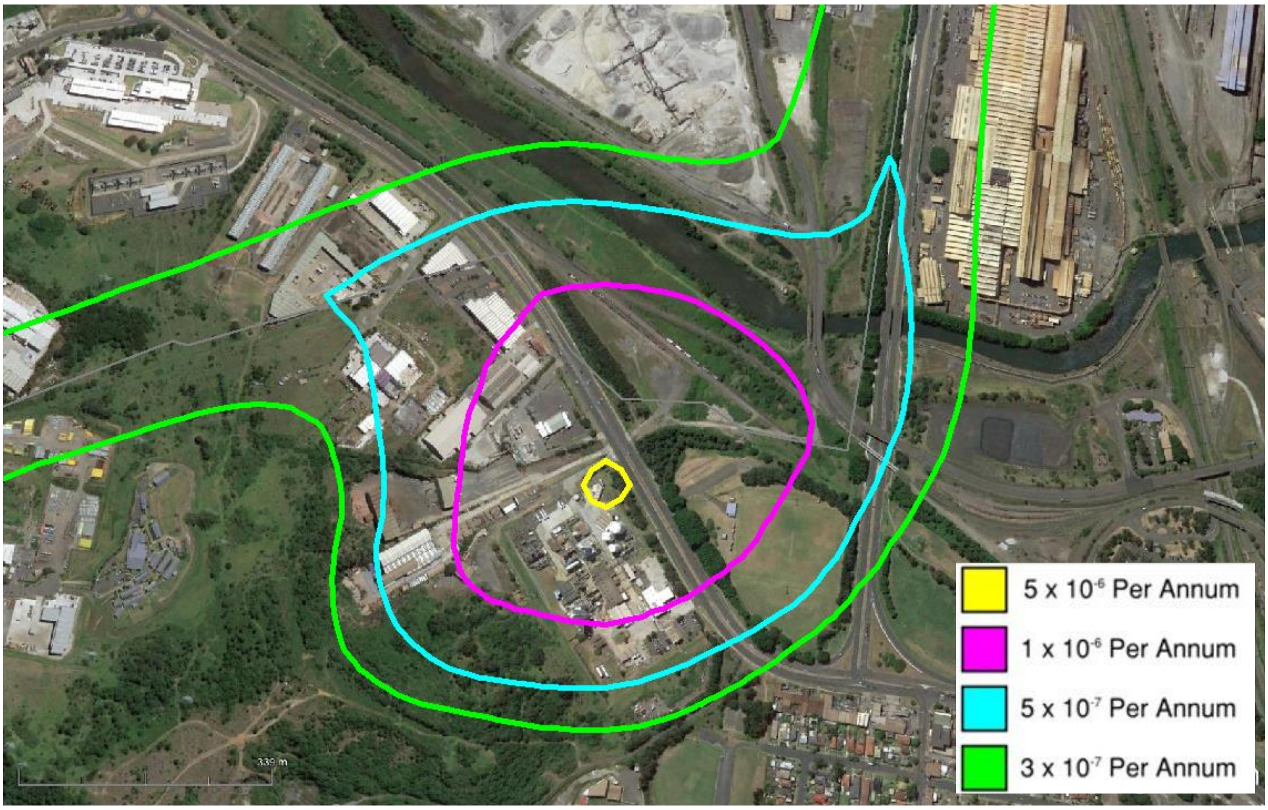


Figure 1-4: Location Specific Individual Risk Contours – Cringila Nitrogen Facility



In addition to production of Location Specific Individual Risk (LSIR) contours, the FHA has considered injury and property damage/accident propagation risk, defined by radiant heat impacts of 4.7, and 23kW/m^2.

Note, results were not generated at this level for the specified HIPAP-4 criterion of 5E-05 per annum (or, fifty in a million per year), and as an alternative, the HIPAP LSIR frequency criteria were applied, as shown in Figure 1-5 and Figure 1-6.

Figure 1-5: Injury Risk (Exposure to 4.7kW/m²)

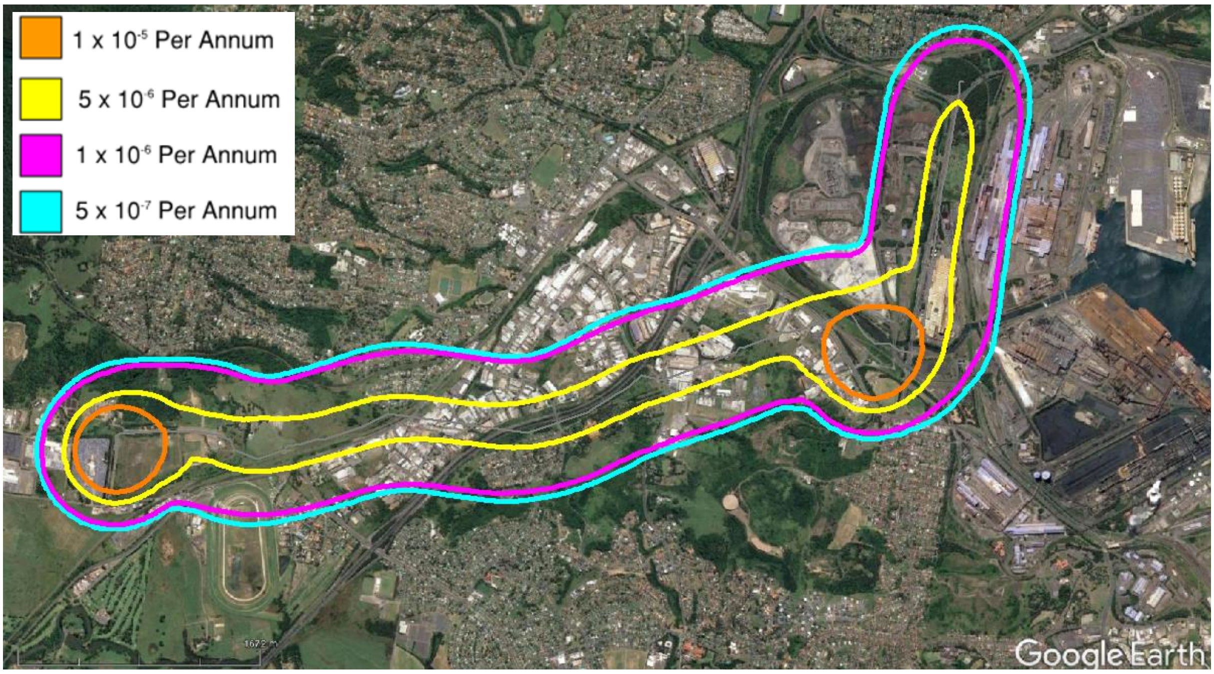
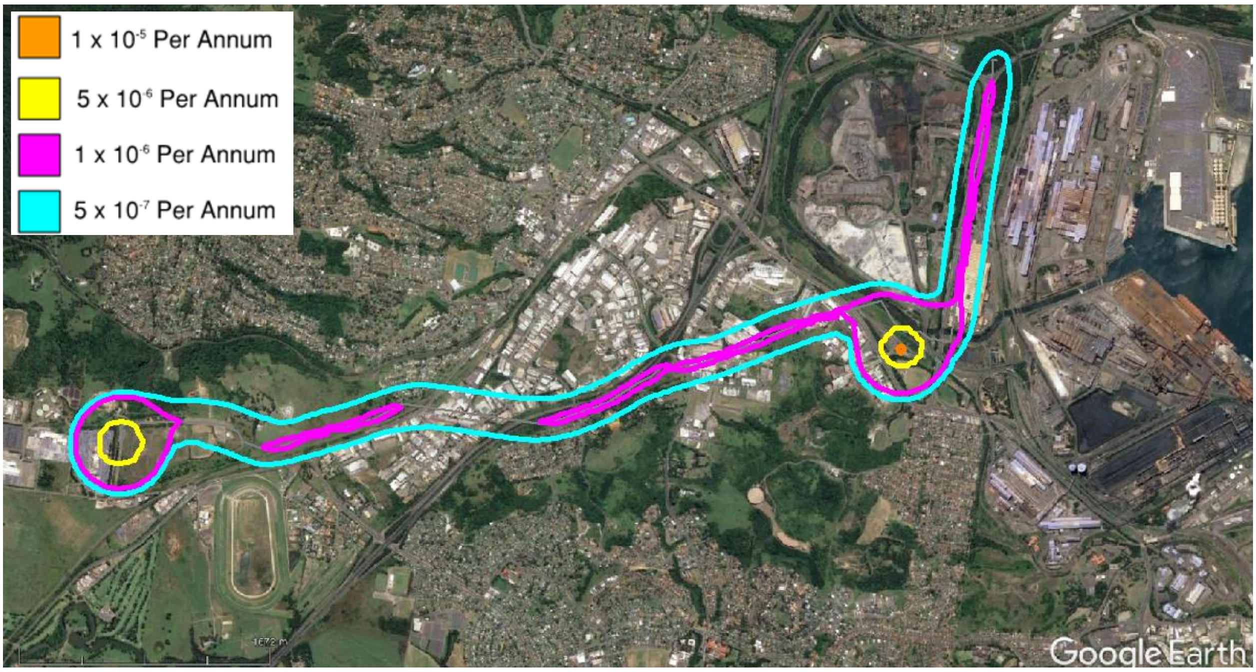


Figure 1-6: Property Damage & Escalation Risk (Exposure to 23kW/m²)



2. Introduction

Jemena is currently planning to upgrade capacity between Port Kembla and the Eastern Gas Pipeline through construction of a new ~11.5km pipeline (Port Kembla Pipeline, PKP) from Port Kembla, through to a new meter station (Kembla Grange Meter Station, KGMS) in the vicinity of Jemena's existing MLB/Lateral Offtake facility. Sections of the PKP will run parallel to the existing Port Kembla Lateral (PKL).

The pipeline will have a nominal diameter of 450mm, and is designed for future operation up to a Maximum Allowable Operating Pressure (MAOP) of 16.55MPa.

As part of the approvals process for the PKP, Jemena was required to complete a Level 2 (Semi Quantitative) Preliminary Hazard Analysis (PHA). The Department of Planning, Industry & Environment (DPIE) guideline "Multi-Level Risk Assessment" requires that incidents that have potential significant consequences beyond the site boundary must be quantified and demonstrated to be below the appropriate criteria. The study [1] demonstrated that life safety risk consequences associated with the PKP and the KGMS were within the tolerable limits specified by HIPAP-4 [2]. As part of the process, Jemena are required to submit a Final Hazard Analysis (FHA) at least one month prior to commencement of construction.

This Quantitative Risk Assessment (QRA) is intended to satisfy the requirements of the FHA.

2.1 Objectives

The objectives of the QRA study are to assess the level of risk posed by Jemena Port Kembla Pipeline and Kembla Grange Meter Station on surrounding land, and compare the level of risk with nominated tolerability criteria. Specific risk metrics to be reported include:

- Location Specific Individual Risk (LSIR)
- Risk of Injury
- Risk of property damage

The QRA is to be consistent with the requirements of Hazardous Industry Planning Advisory (HIPAP) Paper No. 6 – Guidelines for Hazard Analysis (DPE, 2011) [3].

2.2 Scope

The scope of this QRA includes:

- Pipeline Segment 1.2, from the AIE/Jemena interface to Cringila
- Pipeline Segment 2, from Cringila to the Kembla Grange Meter Station
- Kembla Grange Meter Station

Note that for full context, elements of the Australian Industrial Energy (AIE) project scope (FSRU, pipeline to Segment 1.1) are briefly described within this report but are not the subject of the QRA.

2.3 Acronyms

The acronyms used throughout the study are listed in Table 2-1.

Table 2-1: Acronyms

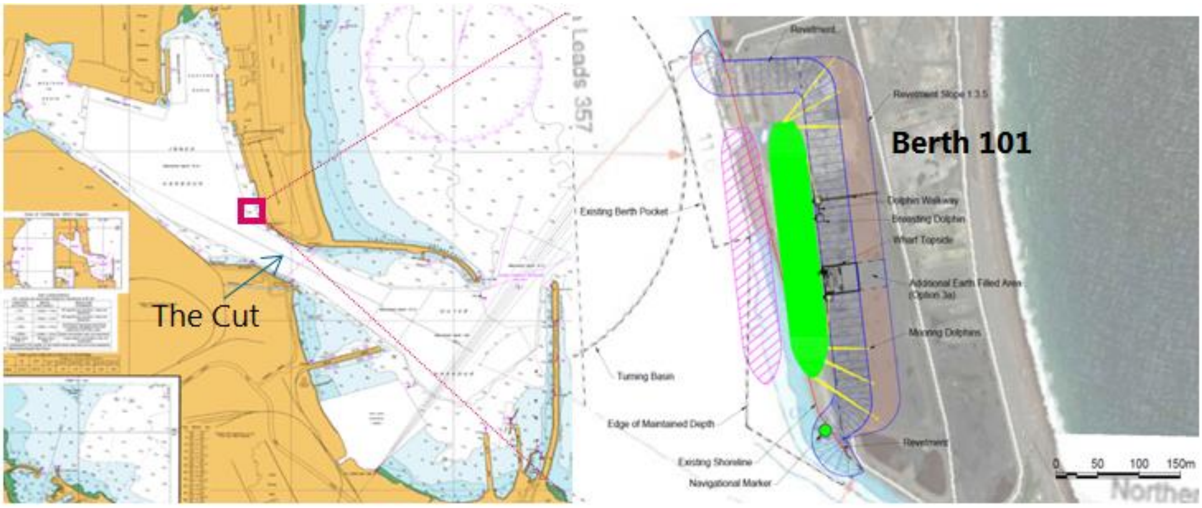
Abbreviation	Definition
AEMO	Australian Energy Market Operator
AIE	Australian Industrial Energy
AS	Australian Standard
BOD	Basis of Design
DPIE	Department of Planning, Industry & Environment
EGP	Eastern Gas Pipeline
FHA	Final Hazard Analysis
FSRU	Floating Storage and Regasification Unit
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HCRD	Hydrocarbon Release Database
HIPAP	Hazardous Industry Planning Advisory Paper
IOGP	International Association of Oil and Gas Producers
KGMS	Kembla Grange Meter Station
LNG	Liquefied Natural Gas
LNGC	Liquefied Natural Gas Carrier
LSIR	Location Specific Individual Risk
MAOP	Maximum Allowable Operating Pressure
MLV	Mainline Valve
NSW	New South Wales
P&ID	Piping and Instrumentation Diagram
PHA	Preliminary Hazard Analysis
PKGP	Port Kembla Gas Project
PKGT	Port Kembla Gas Terminal
PKL	Port Kembla Lateral
PKP	Port Kembla Pipeline
QRA	Quantitative Risk Assessment
SMS	Safety Management Study
UK HSE	United Kingdom Health & Safety Executive
UKOOA	United Kingdom Offshore Operators Association
VCE	Vapour Cloud Explosion

3. System Description

3.1 LNG Terminal Overall Description

The PKGT is planned to be developed at Port Kembla and will include a Floating Storage and Regasification Unit (FSRU) moored to an existing berth in the inner harbour (see Figure 3-1). LNG carriers (LNGC) will moor in a side-by-side configuration to offload the LNG to the FSRU where it will be regasified and sent to shore via marine loading arms and aboveground station piping and connected to an onshore pipeline that will tie-in to the existing Eastern Gas Pipeline (EGP) at Kembla Grange.

Figure 3-1 PKCT Berth 101 layout

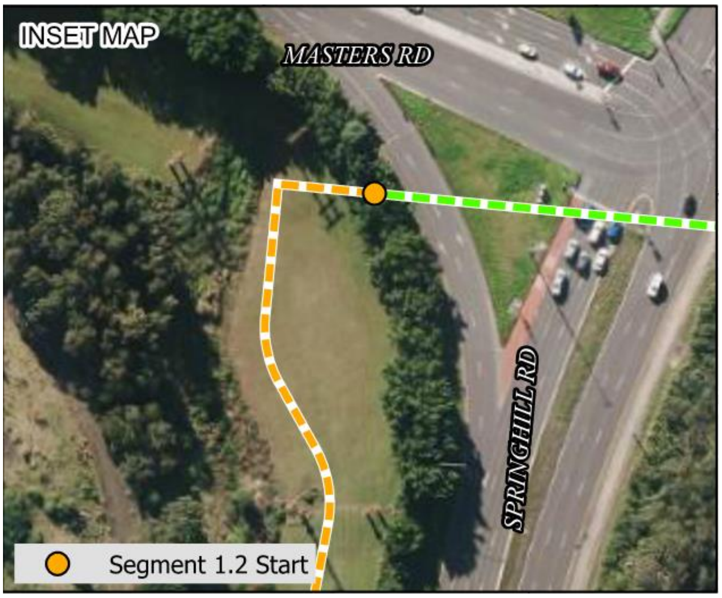


3.2 Onshore Pipeline

The onshore pipeline will run approximately 12.3km pipeline from Port Kembla, through to a meter station (KGMS) in the vicinity of Jemena's existing Kembla Grange mainline valve (MLV)/Lateral Offtake facility.

The first 4.3 km of pipeline (Segment 1.1) will be owned and operated by AIE, with the transfer of ownership between AIE and Jemena located near the intersection of Masters Road and Springhill Road (refer Figure 3-2).

Figure 3-2: AIE to Jemena Interface



Segment 1.2 will be owned and operated by Jemena, and runs approximately 2.5km from the AIE/Jemena interface to Cringila, where nitrogen is injected as required to meet Wobbe index specification. Whilst located within BOC property, the nitrogen facility will be part of Jemena pipeline license PL26.

Pipeline Segment 2 runs approximately 5.5km from Cringila to Kembla Grange, where gas is metered and enters the Eastern Gas Pipeline via a hot tap connection.

Surrounding area of the proposed PKP route is a combination of industrial, residential and rural. A Safety Management Study (SMS) was carried out for the pipeline in line with the requirements of AS 2885.1 [4] and it was agreed in the workshop that based on the usage of land adjacent to the pipeline the overall location class along the pipeline length is Residential (T1), with secondary location class industrial (I) [5].

3.3 Cringila Lateral

The Cringila Lateral is located within the BOC fenceline, however is owned and operated by Jemena, and is considered to be part of the pipeline under PL26.

Gaseous nitrogen is delivered via a 150mm line from BOC, and injected into a 450mm lateral which connects into the main pipeline via a barred tee, at the intersection between pipeline Segments 1.2 and 2. The layout of the Cringila nitrogen injection facility is shown in Figure 3-3, and an aerial view of the location in Figure 3-4.

Figure 3-3: Cringila Lateral

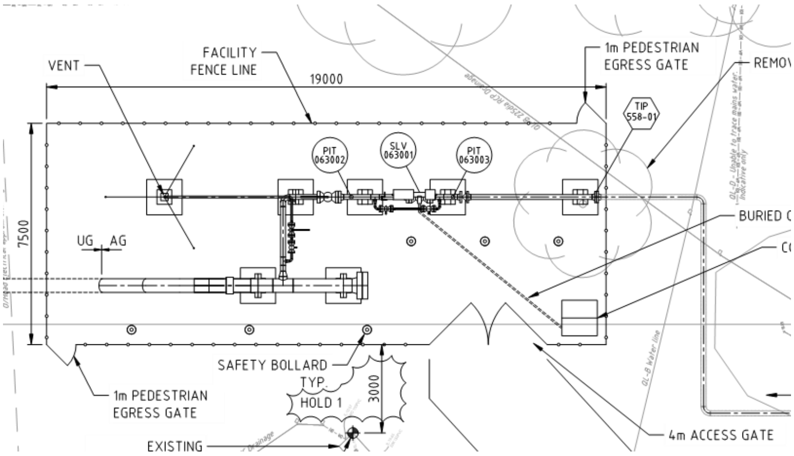


Figure 3-4: Cringila Lateral – Aerial View

The nitrogen facility is protected against reverse gas flow via the following means:

- A check valve immediately upstream of the barred tee.
- A reduced bore isolation valve, with operating stem accessible from the surface, upstream of the check valve.
- A manual block valve, check valve, and actuated shutdown valve on the 150mm nitrogen line.

As a conservative measure, the QRA has considered the Cringila nitrogen injection facility as potentially containing flammable gas, up to the BOC tie in point.

3.4 Kembla Grange Tie-in Facility

The PKP comes above ground to the south of Jemena's existing Kembla Grange MLV/Lateral Offtake facility and tie-in to the EGP. The tie-in facility at Kembla Grange includes a gas custody transfer meter, pigging facility and an actuated shutdown valve to segregate the PKGT from the EGP during an emergency.

Figure 3-5 shows the Kembla Grange facility layout, and Figure 3-6 provides an aerial view of the location.

Figure 3-5: KGMS Facility Layout

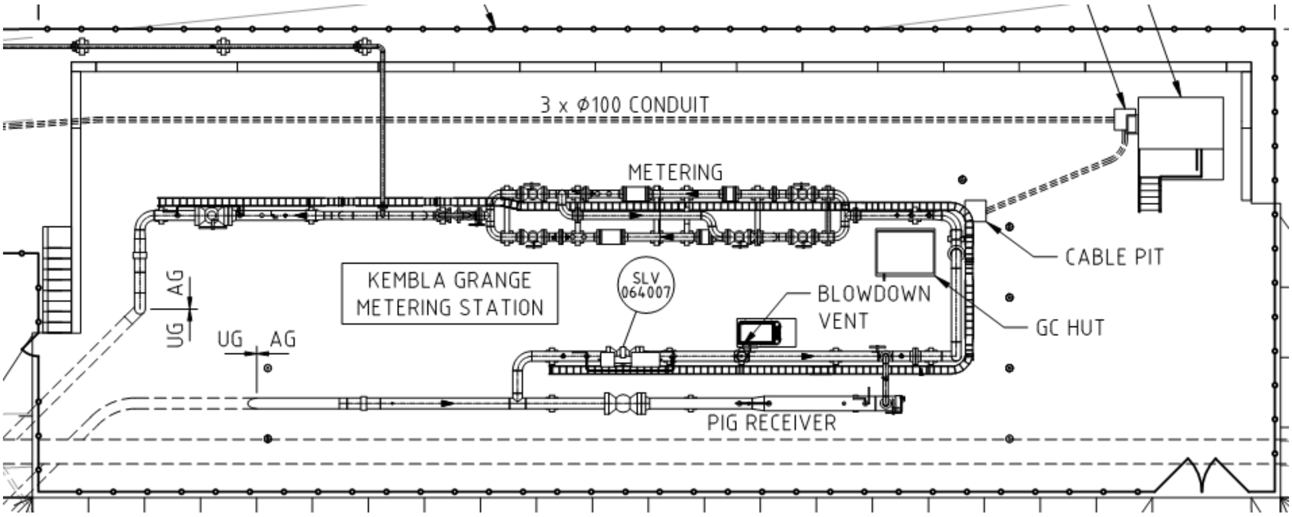
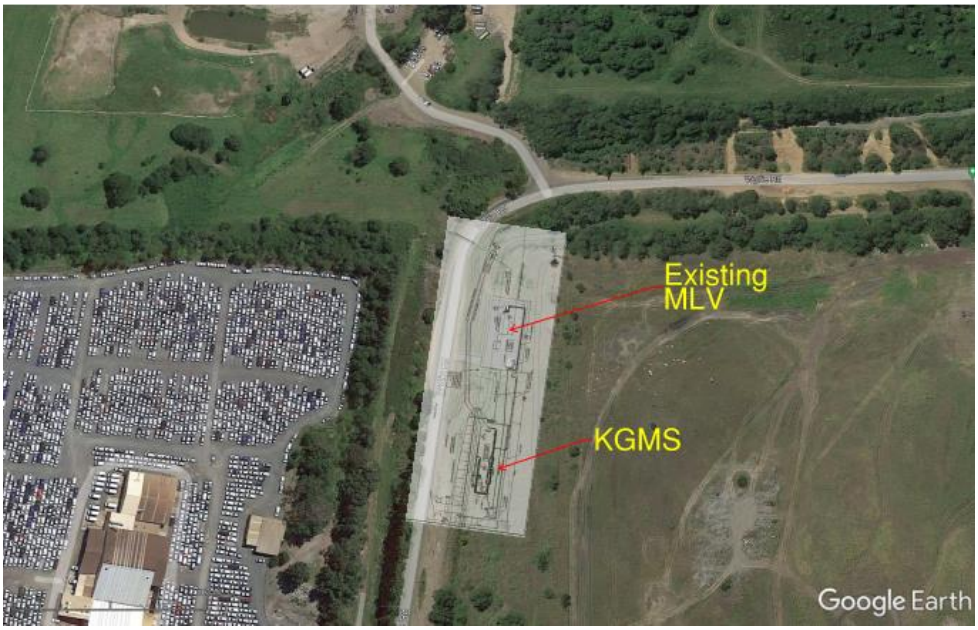


Figure 3-6: KGMS - Aerial View

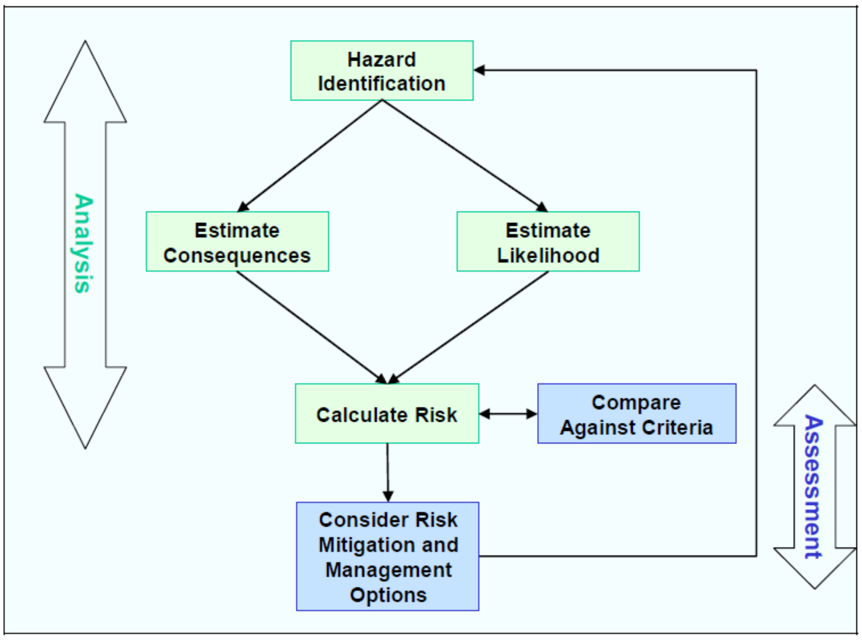


The KGMS is mainly surrounded by rural area. There is an industrial development to the west (predominantly a car yard), and public sporting facilities to the east (Sir Ian McLennan Oval).

4. Methodology

The QRA study has been carried out in accordance with the NSW HIPAP 6 guidelines for hazard and risk assessments [3]. The methodology is outlined in Figure 4-1 below.

Figure 4-1: Hazard Analysis Methodology



The methodology includes the following steps:

- Identification of Hazards (Section 5) – Review of possible accidents and the associated impacts that may occur based on previous accident experience or judgement where necessary.
- Consequences and Impact Analysis (Section 6) – Define the characteristic of the identified possible accidents.
- Frequency Analysis (Section 7) – Define the probability of the identified possible consequences.
- Risk Analysis (Section 8 and Section 9) – Define the acceptable risk levels and compare against the determined Location Specific Individual Risk contours.

5. Hazard Identification

A number of studies have been undertaken which have identified potential hazards associated with the new pipeline and tie-in facility, including:

- HAZID and HAZOP
- Pipeline Safety Management Study

The studies have identified a number of hazard causes which may lead to loss of containment events, including overpressurisation of the system, brittle failure, corrosion, and third-party impacts.

5.1 Loss of Containment Consequences

The only available hazardous material within the scope of this study is natural gas.

Natural gas is known to be a clean source of methane with very few contaminants. The natural gas composition used in this study is as presented in Table 5-1 and is calculated using composition of Rich LNG reported in Port Kembla BOD [6] adjusted with Nitrogen to achieve the AEMO Wobbe Index limitation of 51.9 MJ/Sm^3.

Table 5-1: Natural Gas Composition

Component	NG Composition [mol%]
Methane	79.83
Ethane	12.38
Propane	4.44
n-Butane	0.98
n-Pentane	0.02
Nitrogen	2.34

Natural gas will form a flammable mixture on release, with a lower flammable limit of approximately 4%. Should releases rapidly ignite, a jet fire will form, which is highly directional and will generate significant levels of radiant heat due to efficient burning.

Delayed ignition will result in a flash fire, and if sufficient congestion is present, a vapour cloud explosion (VCE). VCEs occur due to rapid combustion of flammable gas which generates pressure effects due to the acceleration of the flame front by congestion or confinement. As both pipeline and Kembla Grange tie-in facility are located in open areas and the degree of confinement and congestion is very low, explosion is not considered a credible scenario in this study.

The composition of the re-gasified LNG is such that toxic impacts are not considered to be credible. It is noted that significant releases of nitrogen from the lateral connection may pose an asphyxiation risk, however this is considered a lesser risk than flammable gas release. As the QRA is conservatively assuming natural gas may be present at this location, the effects of nitrogen release are not considered.

5.2 Escalation Potential

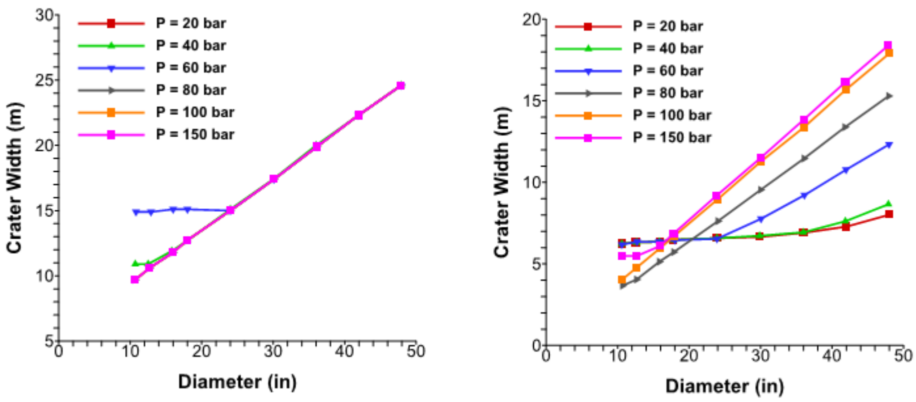
A specific query was raised by DPIE relating to the separation distance between the looping pipeline and the existing pipeline, when they are in proximity in the same corridor.

Guidance with respect to spacing has been taken from "Underground parallel pipelines domino effect: An analysis based on pipeline crater models and historical accidents", published in the Journal of Loss Prevention in the Process Industries [7]. The concept is that inter-pipeline escalation can occur when a crater forms, exposing the adjacent pipeline to direct flame impingement following a release event.

The potential crater dimensions are based on the pipeline pressure, diameter and the soil type. For an 18" (DN450) pipeline in sandy soil, and operating at up to 150 barg, the total crater width (centred on the pipeline) is approximately 13m, and in clay soil the crater width is approximately half of this (refer to Figure 5-1). The new pipeline alignment is such that the separation from the existing pipeline exceeds these separation distances for the vast majority of the common route. There is one location (approximately 20m in length) where the separation is reduced due to physical constraints, however these constraints also make it highly improbable that any third party excavation with the potential for pipeline impact could occur in this area. The risk of inter-pipeline escalation was not identified as a specific threat within SMS reviews, and the pipeline has been designed as "no rupture".

Based on this data, the risk of inter-pipeline escalation has been excluded from this analysis.

Figure 5-1 Pipeline Crater Width



(a) Sandy soil

(b) Clay soil

6. Consequence Modelling Assumptions and Inputs

DNV Safeti version 8.4 was used to model the possible identified consequences from releases of hazardous inventories and resulting risk contours.

The following section describes the assumptions, inputs and scenario development for the modelling undertaken.

6.1 Release Scenarios

The release cases modelled in this study are summarised in Table 6-1 below. All releases have been modelled at a pressure of 16,550 kPag, and temperature of 10˚C.

Table 6-1: Hazardous Inventories

Scenario ID	Scenario
1	Natural Gas pipeline Segment 1.2
2	Natural Gas pipeline Segment 2
3	Kembla Grange - Above ground to SLV 064007, and pig trap isolation
4	Kembla Grange - Metering to hot tap valve assembly
5	Kembla Grange - Pig receiver
6	MLV-1 Tie-in to Kembla Grange Meter Station
7	Cringila Lateral Injection

All releases have been modelled at initial process conditions until depleted, with the exception of very large releases which are modelled based on the release rate at 30 seconds after release. Isolation is provided at both the Kembla Grange facility and at Port Kembla, however the effects of pipeline isolation have been ignored in the consequence modelling.

6.2 Hole Size Distribution

The hole size distributions used in the PHA were consistent with those used in the AIE PKGP Preliminary Hazard Analysis. For the FHA, distribution for above ground facilities has been refined as follows:

- Representative hole sizes have been modelled based on the geometric mean of the range. Per IOGP document 434-01 [8], holes over a given range are best represented by the geometric mean.
- The previous study modelled all releases <rupture as a maximum 100mm hole size. An additional release case has been included between the 100mm, and full bore (450mm) release cases.

The hole size distribution applied for the above ground facilities is provided in Table 6-2.

Table 6-2: Leak Size at Kembla Grange Facility

Range (mm)	Representative Hole Size (mm)
1-10	3
10-25	16
25-50	35
50-100	71
100-450	212
Full Bore	450

For the pipeline, the release sizes are consistent with the previous study, as derived from IOGP 434-04 [9], and presented in Table 6-3.

Table 6-3: Leak Size – Pipeline

Leak Description	Diameter (mm)	Representative Hole Size(mm)
Small	<20	20
Medium	20-80	50
Large	>80	100
Catastrophic	Full Bore Rupture	450

6.3 Leak Direction and Elevation

Three different release orientations were modelled. Directional probabilities are as follows:

- 50% for horizontal;
- 25% for vertical (up); and
- 25% for vertical (down).

A leak from the pipeline is assumed to have following orientation probabilities:

- 20% for vertical (up); and
- 80% for vertical (45° diagonal).

Releases from the Kembla Grange tie-in facility were modelled at an elevation of 1m, and releases from the buried pipeline at an elevation of 0m. All risk impacts have been measured at a height of 1.65m above ground level.

6.4 Environmental Conditions

Environmental conditions and wind direction probabilities used in the consequence modelling are taken from the PKGP PHA [10] and summarised in Table 6-4 and Table 6-5 as follows.

Table 6-4: Weather Parameters

Weather ID	Wind Speed (m/s)	Pasquil Stability	Air Temperature (°C)	Relative Humidity (%)	Ground Temperature (°C)
Calm	1	F	5	68	17
Average	5	D	25	68	21
Windy	10	D	40	68	25

Table 6-5: Weather Probability Distribution

Weather ID	N	NE	E	SE	S	SW	W	NW	Occurrence
Calm – 1F	2.59%	5.80%	2.86%	3.49%	2.77%	3.83%	2.41%	1.55%	25.28%
Average – 5D	5.24%	12.64%	3.52%	5.86%	10.68%	7.53%	6.22%	2.47%	54.15%
Windy – 10D	0.78%	4.20%	0.72%	1.30%	5.49%	2.54%	4.64%	0.90%	20.57%

7. Frequency Analysis

7.1 Release Frequency

Release frequency has been estimated based on a parts count using issued Piping and Instrumentation Drawings (P&IDs), and application of failure rates premised on historical data using correlations provided in OGP 434-01 (Process Release Frequencies) [8] published by the International Association of Oil and Gas Producers.

The release frequencies within the reference are based on historical data sourced from the United Kingdom Health and Safety Executive (UK HSE) Hydrocarbon Release Database (HCRD) which is considered to be the standard source of release frequencies for offshore QRA, and represents a large, high quality collection of release experience. It is acknowledged within the document that the data may be applied for onshore installations, due to an absence of comparable datasets for such installations, with consideration of scaling factors to represent the change in application. Whilst no scaling factors have been applied, the following is noted with respect to the database failure rates, which make application in this context conservative:

- Offshore industry has a range of additional risk contributors not relevant in this application, including a saline marine environment, higher overall facility congestion, increased potential for lifting in close proximity to live equipment, and stresses imposed by facility movement.
- The failure data does not consider the nature of the process fluid. Higher failure rates would be expected to be associated with sour service, or where the stream includes the presence of sand (causing erosion) or water (causing corrosion). In this instance, the service is dry, clean methane gas, and as such failure rates will be significantly lower.
- Failure data is expected to be significantly skewed by aged assets.

The most recent (September 2019) publication of IOGP 434-01 notes that the number of incidents recorded in the HCRD have been steadily decreasing, and it may be appropriate to base the frequency on more recent data on the assumption that this is more representative of what will occur in the future. For this reason, failure rates are presented based on the last 10 years of recordings, as well as over the entire reporting period, with a recommendation to use the former.

The failure rates in IOGP 434-01 are correlated by a model which estimates the probability of a release of size “d” mm or larger, based on the following equation:

$F(d) = Cd^m + B$, where:

- F(d) = frequency of a hole, d mm in diameter or smaller
- C, m and B are parameters for the equipment type, dependent on the equipment size, D

Note that the parts count does not include an estimation of pipe lengths at the facility. Per DNV Report “Technical Report Offshore QRA – Standardised Hydrocarbon Leak Frequencies” section 2.3.3 notes that application of failure rate per unit length of piping results in a very high contribution compared to other equipment, and this is believed to be through an under estimation of overall exposure data. The reference recommends a parts count be completed for all other components, and leaks attributable to pipework defined such that they represent 25% of the release total. This approach has been adopted within this QRA.

The pig receiver 557-E-018001 and associated piping are only in use during pigging operation which is assumed to be a maximum of once every 5 years, and online for a maximum of 80 hours when in use.

The P&IDs used in the parts count are listed in Table 7-1.Release frequencies for each release scenario are summarised in Appendix A.

Table 7-1: Reference P&IDs

Drawing Number	Title	Revision
GAS-556-DW-PD-001	Port Kembla Pipeline Nitrogen Injection Connection	C
GAS-557-DW-PD-001	Kembla Grange Meter Station Pig Receiver	G
GAS-557-DW-PD-002	Kembla Grange Meter Station Metering	F
GAS-557-DW-PD-003	Kembla Grange Meter Station EGP Hot Tap Tie-In	F
GAS-557-DW-PD-004	Kembla Grange Meter Station Remote Actuated MLV & DN200 Sales Tap	C
GAS-558-DW-PD-001	BOC Lateral Inlet Facility BOC Nitrogen Injection	B

IOGP Pipeline failure rate data [9] has been used for the release frequency calculation of the pipeline within this QRA, which correlates release frequency based on pipeline wall thickness. For a pipeline between 17 and 23 inches in diameter, a release frequency of 0.091 per 1000km per year is provided, with no consideration of wall thickness. The distribution of hole sizes for pipeline releases is provided in Table 7-2. Note that APGA maintains a failure database, with failure rates in Australia approximately one order of magnitude lower than overseas failure rates. As such, application of the IOGP data may be considered conservative in this context.

Table 7-2: Pipeline Release Hole Size Distribution

Leak Description	% of Release Cases
Small	70
Medium	15
Large	5
Catastrophic	10

7.2 Ignition Probability

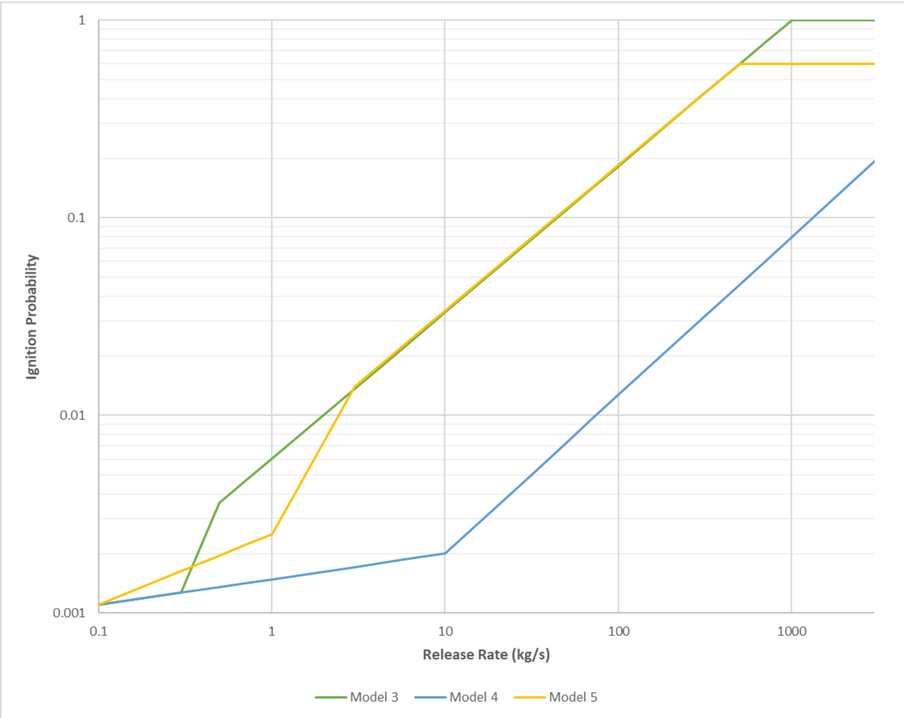
Given a release, the probability of ignition is dependent on a range of factors including:

- Release rate;
- Material state (liquid or gas);
- Material physical properties (flash point, density, flammability limits); and
- Ignition sources present (hot work, uncertified / old equipment, energy sources).

There are a range of correlations available for applying an ignition probability to a release, and most are based on the release rate and state. The ignition probabilities utilised in this QRA are based on the United Kingdom Offshore Operators Association (UKOOA) ignition correlations [11] which take into account the factors above as well as the nature of the surrounding area with respect to potential ignition sources.

The ignition probabilities in this QRA are determined using the UKOOA ignition correlation no. 4 (Pipe Gas LPG Rural) for the releases at Kembla Grange facility and correlation no. 3 (Pipe Gas LPG Industrial) for release from the buried pipeline, and correlation no. 5 (Small plant gas/LPG) for the Cringila facility. Ignition probability as a function of release rate for each model is shown in Figure 7-1, with ignition probabilities for each release scenario summarised in Appendix B.

Figure 7-1: UKOOA Ignition Models



For each ignited event, the proportion of immediate (rapid) to delayed ignition events influences the event outcome (specifically, the probability of a jet or flash fire forming).

Table 2.13 of the IP Research Report [11] (OIR 12 data ignition outcome distribution by media) suggests that 29% of ignited gas releases will result in a jet fire (immediate ignition event), with the remaining 61% flash fires and explosions. This is backed up by Table 2.15 (Plant ignition timings distribution) which suggests that 36% of ignition events occur within 30 seconds of release (media independent). As a base case, it is assumed that 30% of ignition events are immediate, with the balance delayed ignition.

7.3 Fatality Probability

For jet fires, it is assumed that fatality occurs as a result of exposure to a radiant heat. Table 7-3 provides typical effects of radiant heat exposure, as source from HIPAP 4 [2].

Table 7-3: Radiant Heat Consequences

Radiation (kW/m²)	Effect – People
2.1	Minimum level to cause pain after 1 minute

Radiation (kW/m^2)	Effect – People
4.7	Pain in 15-20 seconds, Injury after 30 seconds exposure (second degree burns minimum)
12.6	Significant chance of fatality with extended exposure High chance of injury
23	Likely fatality with extended exposure Chance of fatality with instantaneous exposure
35	Significant chance of fatality

Within the QRA, fatality due to exposure to radiant heat is premised on the following Probit equation for personnel located outdoors:

Probit = $-36.38 + 2.56 \ln (t*q^{4/3})$, where

- t = exposure time, in seconds
- q = radiant heat load, in W/m^2

OGP Report 434-14.1 (Vulnerability of humans) [12] notes in Table 2.2 that exposure above 12.5 kW/m^2 has a significant chance of fatality for medium duration exposure, and Table 2.3 notes at this level extreme pain within 20 seconds, and 100% chance of fatality when exposed to 35 kW/m^2.

Based on these definitions, a maximum exposure time of 20 seconds to radiant heat has been specified, which correlates to approximately 7% chance of fatality at 12.5 kW/m^2, and 98% chance of fatality at exposure of 35 kW/m^2.

For flash fires, fatality is assumed to occur when persons are engulfed within the fire event, which is defined by the extent of the flammable cloud.

8. Risk Criteria

Risk criteria has been derived from Hazardous Industry Planning Advisory Paper (HIPAP) No. 4 “Risk Criteria for Land Use Safety Planning” [2]. The following measures of risk have been utilised, and are summarised below:

- Location Specific Individual Risk
- Injury Risk
- Risk of Property Damage and Accident Propagation

8.1 Location Specific Individual Risk

Location Specific Individual Risk (LSIR) is the level of risk which would be experienced by a person in a particular location, for a full calendar year. LSIR criteria has been sourced from the NSW Department of Urban Affairs and HIPAP No. 4 as follows:

Table 8-1: HIPAP-4 LSIR Criteria

Land Use	Suggested Criteria (risk in a million per year)
Hospitals, schools, child-care facilities, old age housing	0.5
Residential, hotels, motels, tourist resorts	1
Commercial developments including retail centres, offices and entertainment centres	5
Sporting complexes and active open space	10
Industrial	50

8.2 Injury Risk

HIPAP-4 notes that society are concerned about risk of injury as well as risk of death, and proposes a heat radiation injury risk criterion of 4.7 kW/m^2, noting that this should not be exceeded in residential and sensitive use areas at a frequency of more than 50 chances in a million per year.

For explosion overpressure, HIPAP-4 proposes an injury overpressure criterion of 7 kPa not be exceeded at a frequency of more than 50 chances in a million per year, however explosions have not been considered as a credible outcome within this study.

It is noted that the specified injury criteria do not include consideration of flash fire events. As a conservative measure, injury risk within the QRA is estimated with no consideration for the 30% to 70% split between immediate and delayed ignition, with the total ignition probability as determined by the UKOOA model attributed to immediate ignition, and hence producing radiant heat jet fire impacts.

8.3 Risk of Property Damage and Accident Propagation

HIPAP-4 further notes that the siting of a hazardous installation must account for the potential of an accident at the installation causing damage to buildings and propagating to neighbouring industrial operations.

HIPAP-4 notes that heat radiation levels of 23 kW/m^2 as the result of fire incidents at a hazardous plant may affect a neighbouring installation to the extent that unprotected steel can suffer thermal stress that may cause structural failure. This may trigger a hazardous event unless protection measures are adopted.

The suggested HIPAP-4 criterion for radiant heat property damage is 23 kW/m^2 noting that this should not be exceeded at neighbouring potentially hazardous installations or at land zoned to accommodate such installations should not at a frequency of more than 50 chances in a million per year.

As above, this assessment has been undertaken with no consideration for the 30% to 70% split between immediate and delayed ignition, with the total ignition probability as determined by the UKOOA model attributed to immediate ignition, and hence producing radiant heat jet fire impacts.

9. Risk Results

Impact distances for jet fires and flash fires for each weather case are presented in Appendix C.

9.1 Location Specific Individual Risk

Location specific individual risk (LSIR) contours for the entire pipeline length, inclusive of the facilities is show in Figure 9-1, with magnified views for Kembla Grange and Cringila in Figure 9-2 and Figure 9-3 respectively.

The results of the QRA modelling undertaken indicate that risk exposure associated with the PKP and the associated KGMS will be below the fatality risk criteria specified in HIPAP-4, with no risks recorded above 5E-05 per annum (limit for commercially developed land), and no risk above 5E-07 per annum (sensitive land use) impacting on residential areas. Due to the application of a higher probability of ignition model, the Cringila injection facility shows a slightly higher risk than the KGMS, with a localized area showing risk in excess of 5E-06 per annum.

Note along the pipeline length, risk was measured to be <5E-07 per annum, and risk contours of 3E-07 per annum have therefore been recorded to show risk in these locations.

Figure 9-1: Location Specific Individual Risk Contours

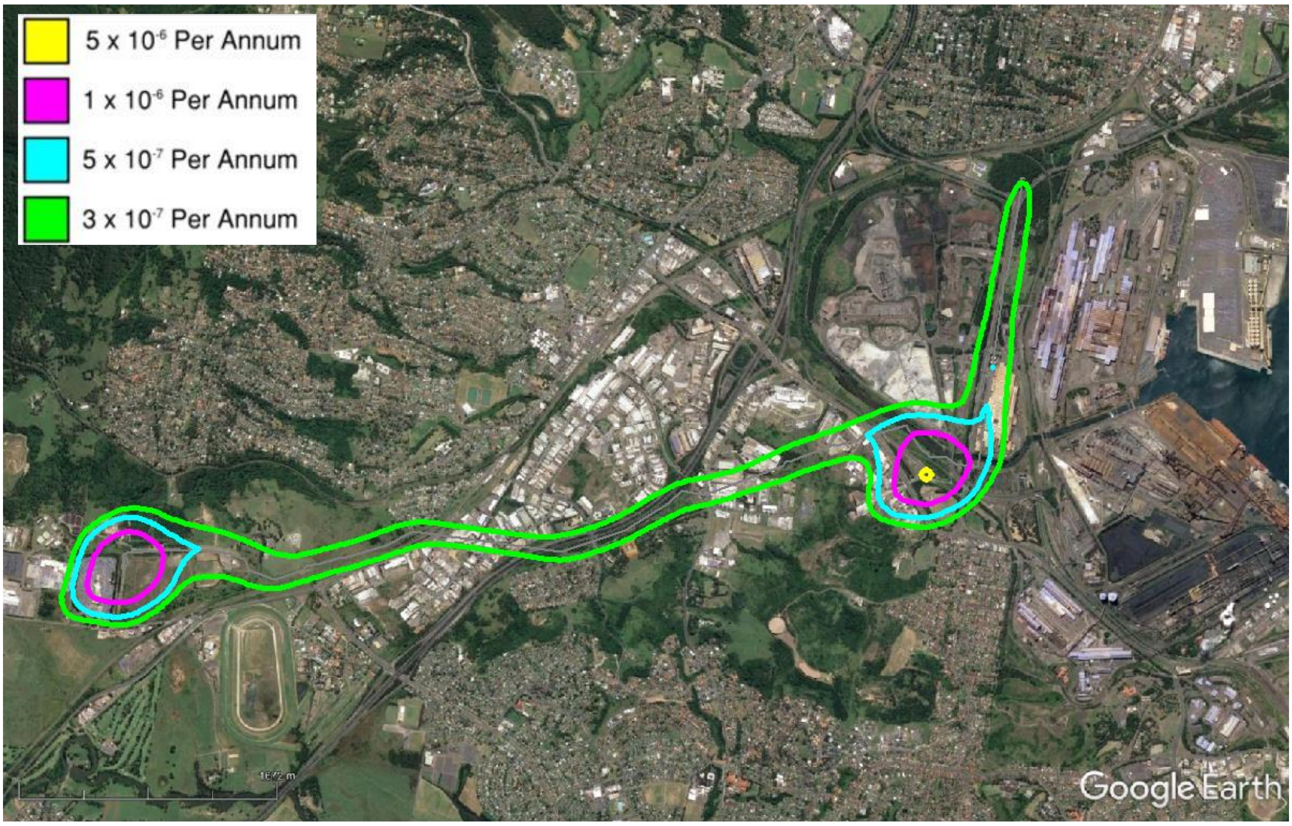


Figure 9-2: Location Specific Individual Risk Contours – Kembla Grange

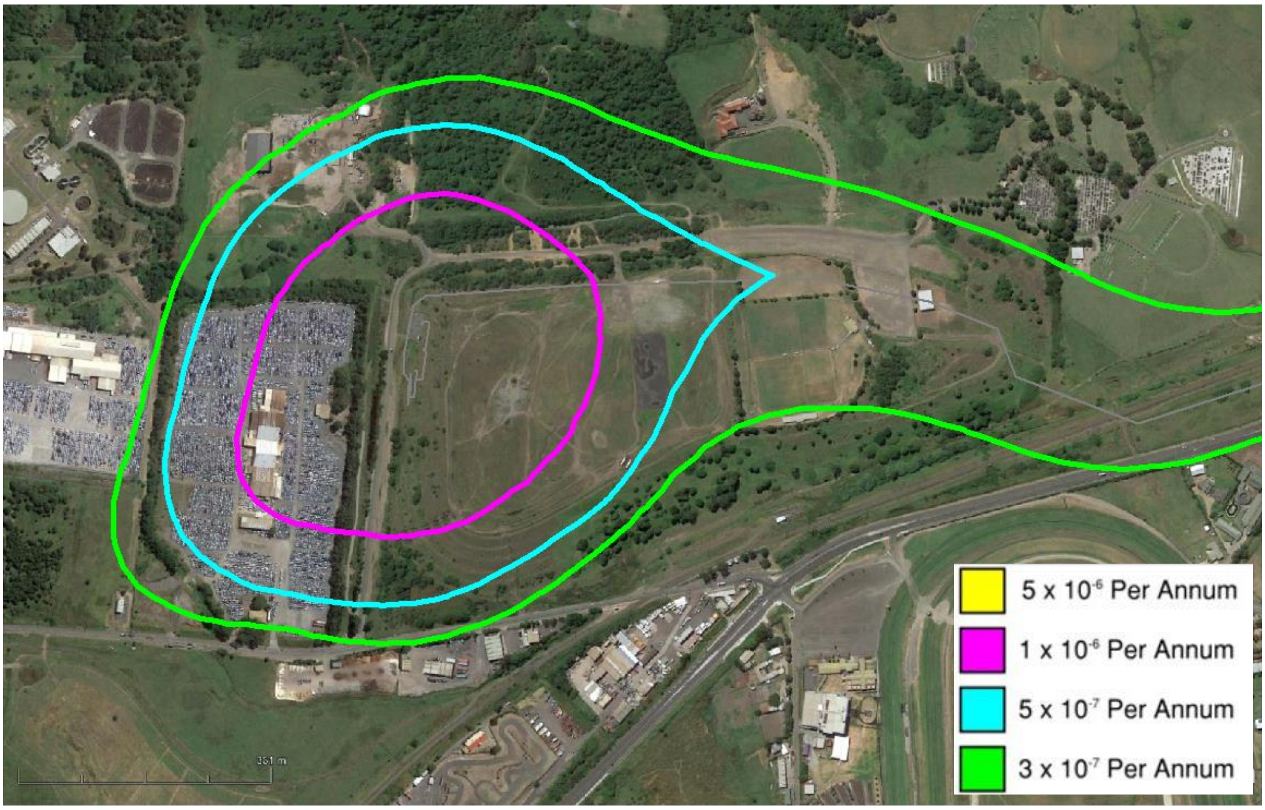
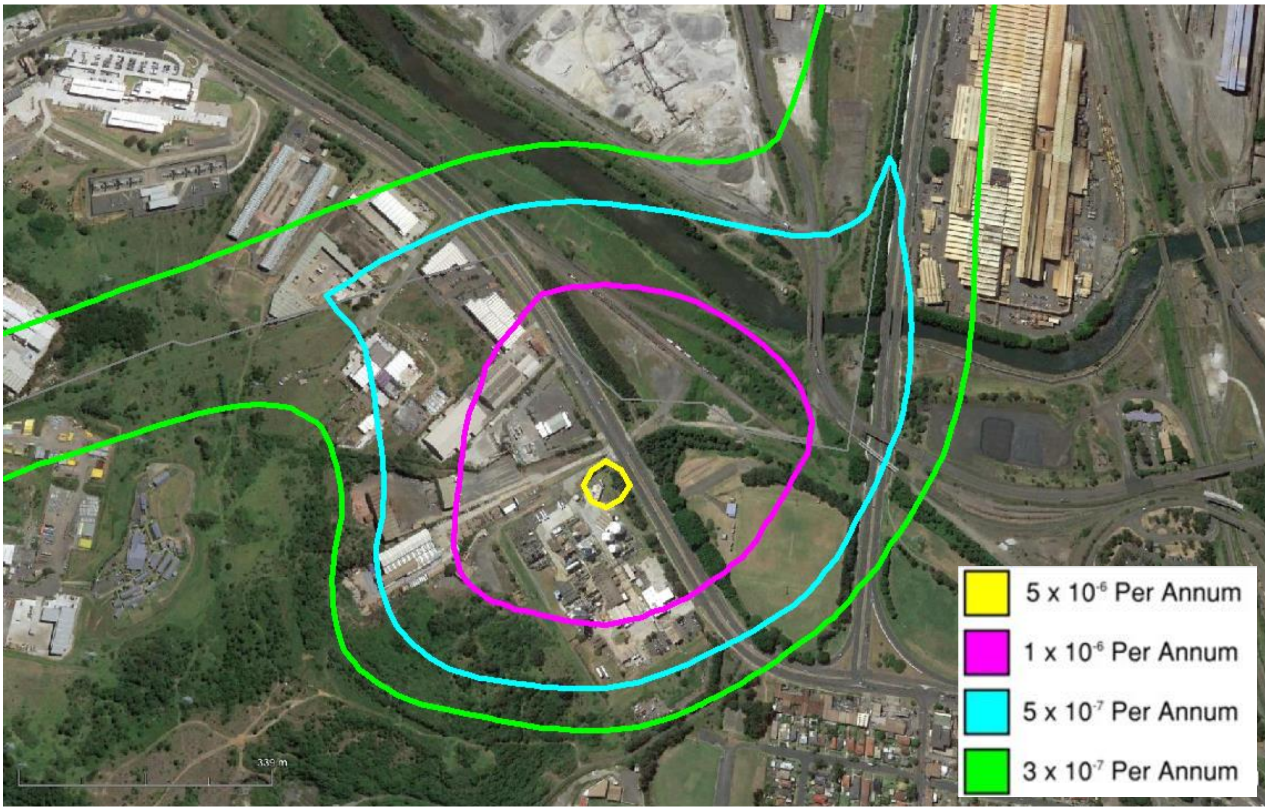


Figure 9-3: Location Specific Individual Risk Contours – Cringila Nitrogen Facility



9.2 Injury and Escalation Risk

In addition to production of Location Specific Individual Risk (LSIR) contours, the FHA has considered injury and property damage/accident propagation risk, defined by radiant heat impacts of 4.7, and 23kW/m^2.

Note, results were not generated at this level for the specified HIPAP-4 criterion of 5E-05 per annum (or, fifty in a million per year), and as an alternative, the HIPAP LSIR frequency criteria were applied, as shown in Figure 9-4 and Figure 9-5.

Figure 9-4: Injury Risk (Exposure to 4.7kW/m^2)

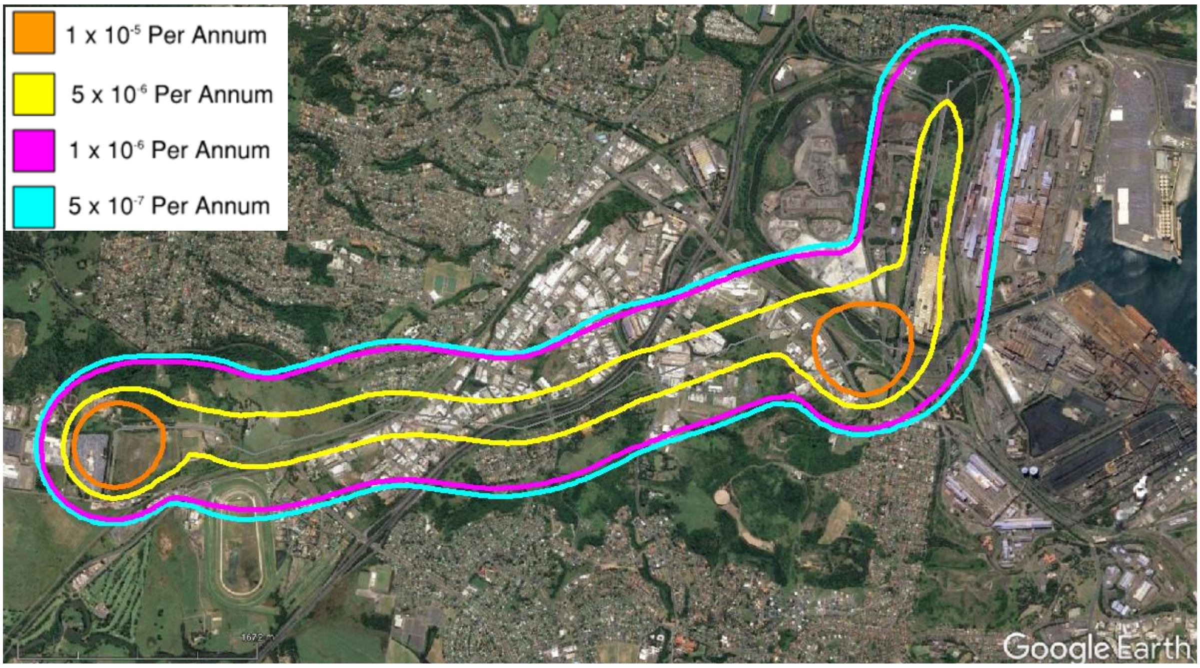
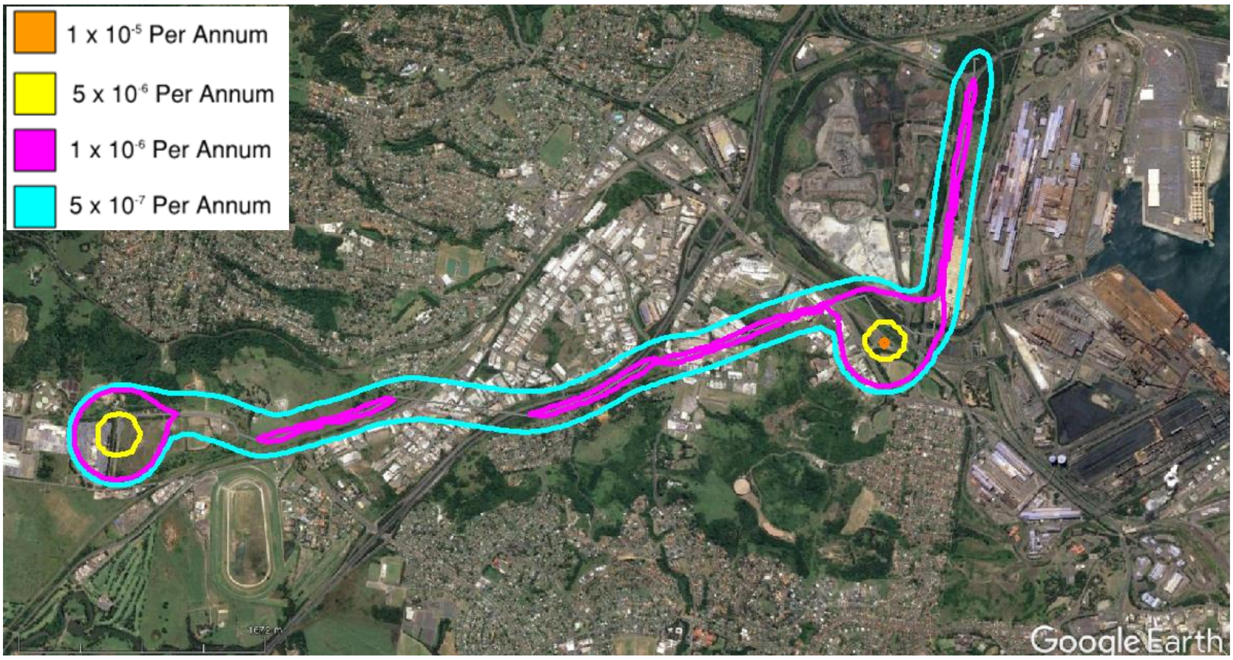


Figure 9-5: Property Damage & Escalation Risk (Exposure to 23kW/m^2)



10. Conclusion

The results of the QRA modelling undertaken indicate that risk exposure associated with the PKP and the associated KGMS will be below the fatality risk criteria specified in HIPAP-4.

11. References

1. 411010-00071-SR-REP-0002, Port Kembla Lateral Looping NGP2 Pipeline FEED, Rev C, October 2020
2. Hazardous Industry Planning Advisory Paper (HIPAP) No. 4, Risk Criteria for Land Use Safety Planning, January 2011
3. Hazardous Industry Planning Advisory Paper (HIPAP) No. 6- Hazard Analysis, January 2011
4. AS2885.1, Pipelines – Gas and Liquid Petroleum – Part 1: Design and Construction, 2012
5. 401010-00071-SR-REP-0001, Port Kembla Lateral Looping PKL Pipeline FEED, Pipeline Safety Management Study Workshop, Rev 0
6. 401010-01496-PM-BOD-0001, Port Kembla Gas Project Basis of Design, Rev 0
7. Underground parallel pipelines domino effect: An analysis based on pipeline crater models and historical accidents, Journal of Loss Prevention in the Process Industries, Vol. 43, September 2016
8. OGP Risk Assessment Data Directory, Process Release Frequencies, Report No 434-01, September 2019
9. OGP Risk Assessment Data Directory, Riser and Pipeline Frequencies, Report No 434-04, September 2019
10. Port Kembla Gas Project, Preliminary Hazard Analysis, 401010-01496-SR-REP-0002, Rev 0
11. IP Research Report, Ignition Probability Review, Model Development and Look-Up Correlations, January 2006
12. OGP Risk Assessment Data Directory, Vulnerability of Humans, Report 434-14.1, March 2010

Appendix A. Parts Count

Section 3: Kembla Grange - Above ground to SLV 064007, and pig trap isolation

Component	Diameter	Count	Hole Size (mm)					
			1-10	10-25	25-50	50-100	100-450	450
INST	40	2	3.44E-04	2.95E-05	2.42E-05	0.00E+00	0.00E+00	0.00E+00
MANVALVE	25	1	2.24E-05	3.24E-06	4.54E-06	0.00E+00	0.00E+00	0.00E+00
FLANGE	50	2	1.27E-05	1.29E-06	5.16E-07	7.50E-07	0.00E+00	0.00E+00
MANVALVE	50	2	4.60E-05	6.29E-06	2.87E-06	5.35E-06	0.00E+00	0.00E+00
ACTVALVE	400	1	1.14E-04	1.01E-05	3.83E-06	2.12E-06	2.74E-06	0.00E+00
MANVALVE	450	1	6.05E-05	9.15E-06	4.37E-06	2.96E-06	3.53E-06	3.00E-06
FLANGE	450	2	5.05E-05	3.22E-06	1.05E-06	5.19E-07	3.95E-07	3.64E-06
PIPE			2.17E-04	2.09E-05	1.38E-05	3.90E-06	2.22E-06	2.21E-06
TOTAL			**8.67E-04**	**8.38E-05**	**5.52E-05**	**1.56E-05**	**8.89E-06**	**8.85E-06**

Section 4: Kembla Grange - Metering to hot tap valve assembly

Component	Diameter	Count	Hole Size (mm)					
			1-10	10-25	25-50	50-100	100-450	450
INST	40	3	5.16E-04	4.42E-05	3.63E-05	0.00E+00	0.00E+00	0.00E+00
INST	50	1	1.72E-04	1.47E-05	5.48E-06	6.62E-06	0.00E+00	0.00E+00
MANVALVE	15	1	2.21E-05	8.00E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MANVALVE	20	4	8.91E-05	3.16E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MANVALVE	25	7	1.57E-04	2.27E-05	3.18E-05	0.00E+00	0.00E+00	0.00E+00
MANVALVE	40	6	1.37E-04	1.91E-05	2.57E-05	0.00E+00	0.00E+00	0.00E+00
FLANGE	40	5	2.98E-05	3.04E-06	2.84E-06	0.00E+00	0.00E+00	0.00E+00
FLANGE	50	4	2.53E-05	2.58E-06	1.03E-06	1.50E-06	0.00E+00	0.00E+00
MANVALVE	50	5	1.15E-04	1.57E-05	7.18E-06	1.34E-05	0.00E+00	0.00E+00
FLANGE	150	3	3.02E-05	3.03E-06	1.20E-06	6.97E-07	1.94E-06	0.00E+00
MANVALVE	150	1	2.51E-05	2.72E-06	1.12E-06	6.66E-07	9.84E-07	0.00E+00
FLANGE	200	5	6.13E-05	5.86E-06	2.29E-06	1.30E-06	4.37E-06	0.00E+00
MANVALVE	200	2	6.06E-05	6.64E-06	2.74E-06	1.64E-06	2.54E-06	0.00E+00
FLANGE	300	24	4.16E-04	3.39E-05	1.23E-05	6.62E-06	3.22E-05	0.00E+00
MANVALVE	300	6	2.62E-04	3.26E-05	1.43E-05	8.99E-06	1.62E-05	0.00E+00
FLANGE	400	4	9.03E-05	6.26E-06	2.12E-06	1.07E-06	7.17E-06	0.00E+00
MANVALVE	400	2	1.11E-04	1.57E-05	7.29E-06	4.81E-06	9.93E-06	0.00E+00
FLANGE	450	1	2.52E-05	1.61E-06	5.27E-07	2.60E-07	1.98E-07	1.82E-06
PIPE			7.36E-04	8.43E-05	4.88E-05	1.42E-05	2.18E-05	0.00E+00
TOTAL			**3.08E-03**	**3.54E-04**	**2.03E-04**	**6.17E-05**	**9.74E-05**	**1.82E-06**

Section 5: Kembla Grange - Pig receiver

Component	Diameter	Count	Hole Size (mm)					
			1-10	10-25	25-50	50-100	100-450	450
MANVALVE	25	1	2.24E-05	3.24E-06	4.54E-06	0.00E+00	0.00E+00	0.00E+00
INST	40	3	5.16E-04	4.42E-05	3.63E-05	0.00E+00	0.00E+00	0.00E+00
FLANGE	50	5	3.16E-05	3.22E-06	1.29E-06	1.88E-06	0.00E+00	0.00E+00
MANVALVE	50	3	6.90E-05	9.44E-06	4.31E-06	8.03E-06	0.00E+00	0.00E+00
FLANGE	200	1	1.23E-05	1.17E-06	4.57E-07	2.60E-07	8.73E-07	0.00E+00
MANVALVE	200	1	3.03E-05	3.32E-06	1.37E-06	8.21E-07	1.27E-06	0.00E+00
PIGTRAP	450	1	2.20E-03	2.75E-04	1.21E-04	7.61E-05	8.19E-05	4.73E-05
FLANGE	450	1	2.52E-05	1.61E-06	5.27E-07	2.60E-07	1.98E-07	1.82E-06
PIPE			9.69E-04	1.14E-04	5.65E-05	2.91E-05	2.81E-05	1.64E-05
TOTAL			**3.87E-03**	**4.55E-04**	**2.26E-04**	**1.16E-04**	**1.12E-04**	**6.55E-05**

Section 6: MLV-1 Tie-in to Kembla Grange Meter Station

Component	Diameter	Count	Hole Size (mm)					
			1-10	10-25	25-50	50-100	100-450	450
INST	40	2	3.44E-04	2.95E-05	2.42E-05	0.00E+00	0.00E+00	0.00E+00
MANVALVE	20	1	2.23E-05	7.89E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FLANGE	40	1	5.96E-06	6.07E-07	5.67E-07	0.00E+00	0.00E+00	0.00E+00
FLANGE	150	10	1.01E-04	1.01E-05	4.01E-06	2.32E-06	6.45E-06	0.00E+00
ACTVALVE	150	1	1.17E-04	1.27E-05	5.20E-06	3.09E-06	4.79E-06	0.00E+00
MANVALVE	150	3	7.52E-05	8.15E-06	3.35E-06	2.00E-06	2.95E-06	0.00E+00
PIPE			2.22E-04	2.30E-05	1.24E-05	2.47E-06	4.73E-06	0.00E+00
TOTAL			**8.88E-04**	**9.18E-05**	**4.98E-05**	**9.89E-06**	**1.89E-05**	**0.00E+00**

Section 7: BOC Nitrogen Injection

Component	Diameter	Count	Hole Size (mm)					
			1-10	10-25	25-50	50-100	100-450	450
INST	40	2	3.44E-04	2.95E-05	2.42E-05	0.00E+00	0.00E+00	0.00E+00
MANVALVE	20	1	2.23E-05	7.89E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FLANGE	50	2	1.27E-05	1.29E-06	5.16E-07	7.50E-07	0.00E+00	0.00E+00
MANVALVE	50	3	6.90E-05	9.44E-06	4.31E-06	8.03E-06	0.00E+00	0.00E+00
FLANGE	150	6	6.04E-05	6.05E-06	2.41E-06	1.39E-06	3.87E-06	0.00E+00
MANVALVE	150	2	5.01E-05	5.43E-06	2.23E-06	1.33E-06	1.97E-06	0.00E+00
ACTVALVE	150	1	1.17E-04	1.27E-05	5.20E-06	3.09E-06	4.79E-06	0.00E+00
FLANGE	450	2	5.05E-05	3.22E-06	1.05E-06	5.19E-07	3.95E-07	3.64E-06
PIPE			2.42E-04	2.52E-05	1.33E-05	5.04E-06	3.67E-06	1.21E-06
TOTAL			**9.69E-04**	**1.01E-04**	**5.32E-05**	**2.02E-05**	**1.47E-05**	**4.85E-06**

Appendix B. Summary of Release Scenarios

Above Ground Facilities:

No.		Hole Size (mm)	Temp	Pressure (barg)	Release Rate (kg/s)	Release Frequency	Ignition Probability	Fire Frequency
3	Pipeline- A/G point at Kembla to SLV-064007	3	10	165.5	0.27	8.67E-04	1.25E-03	1.08E-06
		16	10	165.5	7.62	8.38E-05	1.93E-03	1.62E-07
		35	10	165.5	36.44	5.52E-05	5.63E-03	3.11E-07
		71	10	165.5	149.90	1.56E-05	1.75E-02	2.73E-07
		212	10	165.5	879.30	8.89E-06	7.22E-02	6.42E-07
		431.6	10	165.5	1285.00	8.85E-06	9.78E-02	8.66E-07
4	Metering to U/G point to hot tap valve assembly	3	10	165.5	0.27	3.08E-03	1.25E-03	3.85E-06
		16	10	165.5	7.62	3.54E-04	1.93E-03	6.84E-07
		35	10	165.5	36.44	2.03E-04	5.63E-03	1.14E-06
		71	10	165.5	149.90	6.17E-05	1.75E-02	1.08E-06
		212	10	165.5	879.30	9.74E-05	7.22E-02	7.03E-06
		431.6	10	165.5	1285.00	1.82E-06	9.78E-02	1.78E-07
5	Pig Receiver	3	10	165.5	0.27	3.87E-03	1.25E-03	4.84E-06
		16	10	165.5	7.62	4.55E-04	1.93E-03	8.79E-07
		35	10	165.5	36.44	2.26E-04	5.63E-03	1.27E-06
		71	10	165.5	149.90	1.16E-04	1.75E-02	2.04E-06
		212	10	165.5	879.30	1.12E-04	7.22E-02	8.10E-06
		431.6	10	165.5	1285.00	6.55E-05	9.78E-02	6.40E-06
6	Kembla Grange MLV	3	10	165.5	0.27	8.88E-04	1.25E-03	1.11E-06
		16	10	165.5	7.62	9.18E-05	1.93E-03	1.77E-07
		35	10	165.5	36.44	4.98E-05	5.63E-03	2.80E-07
		71	10	165.5	149.90	9.89E-06	1.75E-02	1.73E-07
		150	10	165.5	648.10	1.89E-05	5.65E-02	1.07E-06
7	BOC Nitrogen Injection	3	10	165.5	0.27	9.69E-04	1.56E-03	1.51E-06
		16	10	165.5	7.62	1.01E-04	2.78E-02	2.79E-06
		35	10	165.5	36.44	5.32E-05	8.77E-02	4.67E-06
		71	10	165.5	149.90	2.02E-05	2.48E-01	5.00E-06
		212	10	165.5	1436.00	1.47E-05	6.00E-01	8.82E-06
		431.6	10	165.5	2502.00	4.85E-06	6.00E-01	2.91E-06

Pipeline:

No.		Hole Size (mm)	Temp	Pressure (barg)	Release Rate (kg/s)	Ignition Probability
1	NG Pipeline Segment 1.2	20	10	165.5	11.90	3.77E-02
		50	10	165.5	74.36	1.46E-01
		100	10	165.5	297.40	4.08E-01
		431.6	10	165.5	2483.00	1.00E+00
2	NG Pipeline Segment 2	20	10	165.5	11.90	3.77E-02
		50	10	165.5	74.36	1.46E-01
		100	10	165.5	297.40	4.08E-01
		431.6	10	165.5	2295.00	1.00E+00

Appendix C. Jet Fire & Flash Fire Impacts

Above Ground Facilities:

Section	Hole Size (mm)	Distance to LFL (m) Horizontal			Distance to LFL (m) Down			Impact Distance to 4.7 kW/m² (m) Horizontal			Impact Distance to 12.6 kW/m² (m) Horizontal			Impact Distance to 23 kW/m² (m) Horizontal		
		1/F	5/D	10/D	1/F	5/D	10/D	1/F	5/D	10/D	1/F	5/D	10/D	1/F	5/D	10/D
Kembla Grange - Above ground to SLV 064007, and pig trap isolation	3	n/a	n/a	n/a	n/a	n/a	n/a	12	9	9	10	7	7	9	7	6
	16	n/a	n/a	n/a	n/a	n/a	n/a	53	43	40	45	35	32	42	32	29
	35	n/a	n/a	n/a	48	43	52	108	87	82	91	70	65	83	63	58
	71	31	30	30	100	103	122	205	164	155	171	132	123	156	118	109
	212	113	111	116	247	285	317	521	500	482	384	378	385	329	321	342
	431.6	142	139	145	308	354	417	662	641	623	501	483	490	429	414	431
Kembla Grange - Metering to hot tap valve assembly	3	n/a	n/a	n/a	n/a	n/a	n/a	12	9	9	10	7	7	9	7	6
	16	n/a	n/a	n/a	n/a	n/a	n/a	53	43	40	45	35	32	42	32	29
	35	n/a	n/a	n/a	48	43	52	108	87	82	91	70	65	83	63	58
	71	31	30	30	100	103	122	205	164	155	171	132	123	156	118	109
	212	113	111	116	247	285	317	521	500	482	384	378	385	329	321	342
	431.6	142	139	145	308	354	417	662	641	623	501	483	490	429	414	431
Kembla Grange - Pig receiver	3	n/a	n/a	n/a	n/a	n/a	n/a	12	9	9	10	7	7	9	7	6
	16	n/a	n/a	n/a	n/a	n/a	n/a	53	43	40	45	35	32	42	32	29
	35	n/a	n/a	n/a	48	43	52	108	87	82	91	70	65	83	63	58
	71	31	30	30	100	103	122	205	164	155	171	132	123	156	118	109
	212	113	111	116	247	285	317	521	500	482	384	378	385	329	321	342
	431.6	142	139	145	308	354	417	662	641	623	501	483	490	429	414	431
MLV-1 Tie-in to Kembla Grange Meter Station	3	n/a	n/a	n/a	n/a	n/a	n/a	12	9	9	10	7	7	9	7	6
	16	n/a	n/a	n/a	n/a	n/a	n/a	53	43	40	45	35	32	42	32	29
	35	n/a	n/a	n/a	48	43	52	108	87	82	91	70	65	83	63	58
	71	31	30	30	100	103	122	205	164	155	171	132	123	156	118	109
	150	87	85	88	204	230	255	423	403	390	308	306	314	265	262	281
BOC Nitrogen Injection	3	n/a	n/a	n/a	n/a	n/a	n/a	12	9	9	10	7	7	9	7	6
	16	n/a	n/a	n/a	n/a	n/a	n/a	53	43	40	45	35	32	42	32	29
	35	n/a	n/a	n/a	48	43	52	108	87	82	91	70	65	83	63	58
	71	31	30	30	100	103	122	205	164	155	171	132	123	156	118	109
	212	114	112	116	247	286	318	523	502	484	385	379	387	330	322	344
	431.6	142	139	146	309	356	418	664	643	625	502	484	491	430	415	432

Pipeline:

Section	Hole Size (mm)	Distance to LFL (m) Angled			Distance to LFL (m) Vertical			Impact Distance to 4.7 kW/m² (m) Angled			Impact Distance to 12.6 kW/m² (m) Angled			Impact Distance to 23 kW/m² (m) Angled		
		1/F	5/D	10/D	1/F	5/D	10/D	1/F	5/D	10/D	1/F	5/D	10/D	1/F	5/D	10/D
NG Pipeline Segment 1.2	20	2.6	2.4	2.6	0.3	0.4	0.4	48	45	44	32	31	32	16	25	26
	50	3.1	2.7	2.8	0.4	0.5	0.6	113	104	100	76	70	70	41	57	55
	100	3.5	3.1	3.2	1.0	0.7	0.8	216	187	175	146	124	119	90	99	96
	431.6	n/a	5.1	5.2	n/a	2.0	2.0	572	509	480	363	347	328	n/a	259	255
NG Pipeline Segment 2	20	2.6	2.4	2.6	0.3	0.4	0.4	48	45	44	32	31	32	16	25	26
	50	3.1	2.7	2.8	0.4	0.5	0.6	113	104	100	76	70	70	41	57	55
	100	3.5	3.1	3.2	1.0	0.7	0.8	216	187	175	146	124	119	90	99	96
	431.6	n/a	5.1	5.2	n/a	2.0	2.0	571	508	478	362	346	327	n/a	259	254