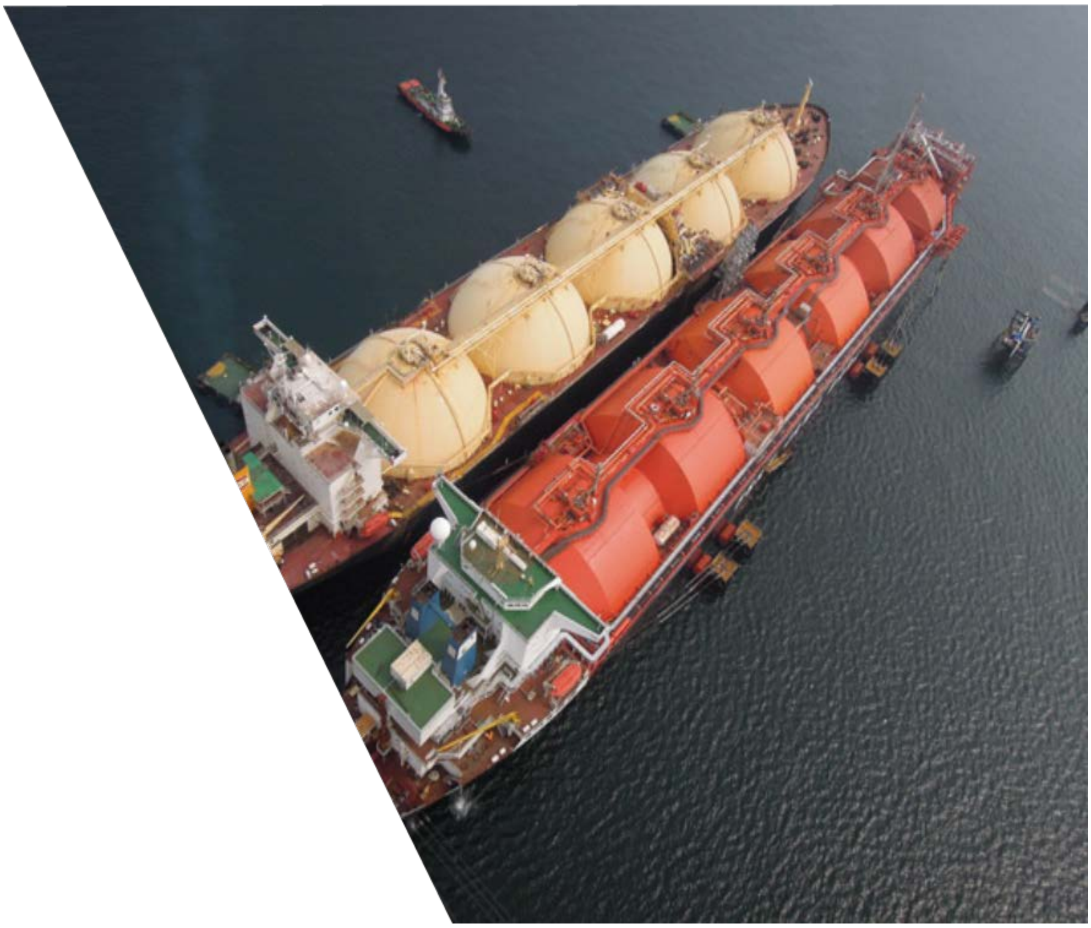
AUSTRALIAN INDUSTRIAL ENERGY

Port Kembla Gas Project

Preliminary Hazard Analysis Addendum



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PROJECT 401010-01496-SR-TEN-0002 – Port Kembla Gas Project

Rev	Description	Original	Review	WorleyParsons Approval	Date	Customer Approval	Date
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1. INTRODUCTION

1.1 Project Background

Australian Industrial Energy (AIE) proposes to develop the Port Kembla Gas Terminal (the project). The project involves the development of a liquefied natural gas (LNG) import terminal at Port Kembla, south of Wollongong in NSW. The project will be the first of its kind in NSW and provides a simple, flexible solution to the state's gas supply challenges.

NSW currently imports more than 95% of the natural gas it uses, with the majority of supplies coming from Victoria and South Australia. In recent years, gas supplies to the Australia east coast market have tightened, resulting in increased prices for both industrial and domestic users. Several recent economic studies have predicted significant future gas shortfalls for NSW by 2022.

The project provides an immediate solution to address predicted shortages and is expected to result in considerable economic benefits for both the Illawarra region and NSW.

The project will have capacity to deliver 100 petajoules of natural gas, equivalent to more than 70% of NSW's gas needs and provide between 10 to 12 days of natural gas storage in case of interstate supply disruption. LNG will be sourced from worldwide suppliers and transported by LNG Carriers (LNGCs) to the Floating Storage and Regasification Unit (FSRU) permanently moored at the Port Kembla Gas Terminal. LNGCs are expected to be required every two weeks for 24 to 36 hours to supply LNG. The LNG will then be re-gasified for input into the NSW gas transmission network.

Key objectives of the project are to:

- Introduce a new source of competitively priced gas to meet predicted supply shortfalls and help put downward pressure on prices
- Provide gas security to NSW with ability to supply more than 70% of the State's gas needs
- Provide long term contracts to industrial users and ability to meet 100% of the State's industrial demand (manufacturers, power stations, hospitals, small businesses etc.)
- Help support the 300,000 jobs across NSW, and the 15,000 jobs in the Illawarra region, which rely on the competitive, reliable supply of natural gas
- Support the diversification and future growth of Port Kembla consistent with the NSW Ports 30 Year Master Plan.

1.2 Objectives

The objectives of this addendum to the Preliminary Hazard Analysis (PHA) are to address the comments and queries resulting from the review of the PHA [3] by the NSW Department of Planning [9].

The key items that are addressed within this Addendum are:

- Multiple transfer hose failure during LNG loading from the LNGC to the FSRU (Section 2) [ID#14, 16 & 32 in Comment Response Sheet (CRS)];
- Multiple Marine Loading Arm (MLA) failure during Natural Gas (NG) unloading from the FSRU to shore (Section 2) [ID#14, 16, 24, 26 & 32 in CRS];
- Further detail on ship collision consequences and risk determination (Section 3) [ID#14, 19 & 33 in CRS];
- Further consideration of the impact of cargo machinery room consequences and assessment of glycol Loss of Containment (LOC) consequences (Section 4) [ID#13 & 31 in CRS];
- FSRU explosion events and potential impacts on LNGC unloading hoses or MLAs (Section 5) [ID#23 in CRS];
- Odorant LOC consequences with respect to public exposure (Section 6) [ID#10 & 35 in CRS];
- Further detail on the ignition probabilities used in the modelling (Section 7) [ID#28 in CRS];
- Further detail on the expected number of people accessing the peninsula along Seawall Road (Section 8) [ID#36, 37 & 41 in CRS];
- Specify the probability distribution for the 3 leak directions (Section 9) [ID#18 in CRS]; and
- Potential impacts from Dangerous Goods transferred at other berths (Section 9) [ID#40 in CRS].

1.3 Risk Criteria

Addressing a number of the items listed in the Objectives requires change to the risk model developed in the PHA. The impact of these items will be assessed by comparing the updated risk contours to those presented in the PHA and the Hazardous Industry Planning Advisory Paper (HIPAP) No 4 Risk Criteria for Land Use Planning [1]. These criteria are presented in Table 1-1 below.

Table 1-1: Fatality Risk Criteria

Risk (pa)	Land Use
5E-07	Sensitive land use; e.g. hospitals, schools, child-care facilities, old age housing
1E-06	Residential area; including hotels, motels, tourist resorts
5E-06	Commercial development; including retails centres, offices and entertainment centres
1E-05	Active open space; including sporting complexes
5E-05	Industrial

1.4 Acronyms

The abbreviations utilised in this project are listed below.

Abbreviation	Definition
AIE	Australian Industrial Energy
AIHA	American Industrial Hygiene Association

Abbreviation	Definition
CMPT	Centre for Marine and Petroleum Technology
CRS	Comments Response Sheet
DN	Nominal Diameter
EIS	Environmental Impact Statement
ERP	Emergency Response Planning
ERPG	Emergency Response Planning Guideline
FSRU	Floating Storage and Regasification Unit
HCRD	Hydrocarbon Release Database
HIPAP	Hazardous Industry Planning Advisory Paper
LFL	Lower Flammable Limit
LNG	Liquefied Natural Gas
LNGC	Liquefied Natural Gas Carrier
LOC	Loss of Containment
MLA	Marine Loading Arm
NG	Natural Gas
NSW	New South Wales
P&ID	Piping and Instrumentation Diagram
PHA	Preliminary Hazard Analysis
PKCT	Port Kembla Coal Terminal
QRA	Quantitative Risk Assessment
UKHSE	United Kingdom Health and Safety Executive
UKOOA	United Kingdom Offshore Operators Association

2. MULTIPLE HOSE AND MARINE LOADING ARM FAILURE

The PHA currently considers a leak or full bore failure of the hoses used to load LNG from the LNGC to the FSRU, and of the MLAs used to transfer the regasified LNG from the FSRU to the wharf.

The item raised was that the PHA does not consider failure or unintended decoupling of multiple transfer hoses or MLAs simultaneously, which could occur due to events such as adverse sea / weather conditions or mooring failure.

In this section the transfer hose and MLA models were reassessed to ensure all possible failure scenarios were adequately considered in the PHA.

2.1 Model Basis and Assumptions

- The transfer hose leaks were modelled at 14m elevation above the wharf to represent a leak from the hose connection on the FSRU / LNGC;
- The MLA leaks were modelled at 7m elevation above the wharf. This was to represent a leak point halfway between the FSRU MLA connection at 14m above grade and the wharf MLA connection at grade;
- There are 4 DN250 LNG transfer hoses and 2 DN250 vapour return hoses [10];
- The LNG transfer rate is 9000m^3/h [10] with a vapour return rate of 20m^3/h [11]. For the full bore failure of 1 LNG transfer hose the flow rate was limited to 2250m^3/h (9000m^3/h between 4 LNG hoses) and for the failure of all 6 hoses the flow rate was limited to 9020m^3/h.
- There are 2 MLAs between the FSRU and the wharf. For the full bore failure of the MLAs the maximum release rate per MLA was limited to half the NG production rate as per Section 6.4 of the PHA [3].
- The transfer hoses and MLAs were modelled as releases over water, this produces conservative consequence results for both releases;
- The LNG transfer conditions of -160°C and 240kPag were used for the hoses, while the NG conditions of 10°C and 12,000kPag were used for the MLAs;
- The transfer hoses were represented by 6 leak models: 10mm, 25mm, 50mm, 100mm, full bore rupture of 1 DN250 hose, and full bore rupture of all 6 DN250 hoses; and
- Each MLA was represented by 5 models per MLA: 10mm, 25mm, 50mm, 100mm, and full bore rupture.

The ignition probabilities were determined based on the release rate using the United Kingdom Offshore Operators Association (UKOOA) ignition correlations [4], with the probabilities split between immediate and delayed ignition based on Cox, Lees and Ang [5], as per Section 7.1 of the PHA [3]. The release rates and ignition probabilities are summarised in Table 2-1.

Table 2-1: Release Rates and Ignition Probabilities

Equipment	Leak Size	Release Rate (kg/s)	Immediate Ignition Probability	Delayed Ignition Probability
Hoses	10mm	0.7	0.002	0.0001
	25mm	4.5	0.010	0.001
	50mm	17.8	0.039	0.005
	100mm	71.4	0.125	0.054
	Full bore rupture of 1 DN250 hose	299	0.455	0.195
	Full bore rupture of 6 DN250 hoses	1198	0.455	0.195
MLA	10mm	2.1	0.005	0.001
	25mm	13.2	0.029	0.004
	50mm	52.8	0.092	0.040
	100mm	211	0.370	0.158
	Full bore rupture of 1 MLA	36.0	0.079	0.011

The leak frequencies for the transfer hose 10mm to 100mm leaks were retained from the PHA based on data from the United Kingdom Health and Safety Executive (UKHSE) Hydrocarbon Release Database (HCRD) [6]. Similarly, the MLA leak frequency data was also retained from the PHA based on data from the Purple Book [7].

For the full bore transfer hose failure another data set from the UKHSE was used [12] which specifies the failure rate when a certain number of hoses are used and the failure rate for simultaneous breaks. The leak frequencies used are summarised in Table 2-2.

Table 2-2: Leak Frequencies

Equipment	Leak Size	Leak Frequency (p.a.)
Hoses	10mm	1.04E-02
	25mm	1.20E-03
	50mm	1.99E-03
	100mm	0.00E+00
	Full bore rupture of 1 DN250 hose	2.50E-05
	Full bore rupture of 6 DN250 hoses	1.00E-07
MLA	10mm	3.33E-04
	25mm	2.00E-04
	50mm	6.67E-05
	100mm	4.50E-05

Equipment	Leak Size	Leak Frequency (p.a.)
	Full bore rupture of 1 MLA	1.50E-05

2.2 Model Results

The impact distance results calculated from the consequence modelling for the hoses and MLAs are included in Appendix A.

The risk contours generated by the transfer hoses and MLAs only are shown below in Figure 2-1.

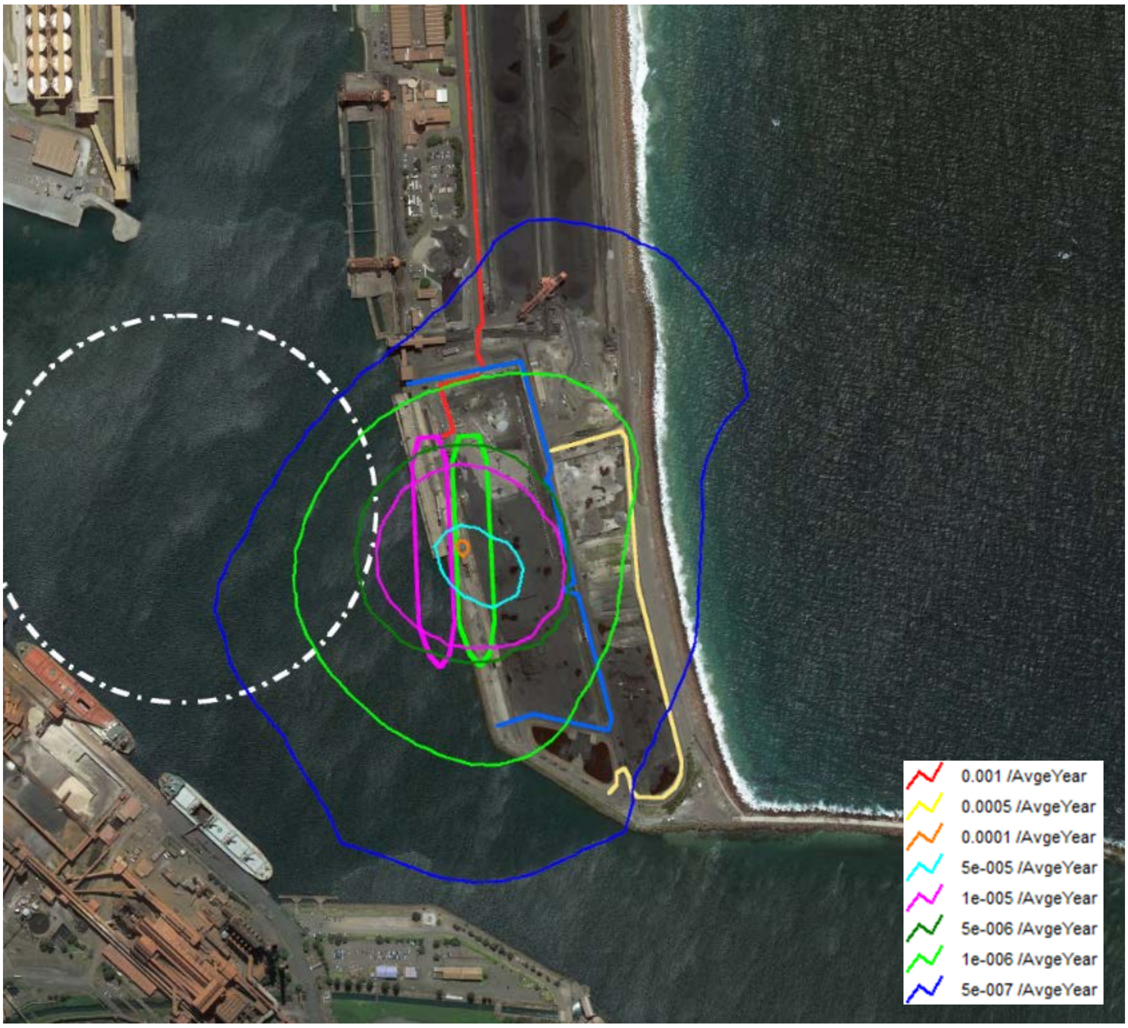

Figure 2-1: MLA and Transfer Hose Risk Contours

The overall risk contours updated to include the changes to the transfer hose and MLA models as described in this section are provided and discussed in Section 11.

3. SHIP COLLISION AND GROUNDING

The PHA considered ship collision using the calculation method specified in the CMPT (A Guide to QRA for Offshore Installations) [8]. It was recommended to review this calculation using a method aimed more specifically at collisions in a port area.

Hence the ship to ship / ship to land hull rupture calculation method described in the technical paper "A Quantitative Risk Analysis Approach to Port Hydrocarbon Logistics" [13] was used to reassess the hull rupture event frequency for the FSRU and LNGC.

3.1 Calculation Method

The event frequency (f_b) of a major spill from the stationary FSRU or LNGC due to a ship collision was calculated using the following equation:

$$f_b = F_b \times T \times \Delta t \times p_M$$

The equation parameters, inputs and results are described in the following table:

Table 3-1: Ship Collision while Stationary

Parameter	Definition	FSRU Value	LNGC Value
F_b	Frequency of a ship collision with stationed FSRU / LNGC	4.00E-06 p.a. per ship [13]	
T	Shipping traffic near berth	1190 ships [3]	
Δt	Duration of exposure to collision	0.93	0.07
p_M	Probability of major spill	1.50E-03 p.a. [13]	
f_b	Calculated Event frequency	6.63E-06 p.a.	5.09E-07 p.a.

The calculated event frequency of a ship collision is less than was used in the PHA.

In addition to a collision while the FSRU and / or LNGC is berthed, the technical paper [13] allows for the calculation of the event frequency (f_{cdf}) of a major spill due to a ship collision or grounding while the LNGC is entering or existing the harbour using the following equation:

$$f_{cdf} = (F_c + F_d + F_f) \times T \times p_M$$

The equation parameters, inputs and results are described in the following table:

Table 3-2: Ship Collision while in Transit

Parameter	Definition	FSRU Value
F_c	Frequency of LNGC collision with land	1.50E-04 p.a. per visit [13]
F_d	Frequency of LNGC grounding	3.00E-05 p.a. per visit [13]
F_f	Frequency of LNGC collision with moored ship	5.00E-05 p.a. per visit [13]

Parameter	Definition	FSRU Value
T	Number of LNGC visits	26 [3]
p_M	Probability of major spill	1.50E-03 p.a. [13]
f_{cdf}	Calculated Event frequency	8.97E-06 p.a.

The PHA risk model was updated with the new ship collision frequencies for when the FSRU and LNGC are stationary, and a model was added for the possible ship collision or grounding of the LNGC while it enters or exits the harbour. The latter was modelled by adding a route model to represent the LNGC as it enters and exits the harbour to the risk model with the calculated event frequency.

All other model inputs were maintained from the method used to model the ship collision as outlined in the PHA.

3.2 Model Results

The consequence modelling results generated in PHAST for a LNG tank rupture are provided in Appendix B.

The risk contours generated by the LNGC ship collision or grounding event while moving through the harbour are shown below in Figure 3-1.

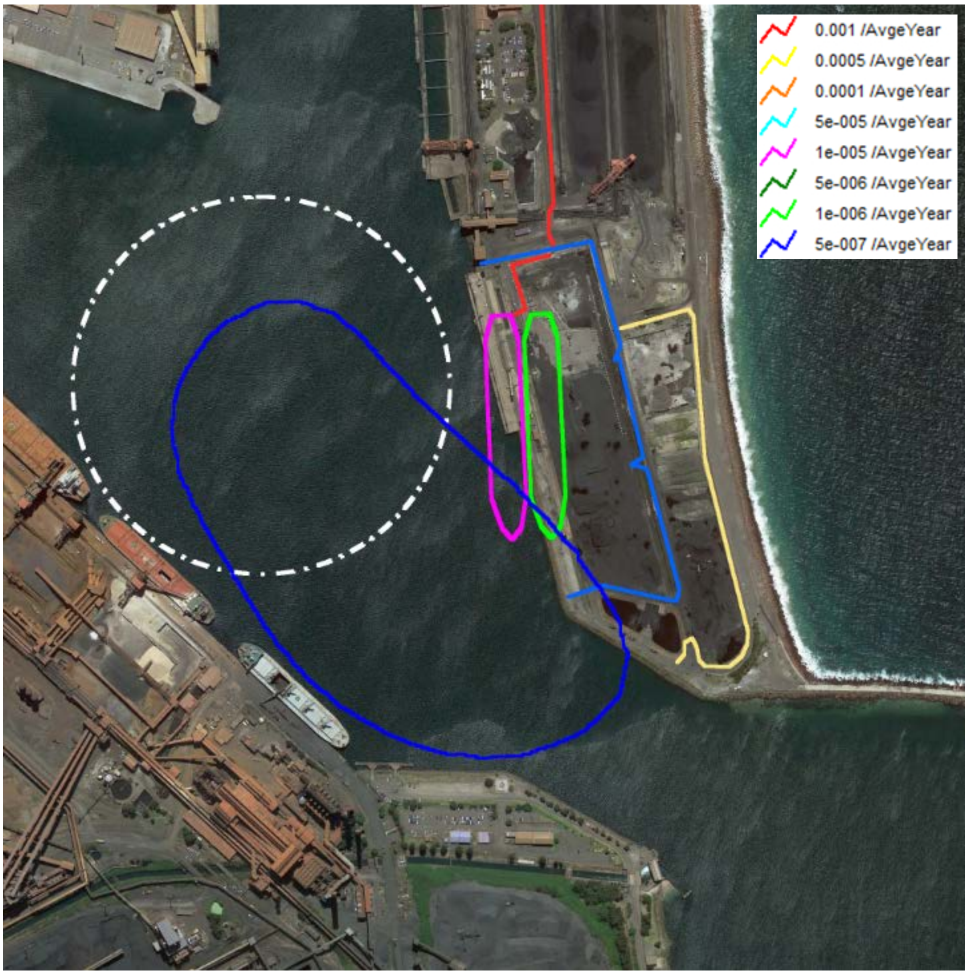

Figure 3-1: Ship Collision while in Transit Risk Contour

Figure 3-1 shows that the highest risk contour generated is 5E-07. This indicates that this model will not contribute significantly to the overall risk contours.

The overall risk contours updated to include ship collision while stationary and in transit as outlined in this section are provided and discussed in Section 11.

4. CARGO MACHINERY ROOM GLYCOL CONSEQUENCES

It was identified that glycol is used in both the regasification unit and the cargo machinery room. While the glycol used as the intermediate heating loop for regasification is heated by seawater, the hot glycol water heating system used to maintain the temperature within the cofferdams is heated by steam from the engine room. The steam pressure and temperature could be as high as 8 barg at 170°C, which could exceed the glycol flash point depending on the type of glycol used.

4.1 Model Basis and Assumptions

As details of glycol heating system are limited, the glycol was assumed to be at 170°C and a pressure of 500kPag for modelling purposes.

Glycol leaks were modelled in all 3 directions (horizontal, vertical up and vertical down) for the 4 leaks sizes (10mm, 25mm, 50mm and 100mm). No full bore rupture was modelled as the size of the glycol system is not known.

4.2 Consequence Modelling Results

The PHAST pool fire modelling results are provided in Appendix C.

It is expected that the glycol spill and subsequent pool fire will be contained within the machinery room and the impacts will be localised as this room is steel frame and plate construction.

The glycol heating system design is currently not known as no detailed P&IDs are available, but it is expected that it will be a small system with minimal potential leak sources and subsequently a low leak frequency. As such it is not expected to contribute significantly to the overall risk contours and offsite risk.

The overall risk model was updated so that the cargo machinery room jet fires and flash fires and the risk associated with these scenarios contribute towards the overall risk contours. The updated overall risk contours are presented and discussed in Section 11.

5. FSRU EXPLOSION ESCALATION EVENTS

The CRS raised an observation regarding the potential for incident escalation due to an explosion on the LNGC or FSRU, in particular with regards to the MLA or transfer hoses being disconnected due to the explosion overpressure.

This section considers the impact distance of overpressure levels of 35kPa which, according to HIPAP No. 4 [1], can lead to overturned plant items and is therefore considered to cause enough damage to potentially lead to further escalation.

Table 5-1 presents the 35kPa impact distances for the explosion sources identified on the FSRU. These impact distances are assumed to be similar for the LNGC where the same type of explosion source is present (i.e. the cargo tanks and cargo machinery room).

Table 5-1: 35kPa Impact Distances

Explosion Source	35kPa Impact Distance (m)
Cargo Tank Top Module	12.7
Cargo Machinery Room	50.7
Suction Drum Module	20.1
Regasification Module	42.9

Figure 5-1 presents the 35kPa impact zone from all identified explosion sources on the FSRU.

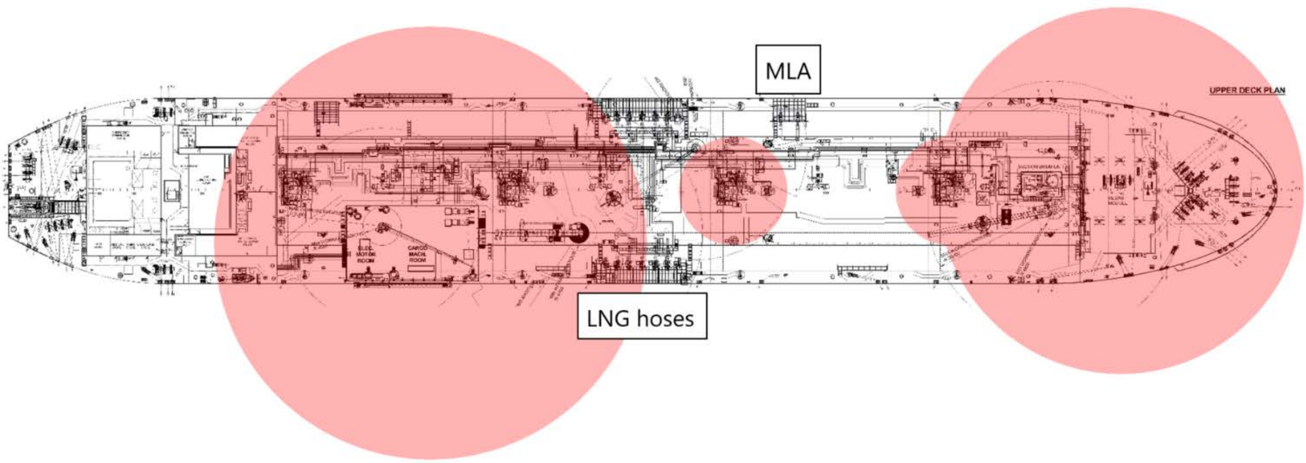

Figure 5-1: 35kPa FSRU Impact Zones

Based on the consequence modelling, an explosion from within the cargo machinery room could potentially impact the LNG hoses on the starboard side with 35 kPa overpressure, however the MLAs are not impacted by 35 kPa overpressure from any of the identified explosion sources. Whilst the likelihood of damage to the transfer hoses themselves is low this level of overpressure could cause damage to the connection points. The failure all LNG transfer hoses has been included in the PHA risk model as per Section 2.

For a confined explosion such as the cargo machinery room, the main mechanism of pressure build-up is the expansion of the gas as it burns and exceeds the vent capacity of the space. It is expected that the overpressure generated within the room would be high and would damage the internal equipment and / or structures. However, as the room fails, the overpressure would rapidly decline as there is not sufficient congestion outside the room for a secondary explosion to generate a high turbulent flame with increasing burning velocity and generate overpressure.

The consequence and risk modelling software PHAST-Risk is limited to simplified empirical models such as TNT, TNO Multi-Energy and Baker-Strehlow explosion models, which provide conservative explosion overpressure results as the model takes no account for how the room will fail and the associated reduction in impact distance as overpressure is vented from the room weak points such as ventilation intakes and exhausts and doors or windows. In addition, the explosion overpressure modelled is based on the worst case scenario where the entire cargo machinery room is completely filled with a stoichiometric mix of air and fuel prior to ignition.

6. ODORANT

The CRS raised the recommendation to assess whether a spill of the odorant used on the wharf facility could impact the public. In response the risk of acute toxic injury and risk from exposure to a potential odorant release was analysed and assessed against the toxic exposure criteria specified in HIPAP No. 4 [1] which are:

1. Toxic concentrations in residential and sensitive use areas should not cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community over a maximum frequency of 50 in a million per year.
2. Toxic concentrations in residential and sensitive use areas should not exceed a level which would be seriously injurious to sensitive members of the community following a relatively short period of exposure at a maximum frequency of 10 in a million per year.

The odorant concentrations at which most people will begin to experience health effects if they are exposed for an hour are based on the Emergency Response Planning Guidelines (ERPGs) developed by the AIHA ERP Committee [14]. The guidelines are developed to protect the general public (and workers) from the consequences of accidental chemical releases.

The ERPGs are defined as follows:

- ERPG-1: The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects or without perceiving a clearly defined objectionable odour.
- ERPG-2: The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.
- ERPG-3: The maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

For the assessment of odorant toxic impact, the ERPG-2 for the odorant was assessed against HIPAP No. 4 toxic criteria 1 and ERPG-3 against toxic criteria 2 as described above.

6.1 Model Basis and Assumptions

The odorant for the project will be a mercaptan type. In order to understand the effects of odorant Loss of Containment (LOC), methyl mercaptan has been selected as the representative odorant compound. The ERPG-2 and ERPG-3 for methyl mercaptan are defined as 25 ppm and 100 ppm, respectively [14].

Consequence modelling has been conducted for the odorant storage tanks using PHAST with the following inputs:

- Leak: 10, 25 and 50mm (Note: 50mm leak is considered to be the maximum piping bore within the odorant injection system);

- Inventory size: 200 kg;
- Storage pressure: 2 barg;
- Storage temperature: Ambient (i.e. 25 °C);
- Leak elevation: 1 m;
- Leak orientation: horizontal, vertical up and vertical down; and
- Measurement height: 1 m above grade.

Other consequence modelling parameters in PHAST are as per the PHA.

6.2 Consequence Modelling Results

The detailed toxic impact distances are summarised in Table 6-1.

Table 6-1: Toxic Release Results

Weather	ERPG-2 (25ppm) Impact Distance (m) at Grade			ERPG-3 (100ppm) Impact Distance (m) at Grade		
	10mm	25mm	50mm	10mm	25mm	50mm
	Horizontal					
Calm	1021	898	825	476	387	365
Average	411	714	702	197	393	403
Windy	304	707	800	142	363	482
	Vertical (Up)					
Calm	1119	714	Not reached	471	273	326
Average	387	843	871	155	426	470
Windy	281	732	852	116	313	457
	Vertical (Down)					
Calm	1112	1063	1040	541	509	483
Average	368	542	515	177	284	285
Windy	302	599	605	147	320	355

The results indicate that the furthest impact distance of methyl mercaptan at the ERPG-2 level of 25ppm from a 10 – 50mm leak is 1119m, while the furthest impact distance at the ERPG-3 level of 100ppm is 541m.

Figure 6-1 shows the distance from the wharf facility to the nearby residential areas.

Figure 6-1: Neighbouring Residential Areas

The closest residential area is 2.18km south of Berth 101, which is sufficiently far from the odorant injection system to not be impacted by the ERPG-2 (25ppm) and ERPG-3 (100ppm) levels for methyl mercaptan. As such the HIPAP No. 4 toxic exposure criteria are met.

7. IGNITION PROBABILITIES

The CRS requested the total ignition probability for each release case be presented.

Ignition probabilities are determined based on the UKOOA ignition correlations [4], with the probabilities split between immediate and delayed ignition based on Cox, Lees and Ang [5], as per Section 7.1 of the PHA [3]. As such there is a different immediate and delayed ignition probability for each leak size modelled for each scenario. A summary of the ignition probabilities used in the model has been provided in Appendix D.

8. SEAWALL ROAD

The PHA risk contours showed that the 1E-05 risk contour for active open space extended beyond the wharf fence line and across the Seawall Road to the shore. The Seawall Road is a private road with a security gate and is controlled by the Port Kembla Coal Terminal (PKCT).

The following statement was provided by the NSW Ports:

"Seawall Road is a private road which runs along the eastern side of the site which is opened to the public during daylight hours, unless closure is required for operational purposes. Operational purposes can include things like weather events, haulage of bulk products, construction/maintenance works and/or other operational requirements. It has security in the form of security fencing and lockable gates which enables the road to be closed when required.

It is not uncommon for the road to be closed 6 – 10 times a year for operational purposes.

The road tends to be used by surfers, rock fishers and occasional on-lookers for unusual events, such as the arrival of a large cruise ship. However, numbers of users are in the dozens, not the 100's, with the largest crowds seen there for the arrival of the Port's first cruise ship. Subsequent cruise ship arrivals have seen the crowd numbers dwindle.

There are a number of vantage points available to the community for viewing ship arrivals other than the Seawall Road area adjacent to the Berth 101 site. These include the Wollongong Head Lighthouse lookout to the north of the site and the Port Kembla Heritage Park to the south of the site.

The Port typically receives 2 – 3 cruise ships a year (6 ship movements). The length of time these ships would take to pass through 'the cut' and past Berth 101 would typically take about 30 – 40 minutes. In total it takes less than 1 hour to pass completely into or out of the Port.

As such, if required for the abundance of safety, it would be feasible to close Seawall Road for the entry and exit of cruise ships either for the brief periods of time they are passing Berth 101 or for a longer period of time."

9. LEAK DIRECTION

As specified in Section 6.3 of the PHA [3] three different release orientations were modelled and the applied directional probabilities are as follows:

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

The exceptions to this are a leak due to a ship collision, which is all assumed to be in a horizontal direction, and a leak from the pipeline, which is as follows:

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

10. DANGEROUS GOODS

Dangerous goods (including class 1 explosives) are transferred at other berths in the inner harbour. The potential for propagation from these hazards could not be assessed within the PHA as the propagation risk information was not available.

In order for the potential impacts from these dangerous goods on the FSRU and wharf to be assessed further information would need to be provided by the other berths including:

- The chemical name of the class 1 explosive(s);
- The mass of each shipment;
- The frequency of vessel movements per year;
- The duration that the vessel is in port; and
- The berths which receive or load out class 1 explosives.

This information has been requested from the Port Kembla Harbour Master and once received an assessment of the potential impacts can be completed.

11. RISK RESULTS

As part of this report the following updates were made to the PHA risk model:

- Addition of multiple transfer hose failure (Section 2);
- Addition of multiple MLA failure (Section 2);
- Update of ship collision frequency when stationary using new calculation method (Section 3);
- Addition of ship collision / grounding while entering / exiting the harbour (Section 3); and
- Update of cargo machinery room to allow risks from LNG jet fires, flash fires, etc. to reach beyond the room (Section 4).

Figure 11-1 and Figure 11-2 show the risk contours generated with the changes above implemented into the PHA risk model.

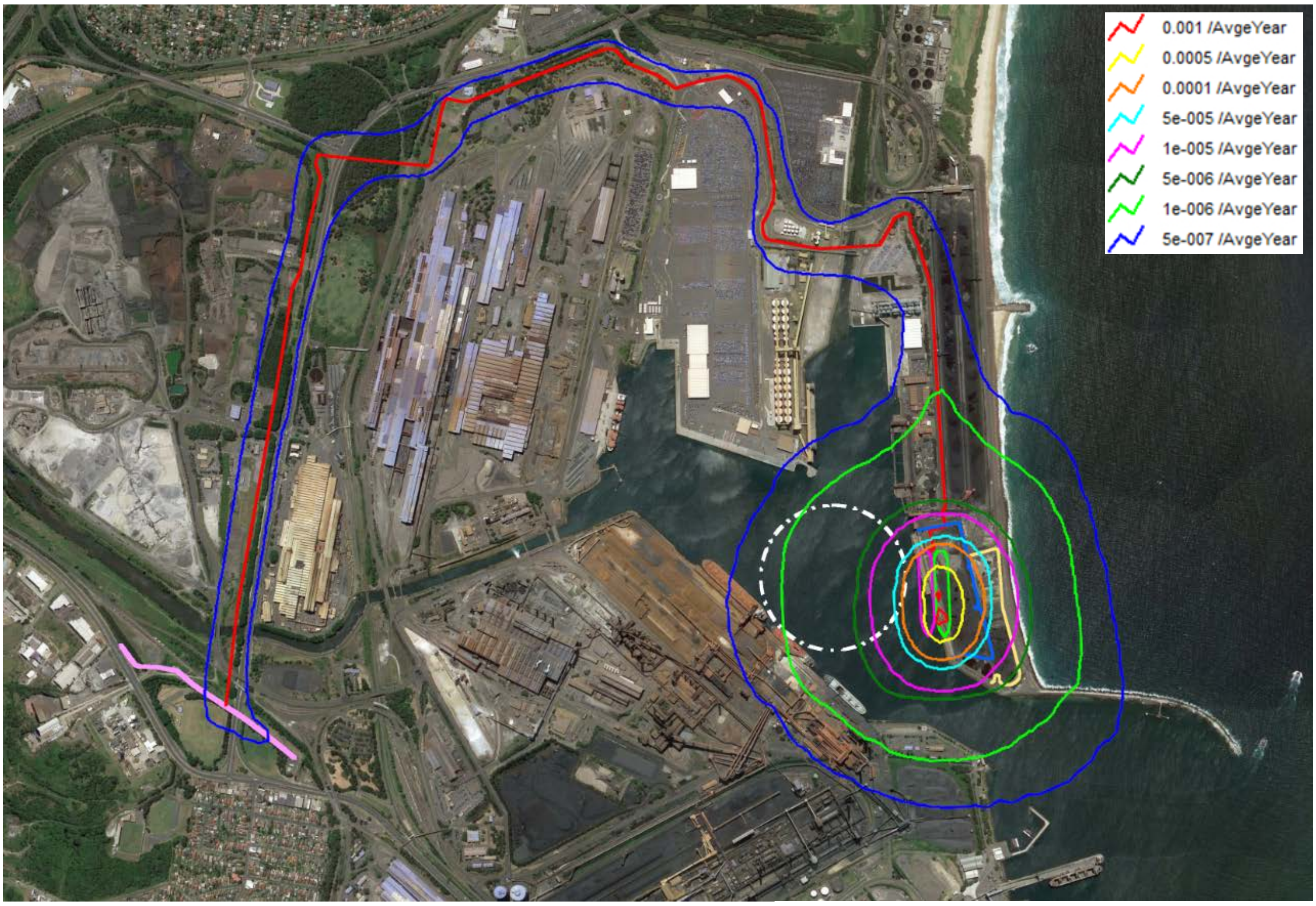

Figure 11-1: Overall Risk Contours (Updated Version)

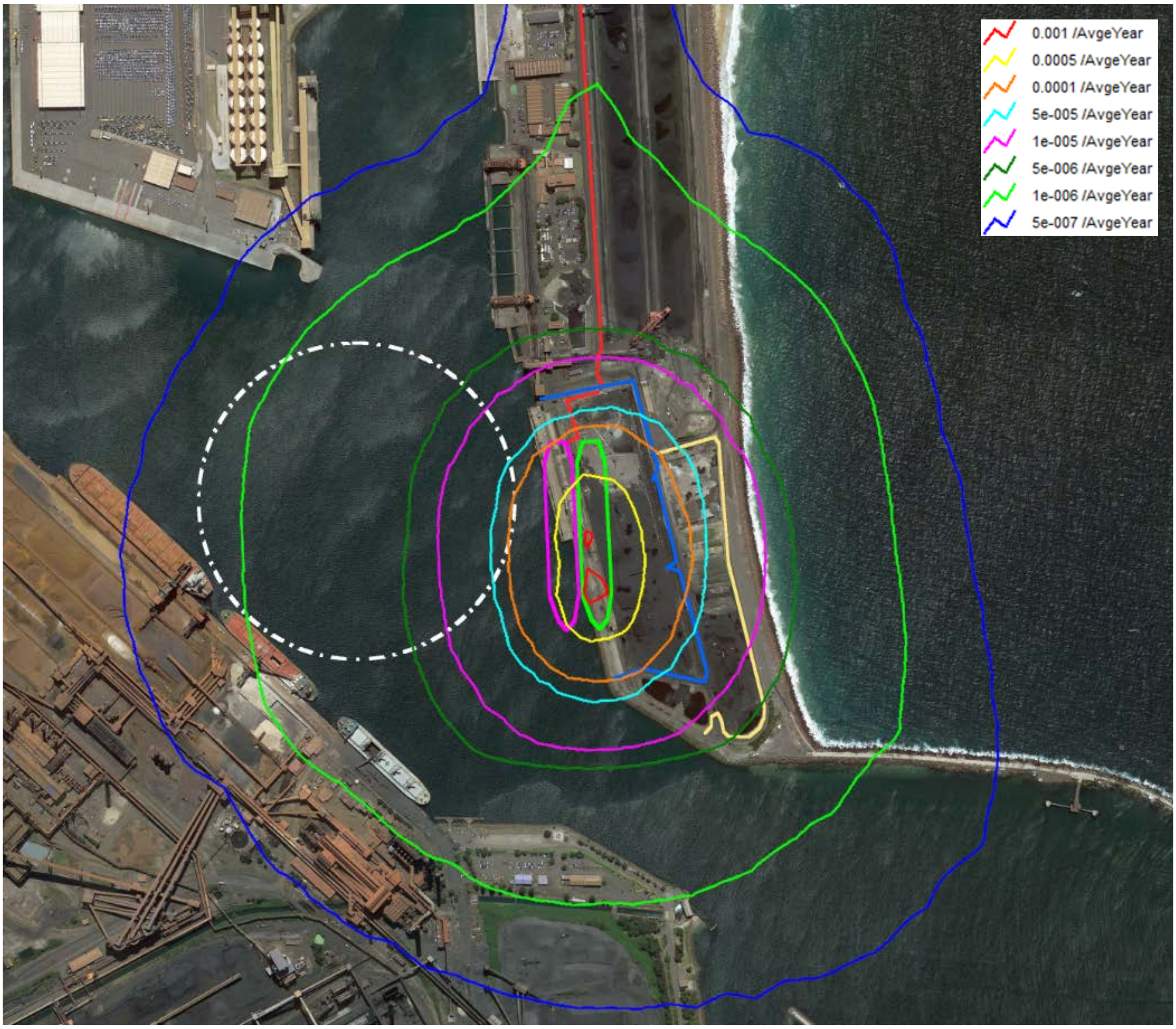

Figure 11-2: Berth Risk Contours (Updated Version)

Figure 11-3 shows the individual fatality risk contours generated from the original PHA modelling conducted.

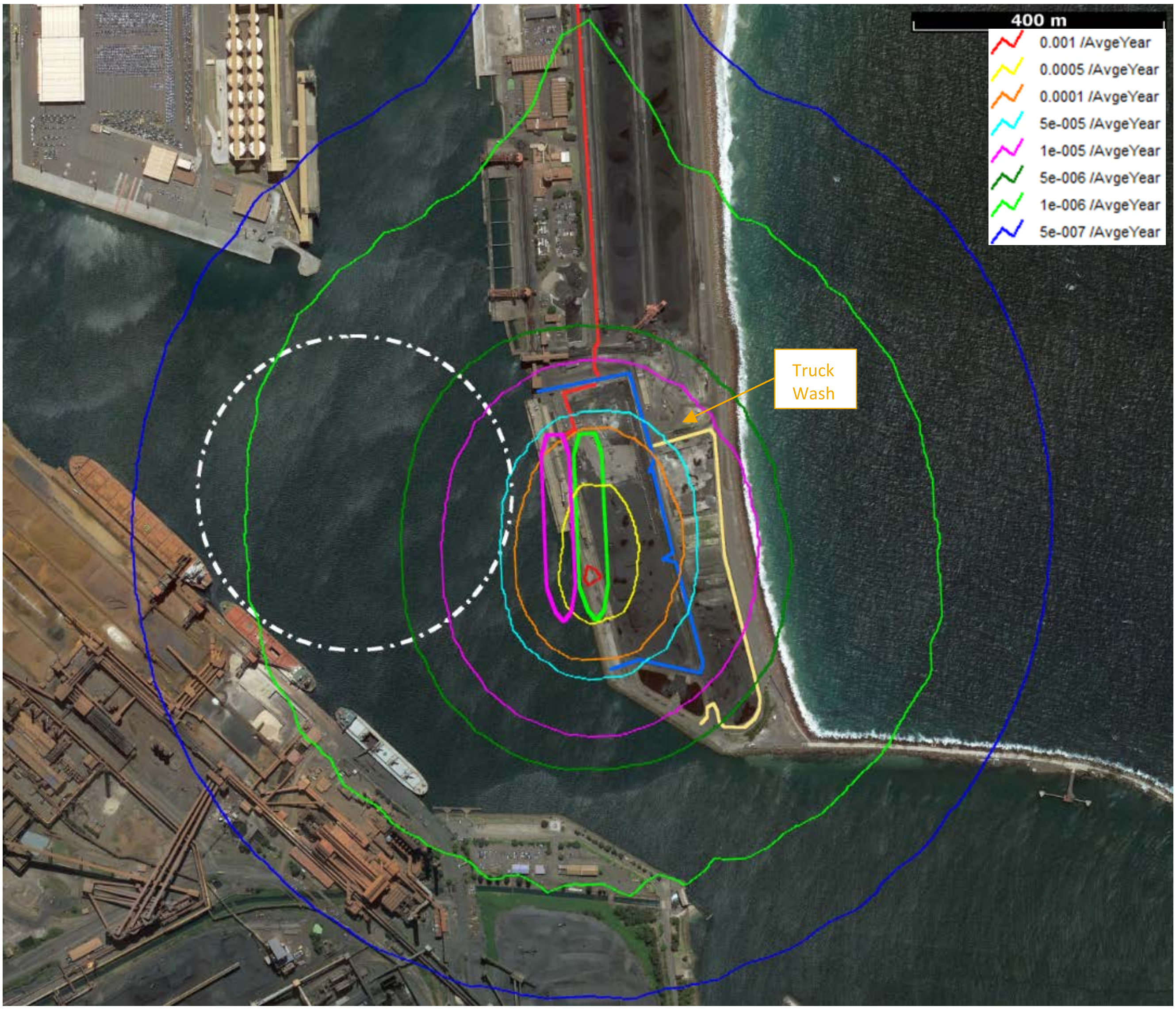

Figure 11-3: Berth Risk Contours (PHA Version)

A comparison of the two sets of risk contours shows there is negligible difference between them. The transfer hoses have generated another 0.001 risk contour on the FSRU, and the LNGC route and multiple MLA failures have changed the shape of the outer contours. The LNGC route has extended the 1E-06 and 5E-07 contours along the ship route through the harbour, while remodelling the two MLAs as 2 separate models rather than 1 has flattened those same contours along the eastern side.

12. REFERENCES

1. Hazardous Industry Planning Advisory Paper No 4 – Risk Criteria for Land Use Safety Planning, January 2011
2. Hazardous Industry Planning Advisory Paper No 6 – Hazard Analysis, January 2011
3. Port Kembla Gas Project Preliminary Hazard Analysis, 401010-01496-SR-REP-0002 Rev 00
4. IP Research Report, Ignition Probability Review, Model Development Lookup Correlations, January 2006
5. A.W. Cox, F.P. Lees and M.L. Ang, Classification of Hazardous Locations, IChemE, 1990
6. UK HSE, Offshore Hydrocarbon Release Statistics, 1999, Offshore Technology Report OTO 1999 079
7. Guideline for Quantitative Risk Assessment (Purple Book), TNO, CPR 18E, December 2005
8. A Guide to Quantitative Risk Assessment for Offshore Installation, The Centre for Marine and Petroleum Technology (CMPT), 1999
9. Port Kembla Gas Terminal – Review of Hazard and Risk Assessment in EIS – Comment Response Sheet (CRS) No. 1, Revision 2, February 2019
10. Port Kembla FSRU – STS LNG Transfer – Technical Memo, O.J. Nedrelid, December 2018
11. M. Kulitsa and D.A. Wood, LNG Cargo Handling – Conclusion: Tandem Pressures between Ships During STS Transfers Cuts Gas Losses, Oil & Gas Journal, April 2017
12. Failure Rate and Event Data for use within Risk Assessments, UK HSE, June 2012
13. A. Ronza, S. Carol, V. Espejo, J.A. Vilchez and J. Arnaldos, A Quantitative Risk Analysis Approach to Port Hydrocarbon Logistics, Journal of Hazardous Materials, January 2006
14. Emergency Response Planning Guidelines (ERPGs), AIHA, 2013

Appendix A. Transfer Hoses and MLAs Consequence Modelling

Flammable Cloud / Flash Fire Results

Table 1. Dispersion Results – Transfer Hoses

Leak Size	10mm			25mm			50mm			100mm			FB (1 Hose)			FB (6 Hoses)		
Initial Leak Rate (kg/s)	0.71			4.46			17.8			71.4			299 (Limited to transfer rate)			1198 (Limited to transfer rate)		
Weather	Flammable Mass in Cloud (kg)	Time to Steady State (s)	LFL Downwind Impact Distance (m)	Flammable Mass in Cloud (kg)	Time to Steady State (s)	LFL Downwind Impact Distance (m)	Flammable Mass in Cloud (kg)	Time to Steady State (s)	LFL Downwind Impact Distance (m)	Flammable Mass in Cloud (kg)	Time to Steady State (s)	LFL Downwind Impact Distance (m)	Flammable Mass in Cloud (kg)	Time to Steady State (s)	LFL Downwind Impact Distance (m)	Flammable Mass in Cloud (kg)	Time to Steady State (s)	LFL Downwind Impact Distance (m)
	Vertical (Down)																	
Calm	0.83	3.84	8.97	66.34	44.10	59.68	797.52	128.63	142.21	8432	345.52	321.90	76943	656.57	431.49	494227	1581.74	1494.87
Average	0.54	2.30	13.12	5.25	3.67	20.61	153.26	34.73	169.65	2699	94.04	463.65	27133	79.21	971.46	101948	230.90	960.54
Windy	0.46	1.87	18.17	4.58	3.04	29.17	25.65	4.29	40.03	1031	35.47	314.45	9989	3.18	707.33	68681	150.35	1306.58

Table 2. Dispersion Results – MLAs

Leak Size	10mm			25mm			50mm			100mm			FB (1 MLA)		
Initial Leak Rate (kg/s)	2.11			13.2			52.8			211			36 (Limited to production rate)		
Weather	Flammable Mass in Cloud (kg)	Time to Steady State (s)	LFL Downwind Impact Distance (m)	Flammable Mass in Cloud (kg)	Time to Steady State (s)	LFL Downwind Impact Distance (m)	Flammable Mass in Cloud (kg)	Time to Steady State (s)	LFL Downwind Impact Distance (m)	Flammable Mass in Cloud (kg)	Time to Steady State (s)	LFL Downwind Impact Distance (m)	Flammable Mass in Cloud (kg)	Time to Steady State (s)	LFL Downwind Impact Distance (m)
	Vertical (Down)														
Calm	4.27	5.74	28.95	70.93	15.62	74.38	684.16	36.66	168.19	5452	73.70	354.11	193.71	14.45	95.85
Average	2.37	2.91	28.51	31.63	5.98	60.53	277.07	14.64	136.95	3654	42.55	377.98	109.27	7.76	87.13
Windy	1.60	1.88	28.31	20.92	3.85	59.16	147.72	6.88	106.27	2020	24.74	343.34	73.01	5.04	83.53

Jet Fire Results

Table 3. Jet Fire Results – Transfer Hoses

Leak size	10mm					25mm					50mm					100mm					FB (1 Hose)					FB (6 Hoses)				
Initial Leak Rate, kg/s	0.71					4.46					17.8					71.4					299 (Limited to transfer rate)					1198 (Limited to transfer rate)				
Weather	Flame Length (m)	Rad. Impact Dist. (m) at EL +14 m				Flame Length (m)	Rad. Impact Dist. (m) at EL +14 m				Flame Length (m)	Rad. Impact Dist. (m) at EL +14 m				Flame Length (m)	Rad. Impact Dist. (m) at EL +14 m				Flame Length (m)	Rad. Impact Dist. (m) at EL +14 m				Flame Length (m)	Rad. Impact Dist. (m) at EL +14 m			
		4.73 kW/m²	12.5 kW/m²	23 kW/m²	35 kW/m²		4.73 kW/m²	12.5 kW/m²	23 kW/m²	35 kW/m²		4.73 kW/m²	12.5 kW/m²	23 kW/m²	35 kW/m²		4.73 kW/m²	12.5 kW/m²	23 kW/m²	35 kW/m²		4.73 kW/m²	12.5 kW/m²	23 kW/m²	35 kW/m²		4.73 kW/m²	12.5 kW/m²	23 kW/m²	35 kW/m²
	Vertical (Down)																													
Calm	19.42	14.61	12.49	11.42	10.56	41.80	32.49	27.33	24.95	23.31	74.45	60.23	50.12	45.43	42.54	129.6	109.2	90.13	81.53	76.22	162.6	140.4	114.9	103.3	95.98	222.9	199.0	161.3	144.0	133.0
Average	13.05	11.71	9.67	8.74	8.15	28.09	27.62	21.42	19.03	17.68	50.03	53.50	39.75	35.20	32.50	88.93	103.1	73.70	65.00	59.93	164.7	205.1	141.4	124.4	114.6	226.3	290.6	195.7	172.4	159.0
Windy	11.65	11.25	8.97	8.12	7.60	25.09	26.82	19.66	17.55	16.39	44.69	51.60	36.40	32.28	29.89	79.43	99.31	67.31	59.47	54.95	147.1	196.9	127.5	112.6	104.2	265.2	378.0	242.4	207.6	192.1

Table 4. Jet Fire Results – MLAs

Leak size	10mm					25mm					50mm					100mm					FB (1 MLA)				
Initial Leak Rate, kg/s	2.11					13.2					52.8					211					36 (Limited to production rate)				
		Rad. Impact Dist. (m) at EL +7 m					Rad. Impact Dist. (m) at EL +7 m					Rad. Impact Dist. (m) at EL +7 m					Rad. Impact Dist. (m) at EL +7 m					Rad. Impact Dist. (m) at EL +7 m			
Weather	Flame Length (m)	4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2	Flame Length (m)	4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2	Flame Length (m)	4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2	Flame Length (m)	4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2	Flame Length (m)	4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2
	Vertical (Down)																								
Calm	17.41	16.30	9.70	7.78	7.10	34.73	45.07	26.87	18.53	15.53	60.41	89.17	53.58	37.48	29.32	110.3	172.0	103.7	72.84	56.74	51.74	71.44	43.10	30.42	23.80
Average	20.72	15.29	11.09	9.97	9.06	40.35	42.83	25.51	21.53	19.46	67.96	85.77	52.09	39.07	34.63	119.8	165.7	102.0	73.96	63.89	58.57	68.25	41.31	31.44	27.63
Windy	23.72	13.66	12.19	11.56	11.29	49.14	37.66	26.93	25.03	23.96	82.22	81.31	49.36	44.71	42.10	143.3	158.2	96.03	82.65	76.66	68.72	65.18	39.68	35.74	33.50

Pool Fire Results

Table 5. Pool Fire Results – Transfer Hoses

Leak size	10mm					25mm					50mm					100mm					FB (1 Hose)					FB (6 Hoses)				
Initial Leak Rate, kg/s	0.71					4.46					17.8					71.4					299 (Limited to transfer rate)					1198 (Limited to transfer rate)				
		Rad. Impact Dist. (m)					Rad. Impact Dist. (m)					Rad. Impact Dist. (m)					Rad. Impact Dist. (m)					Rad. Impact Dist. (m)					Rad. Impact Dist. (m)			
Weather	Pool Diameter (m)	4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2	Pool Diameter (m)	4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2	Pool Diameter (m)	4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2	Pool Diameter (m)	4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2	Pool Diameter (m)	4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2	Pool Diameter (m)	4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2
	Vertical (Down)																													
Calm	Pool fire not formed					Pool fire not formed					7.16	39.36	28.26	23.84	21.52	25.51	122.9	84.72	68.24	58.67	59.11	229.3	151.9	117.7	97.64	122.4	401.9	262.4	200.2	163.5
Average											Pool fire not formed					Pool fire not formed					48.59	198.8	140.8	115.2	102.0	115.1	382.2	263.4	213.7	183.8
Windy																					17.98	90.00	69.99	62.60	58.96	99.73	334.3	242.1	199.0	177.2

Appendix B. Ship Collision Tank Rupture Consequence Modelling

Table 6. LNG Tank Rupture Results

FSRU / LNGC Cargo Tank Puncture													
Release from	1 m² puncture on the side of FSRU / LNGC cargo tank					Initial Rate: 4,747 kg/s		Fluid: Rich LNG		Press: 0 barg		Temp: -160 °C	
Effects	LFL Gas Cloud / Flash Fire			Jet Fire					Pool Fire				
Weather	Flammable Mass in Cloud (kg)	Time to Steady State (s)	LFL Impact Distance (m)	Flame Length (m)	Rad. Impact Dist. (m) at EL +1.5 m above Deck 4.7 kW/m²	12.6 kW/m²	23.0 kW/m²	35.0 kW/m²	Pool Diameter (m)	Rad. Impact Dist. (m) at EL +1.5 m above Deck 4.7 kW/m²	12.6 kW/m²	23.0 kW/m²	35.0 kW/m²
Horizontal at 1.5 m above Water													
Calm	2,430,091	1,835	1,500	338	589	486	438	410	246	713	468	356	287
Average	683,672	821	1,635	252	520	416	371	345	244	703	488	393	332
Windy	210,112	141	1,186	253	538	430	384	357	242	678	486	401	349
Horizontal at 14 m above Water													
Calm	2,430,091	1,835	1,255	338	589	485	438	410	246	715	473	364	299
Average	683,672	821	NR	252	520	416	371	345	244	702	488	397	339
Windy	210,112	141	NR	253	538	430	384	357	242	676	487	403	354

Note: NR = Not Reached

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Appendix C. Glycol Pool Fire Consequence Modelling

Table 7. Pool Fire Results – Glycol

Leak size	10mm					25mm					50mm					100mm				
Initial Leak Rate, kg/s	1.70					10.65					42.61					170.43				
Weather	Pool Diameter (m)	Rad. Impact Dist. (m) 4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2	Pool Diameter (m)	Rad. Impact Dist. (m) 4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2	Pool Diameter (m)	Rad. Impact Dist. (m) 4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2	Pool Diameter (m)	Rad. Impact Dist. (m) 4.73 kW/m^2	12.5 kW/m^2	23 kW/m^2	35 kW/m^2
	Horizontal																			
Calm	12.97	28.15	21.89	18.71	16.50	32.46	44.68	33.06	N/A	N/A	64.90	72.26	52.53	N/A	N/A	129.59	123.40	89.92	N/A	N/A
Average	12.92	29.18	23.85	21.53	18.06	32.37	47.44	36.09	N/A	N/A	64.77	77.77	55.05	N/A	N/A	129.40	132.69	93.52	N/A	N/A
Windy	12.87	30.03	25.53	23.59	20.19	32.28	48.69	36.46	N/A	N/A	64.65	78.54	54.75	N/A	N/A	129.23	134.09	93.16	N/A	N/A
	Vertical (Up)																			
Calm	13.03	53.26	46.98	43.78	41.57	32.59	147.29	135.63	N/A	N/A	65.18	344.08	324.28	N/A	N/A	130.35	433.52	399.89	N/A	N/A
Average	12.95	56.73	51.40	49.07	45.61	32.50	113.35	101.95	N/A	N/A	65.13	205.72	182.90	N/A	N/A	130.34	366.49	327.11	N/A	N/A
Windy	12.88	66.50	62.00	60.05	56.65	32.35	123.96	111.71	N/A	N/A	64.92	211.06	187.20	N/A	N/A	130.16	356.69	315.56	N/A	N/A
	Vertical (Down)																			
Calm	12.95	23.50	17.24	14.07	11.86	32.38	36.84	25.24	N/A	N/A	64.94	61.13	41.39	N/A	N/A	130.15	108.25	74.66	N/A	N/A
Average	12.93	24.38	19.05	16.73	13.26	32.33	39.38	28.05	N/A	N/A	64.80	66.17	43.44	N/A	N/A	129.99	116.92	77.62	N/A	N/A
Windy	12.89	25.14	20.64	18.68	15.29	32.28	40.48	28.25	N/A	N/A	64.69	66.89	42.99	N/A	N/A	129.85	118.20	76.96	N/A	N/A

Note: N/A denotes the radiation level was not reached

Appendix D. Ignition Probabilities

Table 8. Ignition Probability Summary

Scenario	Pressure (kPag)	Temp (°C)	Leak Size (mm)	Total Ignition Probability	Immediate IP	Delayed IP
1 – Boil-off Gas (BOG) from Tanks to Header and Cargo Machinery Room	0	-160	10	1.00E-03	9.60E-04	4.00E-05
			25	1.00E-03	9.60E-04	4.00E-05
			50	1.53E-03	1.47E-03	6.12E-05
			100	2.52E-03	2.22E-03	3.02E-04
			FB – 250	1.57E-02	1.38E-02	1.89E-03
			FB – 300	2.26E-02	1.99E-02	2.71E-03
			FB – 400	4.03E-02	3.54E-02	4.83E-03
			FB – 600	9.06E-02	7.97E-02	1.09E-02
			FB – 700	1.23E-01	1.08E-01	1.48E-02
2 – BOG from High Duty (HD) Compressors for return to shore during LNG loading / unloading	100	-120	10	1.00E-03	9.60E-04	4.00E-05
			25	1.41E-03	1.35E-03	5.64E-05
			50	2.31E-03	2.22E-03	9.24E-05
			100	8.00E-03	7.04E-03	9.60E-04
			FB – 400	1.28E-01	8.95E-02	3.84E-02
			FB (Limited to production rate)	1.80E-01	1.26E-01	5.40E-02
3 – LNG from Tank to Regasification Module	550	-160	10	2.70E-03	2.38E-03	3.24E-04
			25	1.69E-02	1.48E-02	2.02E-03
			50	6.75E-02	5.94E-02	8.10E-03
			FB – 65	1.14E-01	1.00E-01	1.37E-02
			FB – 80	1.73E-01	1.21E-01	5.19E-02
			100	2.70E-01	1.89E-01	8.10E-02
			FB (Limited to half production rate)	9.00E-02	7.92E-02	1.08E-02
			FB (Limited to production rate)	1.80E-01	1.26E-01	5.40E-02
4 – BOG from Low Duty (LD) Compressors for fuel gas or to BOG cooler for reliquefaction	550	60	10	1.02E-03	9.79E-04	4.08E-05
			25	1.92E-03	1.84E-03	7.68E-05
			50	4.82E-03	4.24E-03	5.78E-04
			100	1.93E-02	1.70E-02	2.31E-03
			FB – 150	4.34E-02	3.82E-02	5.21E-03
			FB – 200	7.72E-02	6.79E-02	9.26E-03
			FB – 300	1.74E-01	1.21E-01	5.21E-02
5 – LNG from regasification booster pumps	12000	-160	10	1.26E-02	1.11E-02	1.51E-03
			25	7.89E-02	6.94E-02	9.47E-03
			50	3.16E-01	2.21E-01	9.47E-02
			100	6.50E-01	4.55E-01	1.95E-01
			FB (Limited to half production rate)	9.00E-02	7.92E-02	1.08E-02

Scenario	Pressure (kPag)	Temp (°C)	Leak Size (mm)	Total Ignition Probability	Immediate IP	Delayed IP
			FB (Limited to production rate)	1.80E-01	1.26E-01	5.40E-02
6 – NG from regasification module to wharf and pipeline	12000	10	10	5.27E-03	4.64E-03	6.32E-04
			25	3.30E-02	2.90E-02	3.96E-03
			50	1.32E-01	9.24E-02	3.96E-02
			100	5.28E-01	3.70E-01	1.58E-01
			FB (Limited to half production rate)	9.00E-02	7.92E-02	1.08E-02
			FB (Limited to production rate)	1.80E-01	1.26E-01	5.40E-02