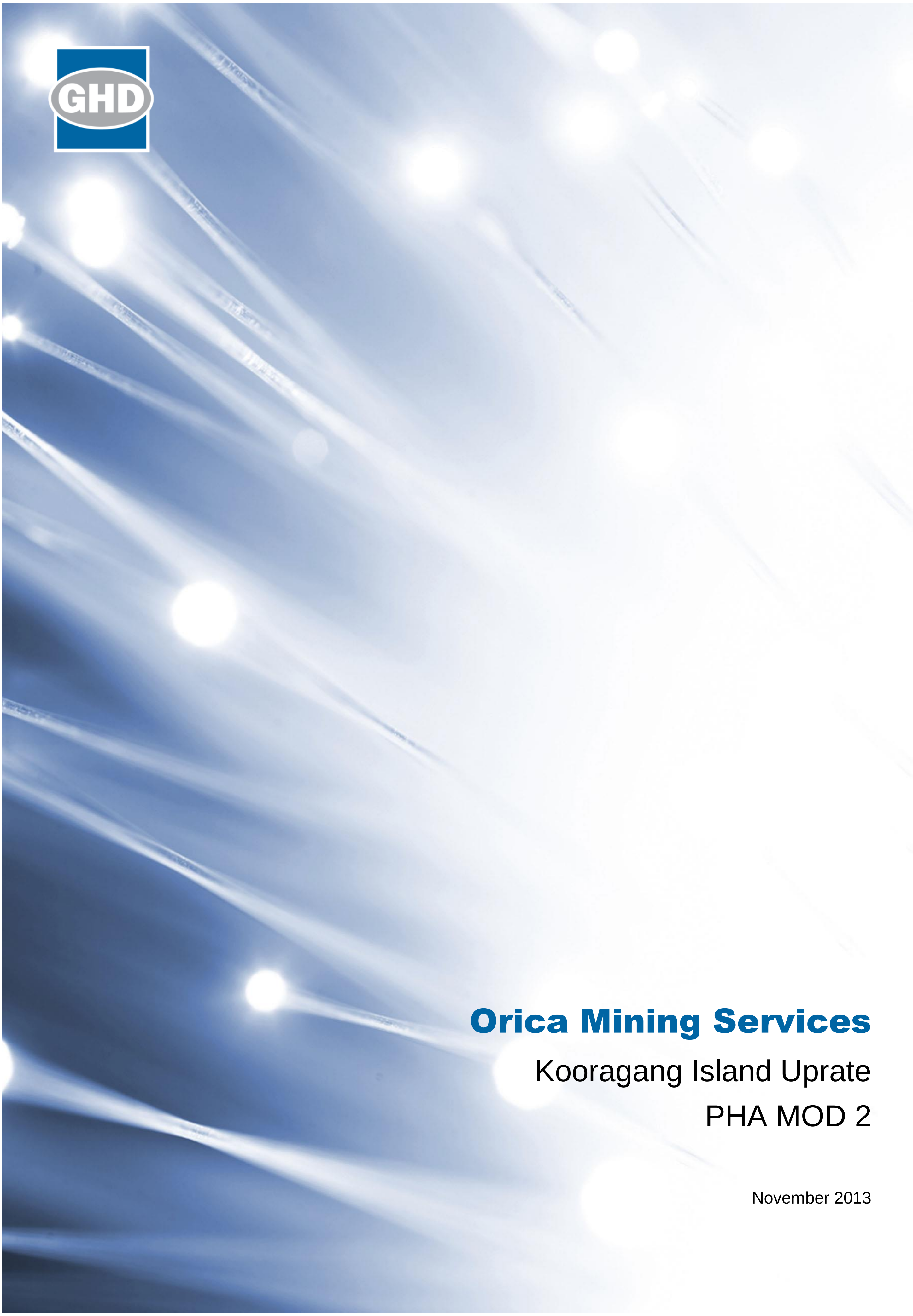

Orica Mining Services

Kooragang Island Uprate

PHA MOD 2

November 2013

WATER | ENERGY & RESOURCES | ENVIRONMENT | PROPERTY & BUILDINGS | TRANSPORTATION

Confidential and Sensitive Document - Exempt from Disclosure under the Government Information (Public Access) Act 2009 (NSW)

This complete Preliminary Hazard Analysis Report is provided to the NSW Department of Planning (DoP) by Orica Australia Pty Ltd (Orica) in confidence for use only within DoP. It is submitted on the basis that there is an overriding public interest against disclosure pursuant to section 14(2) of the Government Information (Public Access) Act 2009 (NSW) ("the Act"). The Report is exempt from disclosure under the Act on the grounds that it contains information associated with the manufacture of Security Sensitive Ammonium Nitrate, disclosure of which could:

- *increase the likelihood of, or prejudice the prevention of, preparedness against, response to, or recovery from, a public emergency (including any natural disaster, major accident, civil disturbance or act of terrorism) (s14(2) Table 2(c));*
- *endanger, or prejudice any system or procedure for protecting, the life, health or safety of any person (s14(2) Table 2(d)); or*
- *facilitate the commission of a criminal act (including a terrorist act within the meaning of the Terrorism (Police Powers) Act 2002) (s14(2) Table 2(f)).*

The information which is exempt from disclosure applies specifically to the following parts of the Report:

- *Appendix II: Hazard Identification*
- *Appendix V: Consequences*
- *Appendix VI: Frequency Analysis.*

The Orica Kooragang Island Ammonium Nitrate Expansion Environmental Assessment (2009) has also been submitted as a public document, with these three Appendices withheld, and without this page, but otherwise in the same form as this document.

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DISCLAIMER

This report has been prepared by GHD at the request of Orica Australia Pty Ltd (Orica) and is for the sole purpose of evaluating the risks associated with the proposed changes to the Kooragang Island Facility at Newcastle, NSW.

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The recommendations, opinions, assessments, analyses and summaries presented in this report are based on information, data, assumptions and advice provided and verified by Orica at the date of preparation of this Report and the previous 2009 PHA[1] *and 2012 PHA MOD 1*[2] *reports information upon which this is based. GHD has no responsibility or obligation to update this Report to account for events or changes occurring subsequent to the date that the Report was prepared. GHD disclaims liability arising from any of the assumptions being incorrect.*

It must be recognised that QRA is only a tool to assist decision making and not a substitute for suitably experienced and competent engineering input. The results of a QRA are only representative of the potential risks which may exist to the extent that the input data, assumptions and rule sets are representative of reality. The uncertainties in QRA inputs, and therefore in the results, are significant, and the conclusions of a QRA are sensitive to variations in the inputs or modelling assumptions. This is an unavoidable limitation of the technique.

In addition, this QRA is reliant on the ability of the Phast Risk software, supplied by Det Norske Veritas (DNV), to correctly model the data and settings for this exercise. GHD have not conducted an independent verification of the software modelling results and data and disclaims any responsibility for the performance of the Phast Risk program.

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[1] Orica Mining Services, Report for Kooragang Island Facility Uprate, Preliminary Hazard Analysis, May 2009, Rev 8, GHD Document Number 158758.

[2] Orica Mining Services, Report for Kooragang Island Uprate PHA MOD1, March 2012, Rev 5, GHD Document Number 31/24733/00/192842

1. Introduction

Orica Australia Pty Ltd (Orica) operates a manufacturing facility on Kooragang Island (KI) near Newcastle, which produces ammonia, nitric acid and ammonium nitrate.

On the 1st of December 2009, approval (DA 08_0129) was granted for the expansion of the site's ammonium nitrate manufacturing capability from 430ktpa to 750ktpa by the NSW Minister for Planning and Infrastructure under Part 3A of the Environmental Planning and Assessment Act 1979 (EP&A Act).

The site expansion project approval broadly consists of:

- An additional Nitric Acid Plant (NAP4);
- An additional Ammonium Nitrate Plant (ANP3);
- Modification of the existing Ammonia Plant;
- Upgrades to existing infrastructure such as cooling towers, air compressors, loading facilities, electrical systems, effluent treatment systems and the steam system.

To support the site's expansion approval application, GHD was commissioned in 2008 to update the Preliminary Risk Assessment (PHA)[3]. This involved the inclusion of additional infrastructure and changes to existing operational parameters in the Quantitative Risk Assessment (QRA).

In 2011[4] (MOD 1 PHA) an application to modify the 2009 approval was lodged by Orica, following the completion of technology selection and feasibility study design work. The modification mainly related to proposed changes to the post expansion site layout. During the regulatory assessment period, a non-routine ammonia release occurred at the site on the 9th of November 2011. As a result of the incident, Orica made several changes to the site's ammonia handling systems and committed to investigating additional safety measures that could be implemented to further reduce the risk associated with the use of ammonia onsite to both the community and site personnel. Improvements to the ammonia handling systems onsite included in the MOD 1 PHA included:

- Consolidation of pressurised liquid ammonia storage and piping systems to reduce inventories and simplify isolation;
- Implementing additional ammonia detection and isolation systems to reduce the quantity of ammonia released to atmosphere as a result of potential leaks from major pipelines between the Ammonia Plant, Ammonia Storage and ammonia storage tank (Bullet) 6; and
- Continuing to explore additional opportunities to further reduce the risks associate with the use of ammonia in site's current operations.

The MOD 1 approval modification was approved on 11 July 2012 (DA 08_0129 MOD 1).

In 2012, Orica consolidated improvement work on ammonia into the Ammonia Management Improvement programme (AMI), tasked with investigating and identifying further opportunities to reduce the risks associate with existing ammonia handling systems located onsite. Since

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[3] Orica Mining Services, Report for Kooragang Island Facility Uprate, Preliminary Hazard Analysis, May 2009, GHD Document Number 158758, Rev 8.

[4] Orica Mining Services, Report for Kooragang Island Facility Uprate, PHA MOD 1, March 2012, GHD Document Number 192842, Rev 5.

completing this review in early 2013, several ammonia handling and ammonia capture and treatment design improvements have been identified.

The purpose of this PHA update (PHA MOD 2) is to identify the effect of proposed changes in relation to the QRA modelling results detailed in MOD 1 PHA and to establish if compliance to HIPAP 4[5] assessment criteria is maintained. The MOD 2 PHA will be submitted to the NSW Department of Planning and Infrastructure to support a further modification to the expansion project approval.

This report presents the changes to the ammonia handling system design compared to what was detailed in the MOD 1 PHA and the updated risk profiles and references the MOD 1 PHA report. The following appendices have been updated:

Appendix II – Hazard Identification

Appendix V – Consequences

Appendix VI – Frequency Analysis

1.1 Scope of MOD 2 PHA

Orica engaged GHD to update the site’s MOD 1 PHA risk model and the associated documentation to accurately reflect the proposed changes associated with the AMI project (MOD 2).

The scope of the MOD 2 PHA includes the following:

- Update the MOD 1 PHA model to reflect the MOD 2 changes as listed in Section 2 (mainly updates to the ammonia transfer pipelines and storage) using Phast Risk v6.7;
- Analyse the consequences and event frequencies associated with the updated and new scenarios;
- Generation of MOD 2 risk contours;
- Comparison of MOD 2 risk contours with the MOD 1 risk contours in the MOD 1 PHA submitted to the DoPI; and
- MOD 2 PHA Report showing the key changes in risk results.

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[5] NSW Department of Planning & Infrastructure, Hazardous Industry Planning Advisory Paper No 4, Risk Criteria for Land Use Safety Planning, Jan 2011

2. Description of MOD 2 Changes

2.1 Ammonia Management Improvement (AMI) Programme

Historically the KI site's existing ammonia management system has been designed to prevent a fatality or serious injury to either onsite personnel or in the community, with non-routine ammonia releases discharged at height and routine ammonia emissions directed to ammonia scrubbers where practicable.

In 2011 the KI site experienced a non-routine ammonia release on 9th of November 2011 from one of the site's pressurised ammonia storage tanks. This resulted in ammonia vapour being released directly to atmosphere. In response to this incident, Orica committed to implementing a risk reduction plan which included several changes to plant, processes and systems and evaluation of options for eliminating or reducing ammonia emissions where the risk has been determined to be significant. Part of this work was incorporated into the MOD1 PHA but with Orica continuing to explore additional opportunities.

In May 2012, Orica undertook a review of the similar manufacturing facilities in Europe, South Africa, North America and Australia to investigate the effectiveness of other company's ammonia management systems and to identify potential improvements to the systems at KI.

The review identified four main areas of focus in reducing the site's risk profile, being:

1. Simplifying the ammonia distribution network;
2. Improving the integrity of ammonia feed tanks;
3. Improving the Ammonia Collection and Scrubbing Capability;
4. Ensuring ammonia treatment systems were appropriate in managing large release scenarios.

Identified improvements, including previously planned work, were consolidated into the Ammonia Management Improvement (AMI) programme to develop through an appropriate project, design and risk assessment process.

2.2 Proposed Modification (MOD 2)

From a PHA update prospective, the main changes to the inputs assessed in the MOD 1 PHA relate to the integrity and quantity of ammonia supply feed tanks, changes to the ammonia distribution network and the inclusion of three ammonia flares located in the Ammonia, Nitrates and Ammonia storage plant areas.

2.2.1 Design improvements aimed at improving ammonia feed tank integrity.

A review of the site's existing three ammonia feed tanks was completed, with an improved ammonia feed tank design identified. The focus of the investigation was to further reduce the quantity of ammonia stored in the tanks and to improve the integrity of the remaining ammonia feed tanks. Consistent with the MOD 1 PHA, No. 1 bullet will be decommissioned, however the following changes to the MOD 1 PHA are proposed:

- Consistent with the MOD 1 PHA, a new ammonia feed tank No. 6 will be installed however the design of the tank will be vertical compared to the horizontal design of the existing ammonia feed tanks 1 and 2. This will result in a significantly reduced fire case due to the reduction of the feed tanks ammonia surface area. The vertically designed ammonia feed tank will operate at a reduced ammonia inventory of 8T, compared to 15T as detailed in the MOD 1 PHA, and operating pressure. This will reduce the volume of ammonia that could potentially be released in the event of the tank's relief valve being activated. In the event of the relief valve activating on the tank, released ammonia will now be directed to a flare rather than directly to atmosphere;

- Ammonia transferred from ammonia feed tank No. 6 to the nitrates plants will no longer be via the ammonia side arm heater but rather via five optimally designed ammonia transfer pumps. This will result in greater integrity of the plant ammonia supply system and remove a significant potential ammonia release point from the site. As a result of the introduction of the five ammonia transfer pumps, several changes have been made to the ammonia distribution network, which are listed in Section 2.2.2 below.
- As required by the site's Environmental protection licence (EPL 828), ammonia feed tank No. 5 (ammonia bottling bullet V115) located in the site's aqueous ammonia and ammonia bottling area will be decommissioned. Ammonia supply to the bottling area will now be supplied directly from the Ammonia Plant. Removal of this ammonia feed tank has resulted in an increase in the operating pressure of the ammonia bottling plant supply pipeline;
- Ammonia feed tank No. 2, previously listed in the MOD 1 PHA as an off-line spare bullet to ammonia feed tank No. 6, is to be decommissioned and hence reducing some complexity in the network.

The revised ammonia feed tank site configuration will result in a further reduction of normal working inventory of pressurised liquid ammonia in the bullets from 25 tonnes (in MOD 1) to a future 8 tonnes (in MOD 2) as shown in the table below.

Table 1: Summary of ammonia storage inventories

Bullet	MOD 1 Max capacity (tonnes)	MOD 1 Normal Working Inventory	MOD 2 Max capacity (tonnes)	MOD 2 Normal Working Inventory
No. 1	Decommissioned	Decommissioned	Decommissioned	Decommissioned
No. 2	Spare*	Spare*	Decommissioned	Decommissioned
No. 5	60(30)**	10***	Decommissioned	Decommissioned
New no. 6	30	15****	15	8****
Total	90(60)	25	15	8

* Replacement bullet to be used as an off-line spare for maintenance. The bullet will be of the same capacity as bullet no.6

**high level trip at 30T

***surge capacity of 15T for occasional road tanker filling

**** surge capacity of 15T to allow for Nitrates plant trips

2.2.2 Design improvements aimed at simplifying the ammonia distribution network

A review of the existing and future ammonia distribution network was undertaken with the aim of reducing the distance, pipe diameter and pressure for which ammonia is required to be transferred across the site has been completed. This is aimed at reducing the consequence associated with a potential release. As a result of the review and changes to the ammonia feed tanks the following improvements have been identified.

- Ammonia transfer pipelines from ammonia feed tank no. 6 to:
  - Ammonium Nitrate Plant 2 will be operated at a reduced pressure;
  - Nitric Acid Plant 3 will be replaced with a smaller diameter pipe;
- Ammonia transfer pipelines from ammonia plant to:
  - Ammonia storage vessel (V101) supply pipeline will be operated at a slightly higher pressure and larger pipe diameter;
- Ammonia transfer pipelines from storage vessel (V101) to:
  - Road loading via storage ammonia heaters will be replaced with a new pipeline due to the decommissioning of ammonia feed tank No. 5;
  - Triella Aqua Plant via storage ammonia heaters will be a new pipeline; to Project Trident vaporisers via the Project Trident ammonia heater will be a new pipeline.
- The ammonia back-up line will be decommissioned;
- The ammonia manifold will be decommissioned. A new refrigeration unit will be installed in Nitric Acid Plant 2 with an inventory of 1000 kg ammonia.

Additional consideration has also been given to the complexities associated with the construction and ongoing maintenance associated with the high integrity double piping of major ammonia pipelines. A simpler alternative strategy, designed to achieve a similar risk reduction has been developed. Ammonia pipelines between the Ammonia Plant, Ammonia Storage and ammonia feed tank No. 6 will be fitted with leak detection and automatic remote isolation capable of pipe isolation within two minutes of ammonia leak detection. This will be achieved through the installation of dual flow meters located at each end of the pipeline. Discrepancies in flow between the different ends of the pipe will result in the automatic isolation of the pipe. This will reduce the quantity of ammonia released as a consequence of a rupture or leak ammonia release scenario.

2.2.3 Design improvements aimed at ensuring ammonia treatment systems were appropriate in managing large release scenarios.

Orica has undertaken a review of alternative ammonia treatment options for large non-routine release scenario’s at the site. The review identified that a flaring system is the preferred option due to the reduced reliance on existing site systems, greater reliability, increased operational simplicity (which can improve effectiveness during emergency events), reduced aqueous ammonia formation and lower capital cost. The flares will provide the site with a final layer of ammonia treatment capability for the site.

Three flares are to be used to treat major non-routine process relief valve discharges, while the existing scrubbing system would continue to treat routine planned ammonia emissions.

Three new ammonia flares will thermally oxidise ammonia released from relief valves located in the Ammonia Plant, Nitrates and Ammonia Storage tank areas.

3. Risk Results

This section presents a comparison of quantitative risk assessments modelling results associated with MOD 1[6] and MOD 2 (AMI Project). As the HIPAP 4 risk criteria applies specifically to new development, it has not been directly applied to the AMI MOD 2 results as they are minor and do not equate to additional infrastructure at the site. However to enable a more complete understanding of all aspects of the risk profile of the AMI Project, risk contours have been calculated for the AMI Project. The results presented in this section include the site results for MOD 1 and MOD 2 for the following risk results against all of the risk criteria of NSW DoP presented in Hazardous Industry Planning Advisory Paper (HIPAP) No 4:

- The individual fatality risk (IFR);
- Societal risk in the form of FN Curve; and
- Toxic Injury and Irritation risk;

The changes in these results are discussed including an assessment to whether the MOD 2 design changes have made an impact on the risk profile of the overall site.

The following risk results remain the same between the MOD 1 and MOD 2 design as none of the site layout changes have been altered. As such they remain compliant to the relevant HIPAP 4 criteria and therefore have not been presented again in this report. These include:

- Thermal radiation; and
- Ammonium nitrate explosion overpressure (injury and property damage and accident propagation).

3.1 Individual Fatality Risk

The following figures show the Individual Fatality Risk (IFR) Contours for MOD 1 and MOD 2.

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[6] Orica Mining Services, Report for Kooragang Island Facility Uprate, PHA MOD 1, March 2012, GHD Document Number 192842, Rev 5

Figure 1: Individual Fatality Risk – MOD 1

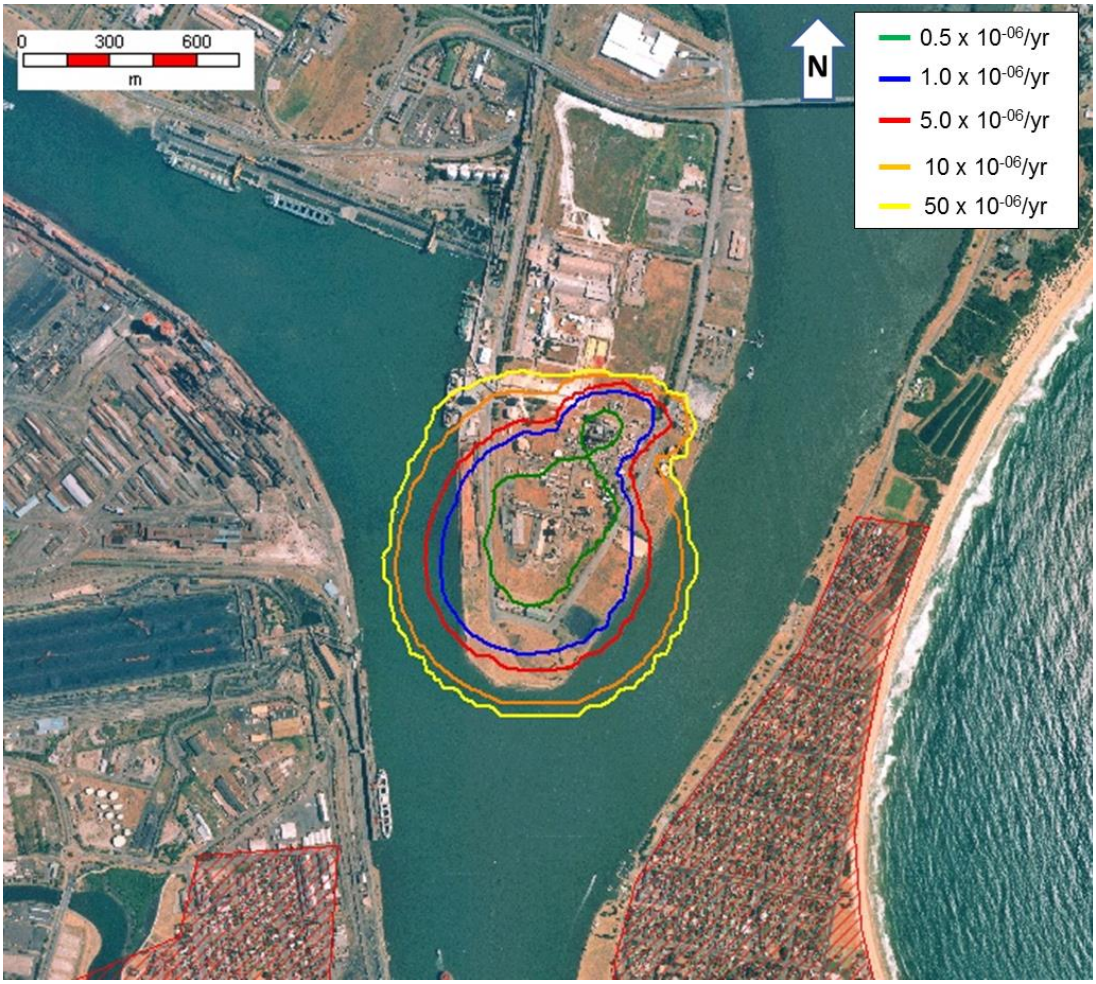
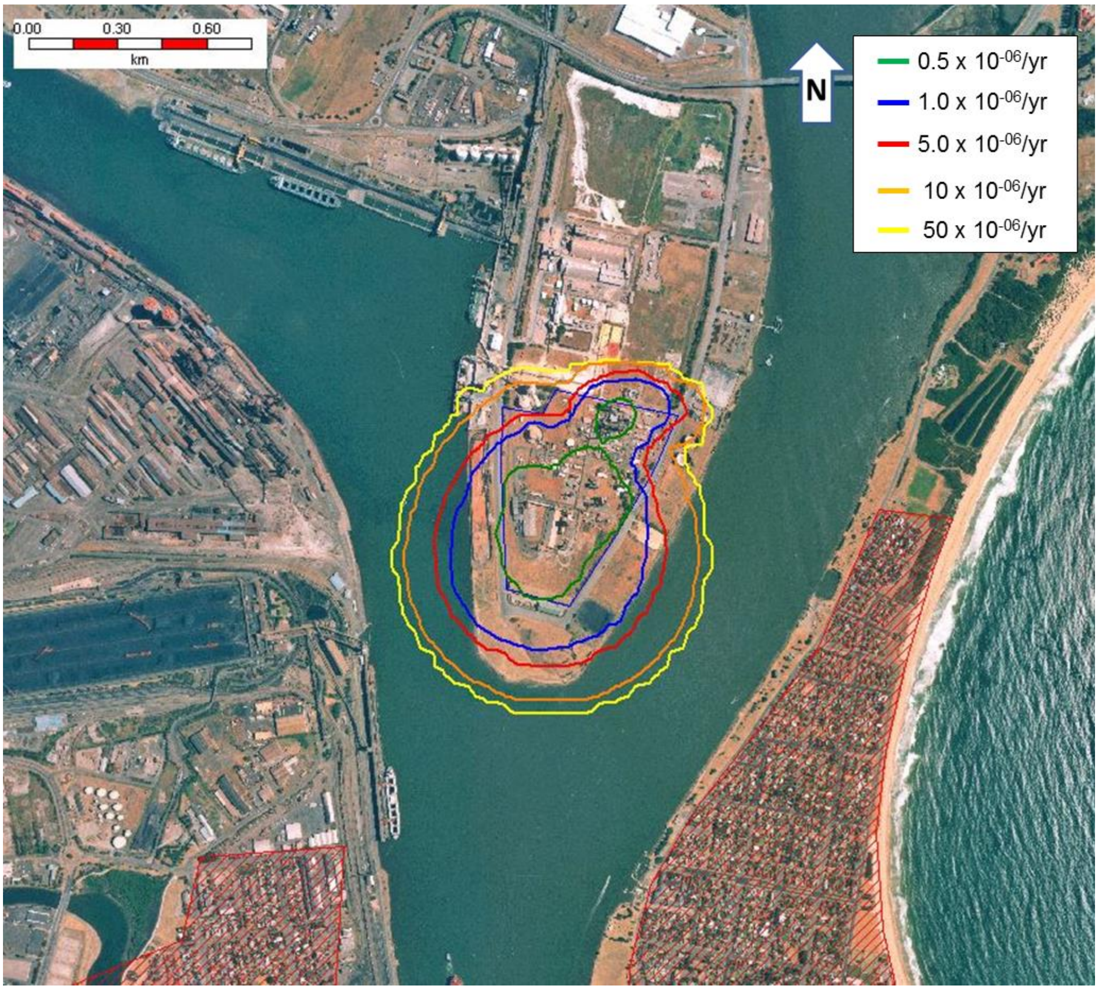


Figure 2: Individual Fatality Risk – MOD 2



Comparing the IFR contours for the MOD 2 case to the MOD 1 case, there have been no significant changes to the inner risk contours. The outer contour (50 x 10^{-6} pa) has contracted slightly in the north-west region. This is expected as there have not been any major changes to the design except for some minor changes to the ammonia storage and distribution system.

The maximum actual IFRs at the Orica site boundary on all sides for the MOD 2 Case and MOD 1 Case are given in Table 2 below. This shows that the actual risk at the northern and western boundaries remain the same between MOD 1 and MOD 2. The actual risk on the eastern side has slightly increased and the actual risk on the southern side has slightly decreased. The HIPAP 4 criterion is 50 x 10^{-6}/yr. This shows that the overall IFR associated with MOD 2 have not increased from the MOD 1 design.

Table 2: Maximum actual IFR at site boundary

Boundary	IFR MOD 1 (x 10^{-6}/yr)	IFR MOD 2 (x 10^{-6}/yr)	Major Contributors
North	56	56	Events in the ammonia plant involving ammonia and gas releases.
East	43	44	Explosion events involving ammonium nitrate
South	81	80	Explosion events involving ammonium nitrate

Boundary	IFR MOD 1 (x 10^{-6}/yr)	IFR MOD 2 (x 10^{-6}/yr)	Major Contributors
West	58	58	Explosion events involving ammonium nitrate

As shown, there has been negligible change in IFR risk due to the design changes made as part of MOD 2. This high level of compliance is due to substantial efforts made to reduce risk, not only in the new plant and equipment but also by modifying existing plant and equipment. These are described in Section 2.

3.2 Societal Risk

The societal risk in the form of a FN-curve for the MOD 1 and MOD 2 cases are shown in Figure 3 and Figure 4 below.

Figure 3: Societal Risk – MOD 1

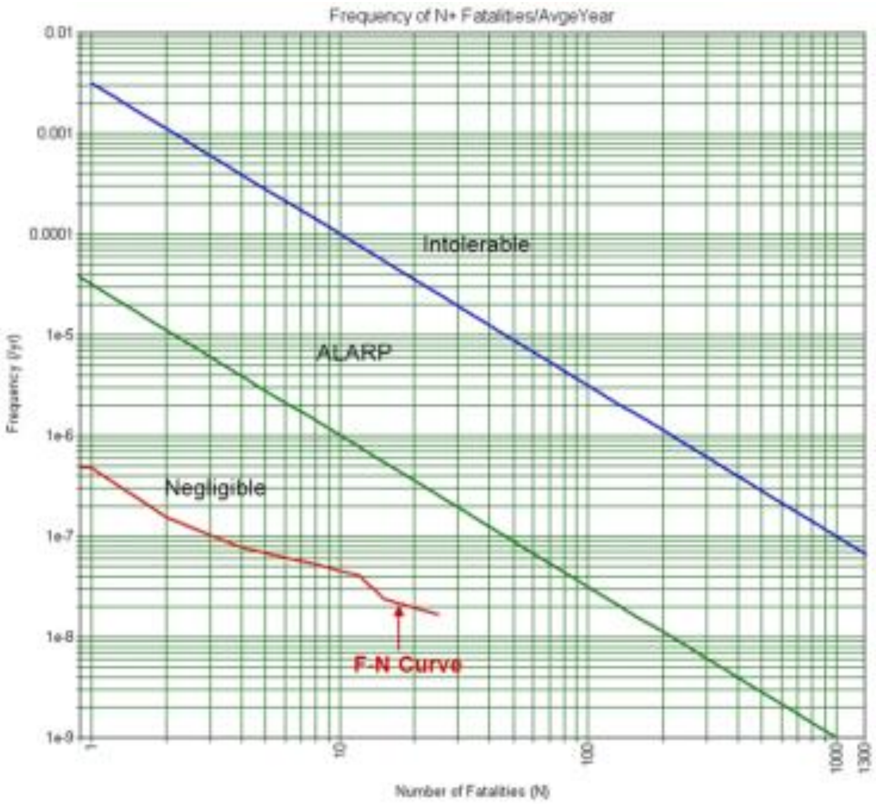
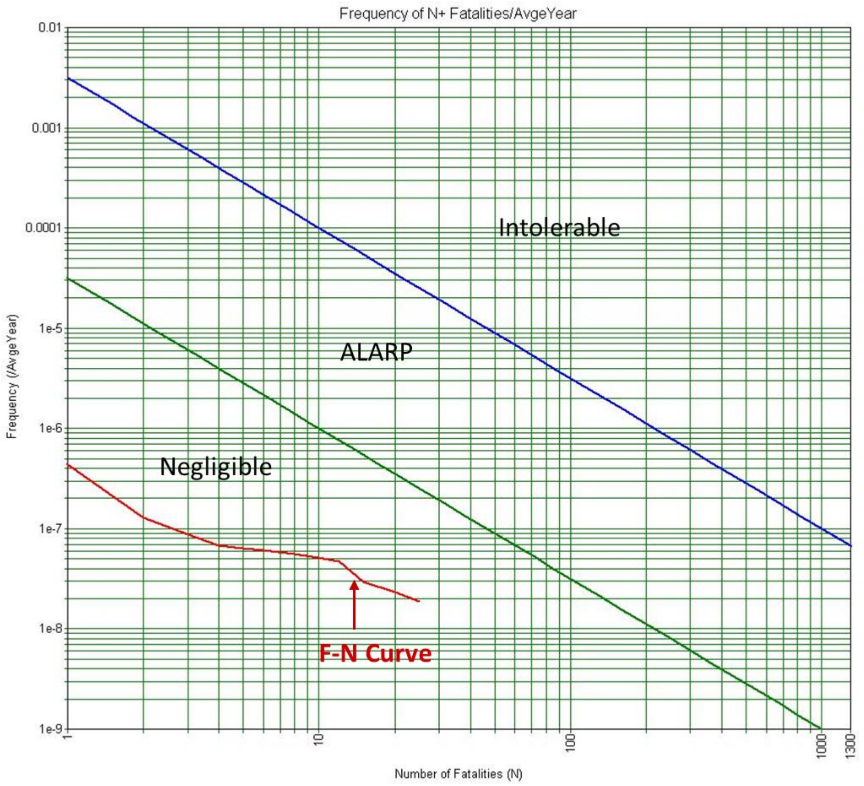


Figure 4: Societal Risk – MOD 2



The FN-curve for the MOD 2 remains entirely within the “negligible” zone.

The risks associated with the Project for the site case remain consistent with the MOD 1 PHA and continue to comply with HIPAP 4 risk criteria for “intensification of hazardous activities in an existing complex”, i.e. the $1x10^{-6}$ contour does not encroach into residential areas and the cumulative risks as shown in the Site FN Curve remain acceptable.

3.3 Toxic Risk

3.3.1 Injury

Figure 5 and Figure 6 below show the toxic injury risk contour at 10 in a million per annum for MOD 1 and MOD 2 (AMI Project). These show that the toxic injury risk contour has decreased with MOD 2. This is mainly due to the simplification of the ammonia storage and distribution system. The toxic injury risk associated with the site remains compliant with the suggested criteria specified in HIPAP 4.

Figure 5: Toxic Risk Injury – MOD 1

Figure 6: Toxic Risk Injury – MOD 2

3.3.2 Irritation

Figure 7 and Figure 8 below show the toxic irritation risk contour at 50 in a million per annum for MOD 1 and MOD 2 (AMI Project). This shows that the shape of the toxic irritation contour has changed slightly between MOD 1 and MOD 2 but remains compliant with the suggested criteria specified in HIPAP 4.

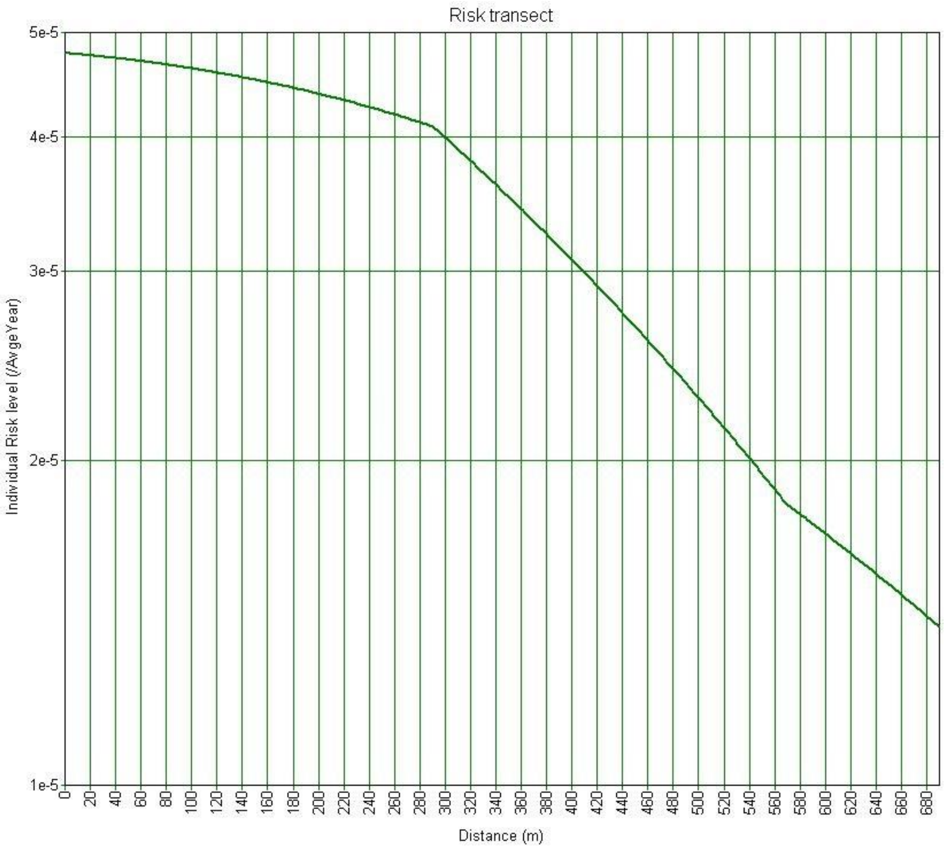
Figure 7: Toxic Irritation Risk – MOD 1

Figure 8: Toxic Irritation Risk – MOD 2

Figure 10 shows the risk transect along the blue line as indicated in Figure 9. This confirms that the risk along the blue line remains below the 50 in a million per year frequency.

Figure 9: Toxic Irritation Risk Close up – MOD 2

Figure 10: Risk Transect Graph



4. Conclusion

Since the preliminary hazard assessment (PHA) update, referred to as PHA MOD 1, was approved by the Minister on 11 July 2012 (DA 08_0129 MOD 1), Orica has undertaken an Ammonia Management system Improvement (AMI) project based on a review of ammonia management practices including benchmarking internationally. These activities have led to a number of variations to the project in relation to the inputs into the preliminary hazard assessment.

The QRA model developed in the PHA MOD 1 was updated to incorporate the changes to the design and layout as part of the AMI project, referred to as PHA MOD 2. The purpose of this was to check the impact of the design changes on the site's risk profiles established during the PHA MOD 1, and produce a MOD 2 Report documenting the changes.

The risk assessment has shown that the site risk results for the MOD 2 case did not change significantly from the results detailed in the MOD 1 design case. The risks associated with the Project continue to comply with HIPAP 4 risk criteria for "intensification of hazardous activities in an existing complex", i.e. the $1x10^{-6}$ contour does not encroach into residential areas and the cumulative risks as shown in the Site FN Curve remain acceptable.

The study has shown that the proposed changes associated with MOD 2 have not resulted in an increase in the risk profile of the site compared to the MOD 1 PHA.

Appendices

Appendix I – Background Data

(Refer to Appendix I in 2009 PHA report Rev 8)

APPENDIX I

A I Background Data

A I.1 Existing Site Layout

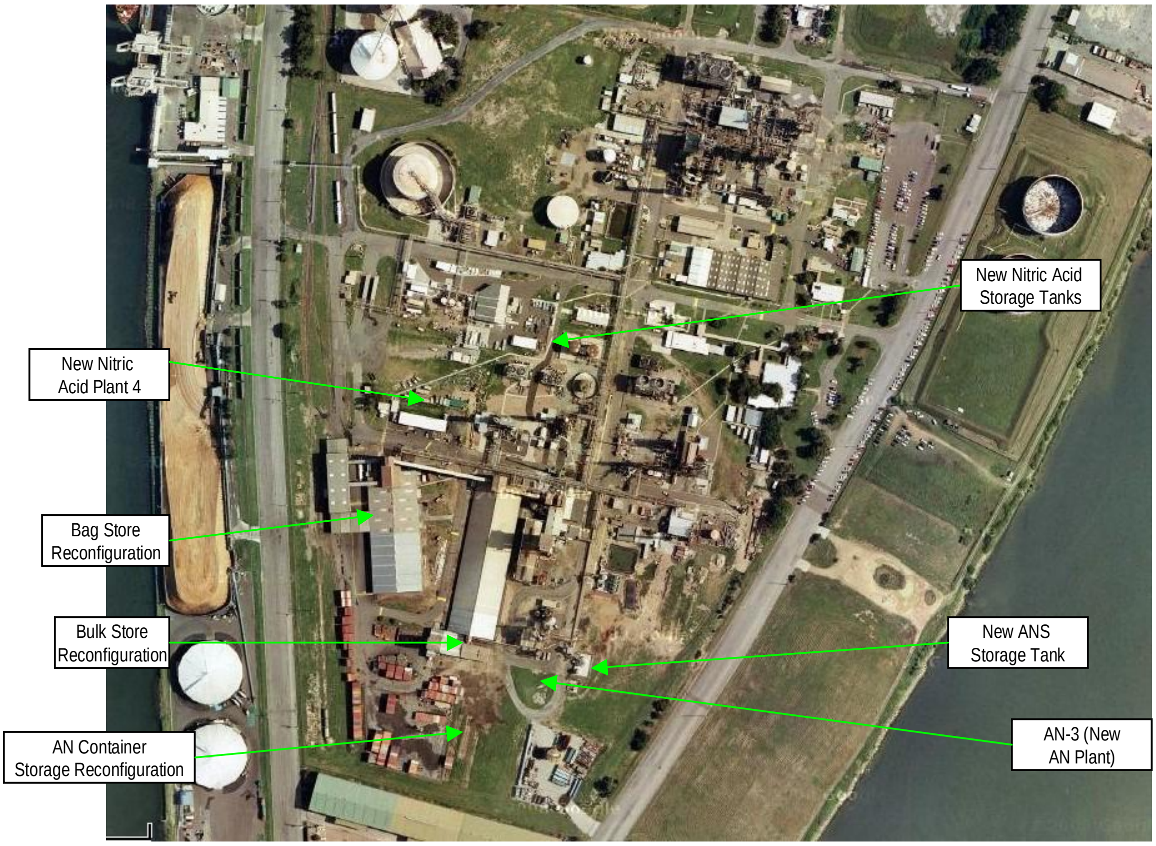
The Kooragang Island existing site layout is shown in Figure AI-1 below.

Figure AI-1: Existing Site Layout

A I.2 Expanded Facility Site Layout

Figure AI-2 shows the proposed plants and modifications as part of the expansion project.

Figure AI-2: Expanded Facility Site Layout



A I.3 Hazardous Material Identification

Hazardous materials identified as being either produced or consumed in the Nitric Acid and Ammonium Nitrate Plants are presented in Table AI-1: Hazardous Materials on Site

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Table AI-1: Hazardous Materials on Site

Hazardous Material	Phase	Class of DG	Produced/Use

Hazardous Material	Phase	Class of DG	Produced/Use
Anhydrous ammonia	Pressurised Liquid and Gas	Toxic	Manufactured on site and used in both plants for the production of acid and ammonium nitrate.
Natural Gas	Gas	Flammable	Feed stock for ammonia.
Ammonium nitrate	Solution and Prill	Oxidising Agent	Produced in Ammonium Nitrate Plant as end product
Nitrogen oxides (monoxide, dioxide, tetroxide, nitrous)	Intermediate Gas	Toxic	Produced in Nitric Acid Plant as part of the production process
Hydrogen	Gas	Flammable	Used as a feedstock for ammonia production.
Nitric acid	Liquid	Highly Corrosive	Produced in Nitric Acid Plant and consumed in Ammonium Nitrate Plant to produce ammonium nitrate.
Alkyl amine (coating agent)	Liquid		Consumed in Ammonium Nitrate Plant for prill coating.
Steam	Liquid and Gas		Produced and consumed by all plants.
Nitrogen	Pressurised Liquid and Gas	Compressed Gas	Consumed by all plants as purge.
Chlorine	Pressurised Liquid and Gas	Toxic	Used in cooling water treatment in the Ammonia Plant

Of the materials mentioned above, only anhydrous ammonia, ammonium nitrate, the nitrogen oxides, chlorine, natural gas and hydrogen were considered capable of having an offsite safety risk impact. These materials are discussed further in the following sections.

A I I.3.1 Ammonia

Ammonia is a toxic gas, which, while flammable, is acknowledged to be extremely difficult to ignite. Considering this, the flammable effects of ammonia were screened from the study with its toxicity being the principal issue considered in this assessment.

Although ammonia is lighter than air, a pressurised or cold release of ammonia may form a dense cloud (due to temperature) after expansion to atmospheric pressure or form a fog resulting from the interaction of ammonia molecules with ambient water vapour.

Ammonia can be readily detected in the atmosphere by smell at concentrations below 20 ppm. It is a powerful irritant to eyes and mucous membranes of the respiratory tract. At low concentrations in air, ammonia vapour irritates the eyes, nose and throat. Inhalation of high concentrations produces a sensation of suffocation, quickly causes burning of respiratory tracts and may result in death.

Table AI-2: Toxicity of Ammonia

Concentration (ppm)	Exposure Effects	Exposure Duration
10-20	Odour detectable by most people.	Prolonged repeated exposure produces no injury.
25	No adverse effects for average workers.	Maximum allowable concentration for 8-hour working day (NIOSH TWA)
35	No adverse effects for average workers.	Exposure should not exceed 15min and there should be no more than 4 periods above 15min, with at least 1 hour between episodes.
300	Nose and throat irritation. Eye irritation with tearing.	NIOSH IDLH, based on statement by AIHA (1971) that 300 – 500ppm for 30 to 60min have been reported as the maximum short exposure tolerance (Henderson and Haggard, 1943).
2000-3000	Convulsive coughing, severe eye irritation.	No permissible exposure.
5000-7000	Respiratory spasm, rapid asphyxia.	No permissible exposure. Rapidly fatal.

“The odour of ammonia can be detected by humans at concentrations >5 ppm; the odour is highly penetrating at 50 ppm (10 min). Human volunteers exposed to ammonia showed slight irritation at 30 ppm (10 min); moderate irritation to the eyes, nose, throat, and chest at 50 ppm (10 min to 2 h); moderate to highly intense irritation at 80 ppm (30 min to 2 hr); highly intense irritation at 110 ppm (30 min to 2 h); unbearable irritation at 140 ppm (30 min to 2 hr), and excessive lachrymation and irritation at 500 ppm. Reflex glottis closure, a protective response to inhaling irritant vapours, occurred at 570 ppm for 21- to 30-year-old subjects, 1,000 ppm for 60-year-old subjects, and 1,790 ppm for 86- to 90-year-old subjects.” (Taken from Ref 16.)

A I I.3.2 Natural Gas

Natural gas is a non-toxic, colourless gas at ambient conditions. While it is odourless of itself, an odorant is normally added before it is transported to end-users. Natural gas is lighter than air. It is a highly flammable gas, with flammability ranging from 5 to 15% volume in air. If it does not immediately ignite upon release, it can form an explosive mixture with air. If it is burned in limited supply of air, carbon monoxide may be produced. While it is regarded as being stable, it is not compatible with strong oxidising agents.

A I I.3.3 Hydrogen

Hydrogen is a highly flammable gas. Its density is much below that of ambient air, so that in a release it rises rapidly. Its flammability range in air extends from 4% to 75% and because of this it will rapidly form an explosive mixture with air. It burns with a pale blue, almost invisible flame, making hydrogen fires more dangerous.

A I I.3.4 Ammonium Nitrate

Ammonium Nitrate (AN) is a strong oxidising agent that will support combustion of organics and metal powders as it produces oxygen as one of its decomposition products. It is not flammable or combustible in itself. When subjected to heat, ammonium nitrate undergoes a series of complex decomposition reactions that produce low levels of nitrogen oxides (namely nitrous oxide) at atmospheric pressure. If the reaction is confined and the gases are maintained at the temperature at which they were formed, further gas phase reactions can occur giving off nitric oxide and nitrogen dioxide gases. Nitrogen dioxide is the most toxic product that may form under these conditions and is discussed in Section A I I.3.5.

The plume of combustion products resulting from an ammonium nitrate fire have been shown to be buoyant due to the high temperatures involved, and disperse to non-hazardous concentrations before returning to grade.

The sensitivity of ammonium nitrate to detonation is largely dependent on three variables; temperature, confinement and contamination. Without any of these three being present, ammonium nitrate would require a strong initiation charge (ie high explosive) to detonate at all.

Variables in the calculation of overpressure consequences from an ammonium nitrate explosion include the proportion of the sensitised material that actually detonates in the explosion (efficiency), and an equivalency of the sensitised material to that of TNT (equivalency). This technique is used because of the significant quantity of information on the consequences of explosions involving TNT.

A I I.3.5 Nitrogen Oxides

Nitrogen oxides (nitrogen monoxide, dioxide, tetroxide, di-nitrogen oxide (nitrous oxide), etc) are produced in the Nitric Acid Plant in the production of acid and by the high-temperature decomposition reaction of ammonium nitrate.

Nitrogen Dioxide

Nitrogen dioxide (NO_2) is a respiratory irritant, however its main danger lies in the delay before its full effects upon the lungs occur. Symptoms include feelings of weakness and coldness, headache, nausea, dizziness, abdominal pain and cyanosis. In severe cases, convulsions and death by asphyxia may follow. Table AI-3 overviews the toxicity of nitrogen dioxide.

Table AI-3: Toxicity of Nitrogen Dioxide

Concentration (ppm)	Exposure Effects
1	NIOSH REL Short Term Exposure Limit (STEL)
3	Recommended Time Weighted Average (TWA) for continued workplace exposure with no adverse effect for an 8hr day, 5 days per week.
5	OSHA PEL (Permissible Exposure Limit)
20	NIOSH IDLH

The exposure limits for nitrogen dioxide as per Acute Exposure guidelines Limit (AEGL) are given below.

Table AI-4: Exposure Limits for Nitrogen Dioxide

	Exposure Duration				
	10 min	30 min	1 hr	4 hr	8 hr
AEGL-1 (Non disabling)	0.5 ppm	0.5 ppm	0.5 ppm	0.5 ppm	0.5 ppm
AEGL-2 (Disabling)	20 ppm	15 ppm	12 ppm	8.2 ppm	6.7 ppm
AEGL-3 (Lethal)	34 ppm	25 ppm	20 ppm	14 ppm	11 ppm

Nitrous Oxide

Nitrous oxide (N_2O) is a non-toxic anaesthetic. However, it may result in a fatality due to an asphyxiation effect by displacing oxygen. Populations exposed to nitrous oxide are likely to feel light-headed and anaesthetised before asphyxiation occurs. Concentrations of approximately 150,000 ppm of gas are required to reduce the oxygen concentration in air to a level, which is considered as the starting point for asphyxiation (18%). Nitrous oxide was therefore screened from the analysis, as concentrations leading to asphyxia will not be reached beyond the site boundary.

Nitric Oxide (NO)

Nitric Oxide is a colourless gas but in high concentrations it changes to brown in colour. It has a sharp sweet odour. Nitric oxide changes to nitrogen dioxide in air. Nitrogen dioxide, NO2, is 5 times more toxic than nitric oxide (NO).

NIOSH Recommended Exposure Limit (REL) for NO is 25 ppm (30 mg/m3) averaged over a work shift of 10 hours per day, 40 hours per week.

A I I.3.6 Chlorine

Chlorine (Cl_2) is a greenish-yellow gas or clear amber liquid (under pressure) with a pungent suffocating odour. It is shipped in 920 kg drums as a compressed liquefied gas under a pressure of approximately 650 kPa at 21.1 deg C. The exposure limits to chlorine based on AEGL and NIOSH recommendations are given in Table AI-5. The Immediately Dangerous to Life and Health (IDLH) value is 30 ppm and is ‘based on the statement by ILO (1971) that exposure to 30 ppm will cause intense coughing, fits, and exposure to 40 to 60 ppm for 30 to 60 minutes or more may cause serious damage’.

Table AI-5: Toxicity Effects of Chlorine

Classification	Exposure Duration				
	10 min	30 min	1 hr	4 hr	8 hr
AEGL-1 (Non disabling)	0.5 ppm	0.5 ppm	0.5 ppm	0.5 ppm	0.5 ppm
AEGL-2 (Disabling)	2.8 ppm	2.8 ppm	2.0 ppm	1.0 ppm	0.71 ppm
AEGL-3 (Lethal)	50 ppm	28 ppm	20 ppm	10 ppm	7.1 ppm
NIOSH Recommended Exposure Limit (REL)	0.5 ppm (max 15 minute ceiling)				
OSHA Permissible Exposure Limit (PEL)	1.0 ppm				
IDLH – Immediately Dangerous to Life or Health	10 ppm				

A I I.3.7 Miscellaneous Chemicals

The remainder of materials mentioned above are considered to only have localised effects.

- Nitric acid and Steam will cause severe burns with bodily contact however will not travel sufficient distances upon release to affect an offsite populations.
- The coating agent (alkyl amine) may cause localised pool fires that likewise were considered unable to affect an offsite population. Toxic smoke plumes will not affect offsite populations due to the separation distance of the storage / production facilities from the site boundary.
- Nitrogen poses both an asphyxiation and frostbite hazard however will rapidly disperse to safe concentrations, before reaching the site boundary.

A I I.3.8 Storage and Quantity

Table AI-6 lists the full range of dangerous goods stored on Orica's KI site, along with their storage method, quantity and throughput.

Table AI-6: List of Dangerous Goods Stored Onsite

DG Storage Description	Proper Shipping Name	UN Number	Class	PG	Product / Common Name	Current			New		
						Max storage capacity	**Typical Quantity**	**Annual Throughput (per annum)**	**Max storage capacity**	**Typical Quantity**	**Annual Throughput**
AN Bag Store	Ammonium Nitrate	1942	5.1	III	Ammonium Nitrate	2500 t	2 000 t	100 000 t	No change	No change	150 000 t
AN Bulk Store	Ammonium Nitrate	1942	5.1	III	Ammonium Nitrate	15 500 t	9 200 t	220 000 t	No change	9 200 t	400 000 t
Ammonium Nitrate Container Storage	Ammonium Nitrate	1942	5.1	III	Ammonium Nitrate	4 800 t	3 250 t	95 000 t	No Change	No Change	150 000 t
CPAN Store	Ammonium Nitrate	1942	5.1	III	Ammonium Nitrate	300 t	200 t	8 000 t	600 t	200 t	No Change
AN Solution Tanks	Ammonium Nitrate Liquid	2426	5.1	II	88.5% Ammonium Nitrate Solution	375 t	350 t	110 000 t	1 375 t	1200 t	200 000 t
60% AN Solution Tanks	Dilute Ammonium Nitrate Liquid	3098	5.1	II	60% Ammonium Nitrate Solution	-	-	-	250 t	200 t	50 000 t

DG Storage Description	Proper Shipping Name	UN Number	Class	PG	Product / Common Name	Current			New		
						Max storage capacity	Typical Quantity	Annual Throughput (per annum)	Max storage capacity	Typical Quantity	Annual Throughput
Chlorine Cylinder – NH3 Cooling Tower	Chlorine	1017	2.3	-	Chlorine	4 t	3 t	16 t	No change	No change	No change
Refrigerated Ammonia Storage Tank (V101)	Anhydrous Ammonia	1005	2.3	-	Anhydrous Ammonia	12 000 t	8 000 t	100 000 t	No change	No change	50 000 kt
Pressurised Ammonia Bullets	Anhydrous Ammonia	1005	2.3	-	Anhydrous Ammonia	183 t	100 t	200 kt	100 t	50 t	350 kt
Cylinder Store	Acetylene Dissolved	1001	2.1	-	Acetylene Dissolved	270 kL	150 kL	288 m^3	No change	No change	No change
Nitric Acid Tanks	Nitric Acid	2031	8	I	Nitric Acid	2930 t	1663 t	345 000 t	5022 t	2682 t	605 000 t
Nitrogen Tank	Nitrogen Refrigerated Liquid	1977	2.2	-	Nitrogen Refrigerated Liquid	40 kL	30 kL	690 000 m^3	No change	No change	No Change

DG Storage Description	**Proper Shipping Name**	**UN Number**	**Class**	**PG**	**Product / Common Name**	**Current**			**New**		
						Max storage capacity	**Typical Quantity**	**Annual Throughput (per annum)**	**Max storage capacity**	**Typical Quantity**	**Annual Throughput**
MDEA Solution Tank	Amine Liquid Corrosive N.O.S – 40%.	2735	8	II	M.D.E.A.	400 kL	0 kL	40 kL	No Change	No Change	No Change
MDEA Solution Tank	Amine Liquid Corrosive N.O.S – 100%	2735	8	II	M.D.E.A.	40 kL	30 kL	40 kL	No Change	No Change	No Change
Aqua Ammonia Tanks	Ammonia Solution	2672	8	III	Ammonia Solution	220 kL	125 kL	904 t	No Change	No Change	No Change
Caustic Soda Tank	Sodium Hydroxide Solution	1824	8	II	Sodium Hydroxide Solution	30 t	25 t	460 t	No Change	No Change	No Change
Sulfuric Acid Tank	Sulfuric Acid <51%	1830	8	II	Sulfuric Acid <51%	30 t	25 t	300 t	No Change	No Change	No Change
R407C ISOTainer	Pentafluoroethane,1,1,1-Trifluoroethane & 1,1,1,2-Tetrafluoroethane azeotropic mixture	3340	2.2	-	Refrigerant Gas R407C	16 t	15 t	36 t	No Change	No Change	No Change

DG Storage Description	Proper Shipping Name	UN Number	Class	PG	Product / Common Name	Current			New		
						Max storage capacity	Typical Quantity	Annual Throughput (per annum)	Max storage capacity	Typical Quantity	Annual Throughput
R134A ISOTainer	1,1,2-Tetrafluoroethane	3159	2.2	-	Refrigerant Gas R134A	16 t	15 t	194 t	No Change	No Change	No Change

A I.4 Weather Data

Weather is classed according to wind speed and weather stability class. Table AI-7 below shows the different weather stability classes.

Table AI-7: Weather Stability Classes

Class	Type	Description
A	Very Unstable	Daytime – sunny, light winds (strong insolation)
B	Unstable	Daytime – moderately sunny, light to moderate winds
C	Unstable / Neutral	Daytime – moderate winds, overcast or windy and sunny
D	Neutral	Daytime – windy, overcast or Night-time - windy
E	Stable	Night-time - moderate winds with little cloud or light winds with more clouds
F	Very Stable	Night-time - light wind, little cloud (strong temperature inversion)

To ensure consistency, GHD have used meteorological data provided by Orica, which was used by ENSR for stack plume modelling. The wind/weather data set obtained covers the period of 2006 and was divided into four classes based on wind speed and weather class as follows:

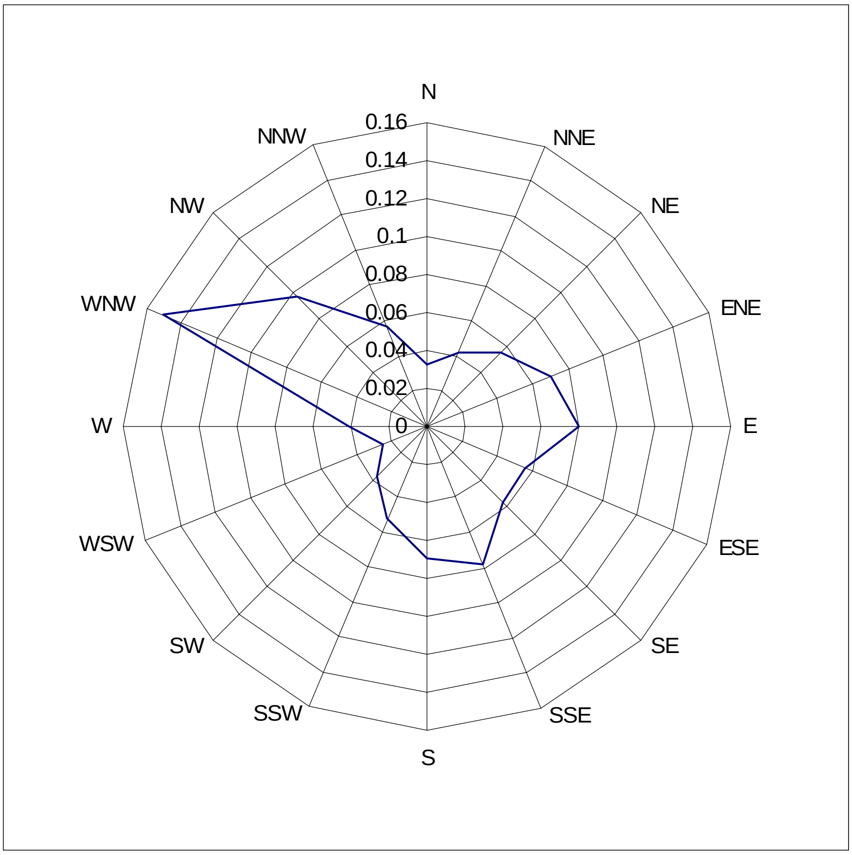
- Wind 1 m/s, weather stability class C;
- Wind 3 m/s, weather stability class D;
- Wind 7 m/s, weather stability class D; and
- Wind 1.5 m/s, weather stability class F.

The combined wind rose for all wind speeds and weather classes is shown in Figure AI-3 below.

The annual average ambient weather conditions identified for the site are as follows;

- 18°C
- 70% humidity.

Figure AI-3: Annual Average Wind Rose



A I.5 Population Data

The population data for the residential areas used in the model was obtained from the ABS 2006 census. The population of the surrounding industrial sites is not included in the model.

The cut off for the population count was based on the distance to 1% fatality (4 km from KI).

Table AI-8: Population Data Used in QRA

Area	Population
Stockton	4200
Suburban (Tighes Hill, Islington, Carrington, Mayfield, Wickham, Maryville, Newcastle)	12418

References

1. Assessment of the Dangerous Toxic Load (DTL) for Specified Level of toxicity (SLOT) and Significant Likelihood of Death (SLOD), UKHSE www.hse.gov.uk/hid/haztox.htm.
2. Hazardous Industry Planning Advisory Paper No. 6 "Guidelines for Hazard Analysis", NSW Department of Planning. 1992.
3. International Toxicity Estimates for risk Database ITER, hazardous Substances database for furfural, CAS Number 98-01-1.
4. Lees, F.P. (1996), "Loss Prevention in the Process Industries", 2nd Edition, Butterworth-Heinemann, Oxford, UK.
5. NIOSH documentation for immediately Dangerous to Life or health Consideration www.cdc.gov/niosh/idlh/idlhintr.html.
6. Perry, R.H. & Green, D.W. (1997), "Perry's Chemical Engineers' Handbook", 7th edition, McGraw-Hill, New York.
7. DNV Technica, *Effects of Radiation (World Bank) Table*. SAFETI Training Manual, Page 3.15, February 1999.
8. Clancy, V.J. *Diagnostic Features of Explosion Damage*, 6th International Meeting of Forensic Sciences, Edinburgh, 1972.
9. TNO Purple Book (CPR 18E) "Guidelines for Quantitative Risk Assessment", 1999
10. DSM Memo 1156 CVM/78 "Invloed van Toxische Stoffen", ten Berge W.F., 1978
11. AIHA, Emergency Response Planning Guidelines, AIHA, Akron, 1989.
12. Cox, A.W., Lees, F.P. and Ang, M.L. Classification of Hazardous Locations, Pub. I. Chem.E, 1990
13. HSE (2001): *Offshore Hydrocarbon Releases Statistics 2001*, Offshore Technology Report, United Kingdom HMSO.
14. Matheson, Matheson Gas Data Book, Sixth Edition, December 1980.
15. Encyclopaedia of Occupational Health and Safety, Vol 1 & 2, 3rd Edition, 1985.
16. Acute Exposure Guideline Levels for Selected Airborne Chemicals, Volume 6, 2008)

Appendix II – Hazard Identification

This Appendix has been withheld from the publicly exhibited Environment Assessment as it is an "exempt document" for the purposes of the Government Information (Public Access) Act 2009 (NSW).

Appendix III – Consequence Models

(Refer to Appendix I in 2009 PHA report Rev 8)

APPENDIX III

A III Consequence Modelling

One part of the risk assessment process involves generating consequences for the release events identified. The steps involved in determining consequences are:

- Determine release conditions based upon materials involved, process conditions and available inventory etc;
- Based on release conditions, determine the types of events which will occur (eg jet fire, toxic cloud, evaporating pool or explosion etc);
- Calculate the extent of the consequences; and
- Establish the impact of the consequence (e.g. proportion of people killed when exposed to a toxic dose)

The consequences are calculated using empirically derived models, which can then be used to determine which release cases generate offsite effects and should be included in the risk model. The level at which fatal consequences are considered to occur will directly influence the risks.

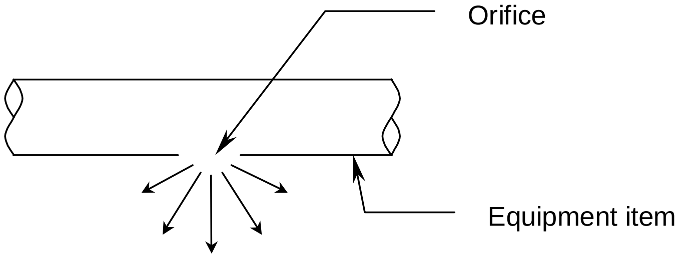
This Appendix discusses basic concepts and theory behind the various consequence models used in the analysis. The models discussed are:

- Discharge Modelling
- Dispersion
- Flammable Effects - Jet Fire
- Toxic Effects
- Ammonium Nitrate Explosions

A III.1 Discharge Modelling

If there is a hole in a pipeline, vessel, flange or other piece of process equipment, the fluid inside will be released through the opening, provided the process pressure or static head is higher than ambient pressure. The properties of the fluid upon exiting the hole play a large role in determining consequences, eg, vapour or liquid, velocity of release etc. Figure AIII-1 illustrates an example scenario.

Figure AIII-1: Typical Discharge



The discharge can be considered to occur in two stages, the first is expansion from initial storage conditions to orifice conditions, the second from orifice conditions to ambient conditions.

The conditions at the orifice are calculated by assuming isentropic expansion, i.e., entropy before release equals entropy at orifice. This allows enthalpy and specific volume at the orifice to be calculated.

The equations for mass flow rate ($\dot{m}$) and discharge velocity (u_0) are then given by:

$$\dot{m} = C_d A_o \rho_o \sqrt{-2\left(H_0 - H_i\right)}$$

AND

$$u_0 = C_d \sqrt{\left(-2(H_0 - H_i\right)}$$

Where

- C_d = Discharge coefficients
- A_o = Area of the orifice
- ρ_o = density of the material in the orifice
- H_o = Enthalpy at the orifice
- H_i = Enthalpy at initial storage conditions

The discharge parameters passed forward to the dispersion model are as follows:

- Release height (m) and orientation;
- Thermodynamic data: release temperature (single phase) or liquid mass fraction (two-phase), initial drop size;
- Other data:
  - for instantaneous release: mass of released pollutant (kg), expansion energy (J)
  - for continuous release: release angle (degrees), rate of release (kg/s), release velocity (m/s), release duration (s).

A III.2 Dispersion

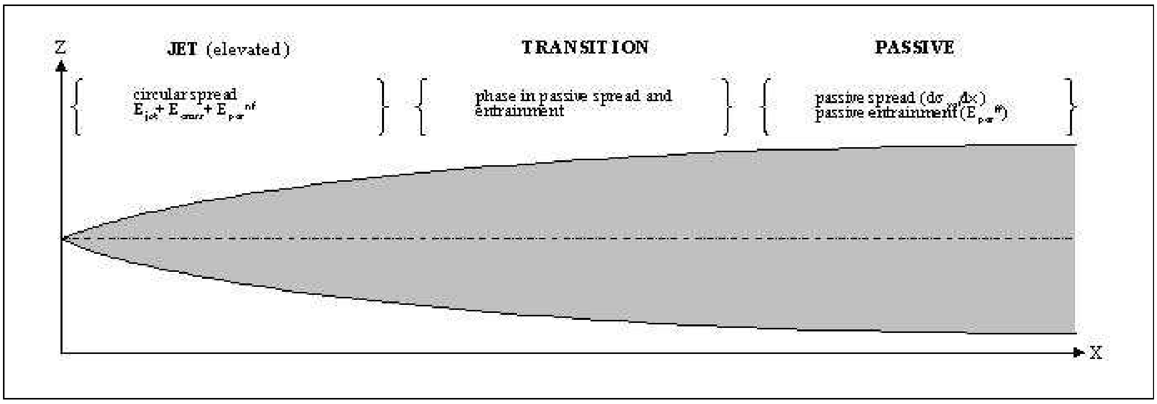
When a leak occurs, the material will be released into the atmosphere. Upon being released, it will start to disperse and dilute into the surrounding atmosphere. The limiting (lowest) concentration of interest is related to flammable and toxic limits for flammable and toxic substances respectively. The model used to determine extent of release is described below, along with some of the key input parameters.

PHAST is a consequence-modelling package that utilises the Unified Dispersion Model (Witlox *et al*, 1999). This models the dispersion following a ground level or elevated two-phase unpressurised or pressurised release. It allows for continuous, instantaneous, constant finite duration and general time varying releases. It includes a unified model for jet, heavy and passive two phase dispersion including possible droplet rain out, pool spreading and re-evaporation.

A III.2.1 Jet Dispersion

For a continuous, pressurised release, the material is released as a jet, i.e., high momentum release. The jet eventually loses momentum and disperses as a passive cloud. Figure AIII-2 below shows a typical release and the various phases involved.

Figure AIII-2: Jet Dispersion



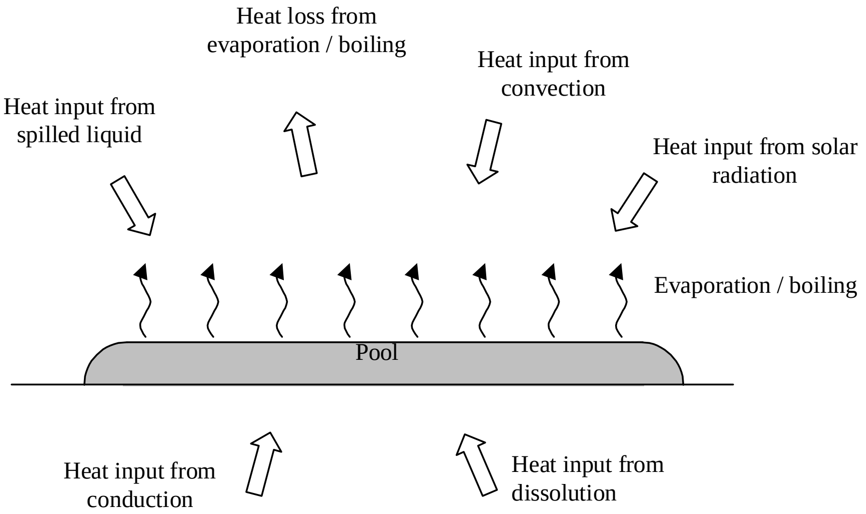
The cloud is diluted by air entrainment until it eventually reaches the lower limit of concern. During the jet phase, the mixing is turbulent and much air is entrained. In the passive phase, less air is potentially entrained, and it occurs via a different mechanism to the turbulent jet phase. The calculation of the plume therefore depends on many factors, the key parameters being:

- Material released, specifically molecular weight;
- Discharge conditions including phase(s) of release, velocity, etc.;
- Atmospheric conditions (a cloud will generally travel further in more stable conditions with lower wind speeds).

A III.2.2 Dispersion from Pool Evaporation

If a rupture occurs from a refrigerated tank or vessel such as the refrigerated ammonia tank V101, the refrigerated liquid product will leak out and form a pool on the ground. (This may also occur to some extent with pressurised liquids stored at ambient conditions such as liquid chlorine, due to 'self-refrigeration' ie evaporative cooling, where much of the liquid will vaporise immediately on vessel rupture but some will not vaporise, or will condense and rain out, and form a pool.) This pool will evaporate and the resulting vapour cloud disperses as a low momentum cloud. Due to the low momentum, the cloud is not turbulent, which is a significant factor in air entrainment and dilution of the cloud. Figure AIII-3 below shows a typical release and some of the inputs into the calculation.

Figure AIII-3: Pool Evaporation Heat Balance



The rate of the evaporation depends on numerous factors, the most important ones being:

- Surface it is released onto (eg. its thermal properties and temperature);
- Atmospheric conditions (a cloud will generally travel further in more stable conditions with lower wind speeds).
- Boiling point of the liquid;
- Pool size.

The concentration of interest is normally related to the flammable or toxic limits set for the hazardous material.

A III.3 Flammable Effects

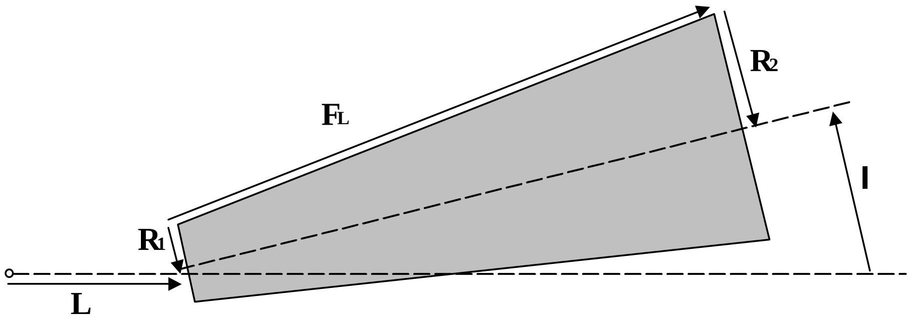
If the release is of a flammable material, it is possible for the release to be ignited. The resulting type of fire (eg. jet, pool, explosion etc) depends on the physical properties of the release and whether the ignition is immediate or delayed. For Orica's Kooragang Island facility, only jet fire is of interest for flammable effects due to the nature of the materials that can be released.

A III.3.1 Jet Fire

Jet fires are a result of high momentum releases. If a flammable release is ignited instantaneously, a jet fire will result. The flame will have a degree of 'lift off' as the flammable mixture has to dilute to be within the flammable limits. This section briefly discusses the model used for jet fires as well as key parameters in the calculation.

The jet fire calculation utilises the Chamberlain model (Chamberlain 1987). In this model, jet fires are modelled as a conical flame, with the ignited portion lift off, inclination and shape being determined by the material being released, the pressure at which it is being released and the hole size that it is being released through. These release parameters are the main inputs to the jet fire radiation calculations. Figure AIII-4 below shows a graphical representation of the jet fire model.

Figure AIII-4: Truncated Cone Jet Fire Model



Where;

L = Lift off

I = Flame Inclination

R_1 = Flame Base Radius

R_2 = Flame End Radius

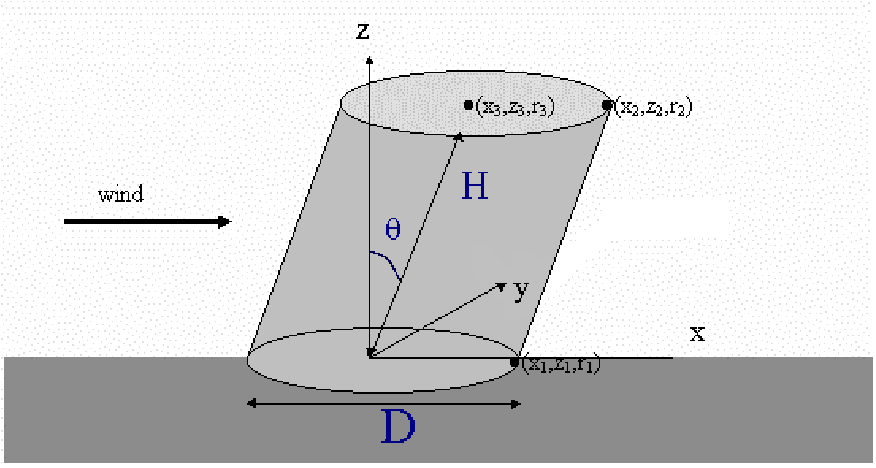
F_L = Flame Length

The jet fire calculations model radiation from the entire surface of the ignited portion of the jet. This includes radiation from the cone forming the body of the flame, as well as from the ends of the cone. The amount of radiation that a nearby receiver is exposed to is determined by its distance from the flame surface, as well as by the orientation of the flame relative to the receiver. The key parameters in the calculation of the radiation exposure of a receiver are therefore the flame lift off, the flame inclination, and the dimensions of the ignited portion of the jet (i.e. flame length and end radii).

A III.4 Pool Fire

Pool fire flames are modelled as cylinders sheared in the direction of the wind, with diameter *D*, height *H* and tilt angle *q* (measured from the vertical). The flame is described by three circles (c1, c2, c3) arranged along the centreline of the flame, each defined by the downwind co-ordinate *x* and elevation *z* of the centre of the circle, and by the radius *r*. These flame-circle co-ordinates are the main input to the radiation calculations.

Figure AIII–5: “Sheared Cylinder” Pool Fire Model



With these three circles, the radiation calculations will model radiation from two surfaces: from the side of the flame between c1 and c2, and from the top of the flame between c2 and c3. This approach ensures that the bottom of the pool fire is not treated as a radiating surface.

The flame length *H*, flame diameter *D* and tilt angle θ are used to calculate three co-ordinates of the flame, as follows:

$$
\begin{array}{lll}
x_1 = 0.0 & x_2 = H\sin\theta & x_3 = H\sin\theta \\
z_1 = d_{elev} & z_2 = H\cos\theta + d_{elev} & z_3 = H\cos\theta + d_{elev} \\
r_1 = D/2 & r_2 = D/2 & r_3 = 0.0 \\
\phi_1 = 0.0 & \phi_2 = 0.0 & \phi_3 = 0.0
\end{array}
$$

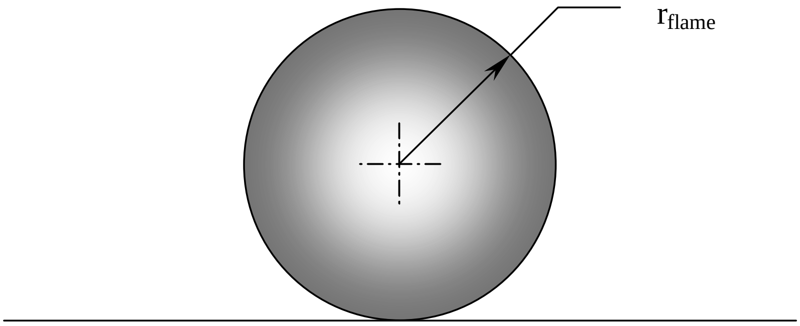
ϕ is the inclination of the circle with respect to the horizontal. For pool fires, this is set to zero for all three circles, but for jet flames each circle may have a different, non-zero inclination.

A III.5 BLEVE

A BLEVE is a ‘Boiling Liquid Expanding Vapour Explosion’ and refers to the release of energy when a vessel of liquefied gas erupts due to flame impingement. If there is direct flame impingement beneath the liquid line on the vessel, the evaporating liquid will provide cooling to the vessel walls. If designed correctly, the vessel pressure relief ensures that the pressure inside the vessel does not rise above design limits. If the flame impingement is on the vapour space, the pressure will also increase but there is inadequate cooling of the vessel wall. The metal temperature will rise to an extent where the mechanical strength is reduced. A point will be reached where the mechanical integrity of the vessel is insufficient for the pressure inside the vessel and the vessel erupts in a BLEVE. The BLEVE itself is the explosion resulting from rapid evaporation of the liquefied gas as it is released to atmospheric pressure. This section describes the equations used to determine BLEVE properties and key input parameters.

BLEVEs are modelled as spheres as shown below, with the shape described by ten circles. The method of using circles is also used for pool and jet fires. These circles are equally spaced along the flame diameter. Each circle is defined by the elevation z of the centre of the circle and the radius r. The centre of the fireball is located immediately above the point of release, at a height equal to the radius of the fireball.

Figure AIII-6: BLEVE Model



The radius of the BLEVE is calculated from:

$$r_{flame} = 2.9M_{BLEVE}^{\frac{1}{3}}$$

Where M_{BLEVE} is the flammable mass involved in the BLEVE. This is a function of the total mass released and the vapour fraction.

The duration of the BLEVE is important as it gives the time for which personnel are exposed to the effects of the fireball. It is a function of the BLEVE mass, and is given by the equations below:

$$t_{flame} = \begin{cases} 0.45M_{BLEVE}^{\frac{1}{3}}, & M_{BLEVE} < 37000kg \\ 2.59M_{BLEVE}^{\frac{1}{6}}, & M_{BLEVE} \geq 37000kg \end{cases}$$

The amount of radiation that a person receives is dependent not only on the duration of exposure but also on their distance from the fireball and the heat emitted by the fireball. The emissive power of the flame surface is a function of M_{BLEVE}, heat of combustion of the material and fire ball size and duration.

A III.6 Overpressure

The overpressure from an explosion can lead to much damage due to the pressure wave which results from the explosion. Generally with an explosion, the pressure wave causes more damage than the fireball. This is because the size of the pressure wave is larger than the fireball.

The TNT equivalence model is used to calculate explosion overpressure. This compares the heat of combustion of the material to the value for TNT, and thus calculates an equivalent mass of TNT. This mass is reduced by a factor for the explosion efficiency.

The explosion overpressure is then calculated according to the relationship developed by Kingery & Bulmash:

$$\log_{10} P = a(\log_{10} z)^2 + b\log_{10} z + c$$

Using the efficiency and equivalence factors, a mass of ammonium nitrate is equated to a mass of TNT. The distances to defined overpressures of interest are calculated using the 'TNT overpressure vs. scaled distance' relationship.

Z is a scaled distance and is calculated according to $z = \frac{R'}{m_{TNT}^{1/3}}$

Where m_{TNT} is the mass equivalence of TNT and R' is the explosion radius.

In calculating the overpressure distance for ammonium nitrate the equation is represented as:

$R' = m_{TNT}^{1/3} \text{ x } 10^{(2.061-1.092\log10(P) + 0.158(\log10(P)^2))}$

A III.7 Toxic Impact

The toxic effects of an on-site toxic release are evaluated using a probit equation in SAFETI. The probit uses dispersion data from the consequence modelling to determine the probability of fatality for a person at a given distance from the release, over the entire duration of the release.

The probit function, generally used for calculating fatality consequences from toxic releases is a measure of time dependent probability of fatality from exposure to toxic chemicals. For toxicity it is a function of concentration of exposure and time exposed to this concentration. The general form of the function is:

$$\Pr = k_1 + k_2 \ln\left[C^n t\right]$$

Where Pr = Probit value

C = Concentration of interest

t = time exposed to concentration, C

k_1, k_2, n = constants specific to each material

It is converted to a probability of fatality via the function:

$$P(death) = \frac{1}{2}\left[1 + erf\left(\frac{\Pr - 5}{\sqrt{2}}\right)\right]$$

The Probit functions used are shown in Table AIII-1 below.

Table AIII-1: Toxic Probits

Material	Probit Function Used	Source
Ammonia	-9.82 + 0.71ln[C^2 x t]	DCMR 19853, C3399
Nitrogen Dioxide	-13.79 + 1.4ln[C^2 x t]	Harris DSM78
Chlorine	-10.1 + 1.11ln[C1.65 x t]	Van Heemst

A III.8 Ammonium Nitrate Explosion

The following sections detail the scenarios that can result in the detonation of ammonium nitrate, the modelling of the resultant overpressure and fatalities and finally the risk that this poses on the facility and offsite.

Since completion of the 1992 study, there has been increased understanding of the risks of ammonium nitrate (AN) explosions. In particular, it is now recognised that it is possible for solid AN explosions to occur in storage as a result of intense and prolonged fires, or following substantial contamination with certain sensitising materials. It has also been found that solid AN may detonate if exposed to sufficiently high energy initiation, such as from a high energy missile or projectile which could be produced in an adjacent plant detonation.

Highly concentrated AN solutions may explode if sufficiently contaminated and acidic, when heated for prolonged periods to abnormally high temperatures.

As a result additional hazardous scenarios have been included in the PHA covering such events.

A III.8.1 Detonability of Ammonium Nitrate

Ammonium nitrate, as prepared by Orica, is classed as an oxidiser and has the following characteristics:

- It cannot burn without a combustible material present;
- It melts at 169ºC;
- It starts to decompose after melting, releasing fumes of NO_X, HNO_3, NH_3 and H_2O;
- At roughly 290ºC decomposition reactions of both exothermic and endothermic types generate an equilibrium keeping the temperature constant at this temperature, noting that this is dependant upon the decomposition gases being able to vent.

The sensitivity of ammonium nitrate to detonation is largely dependant on three variables; temperature, confinement and contamination. Without any of these three being present, ammonium nitrate requires a strong initiation charge (an example being high explosives) to detonate.

Higher temperature makes ammonium nitrate more sensitive to detonation as detailed below:

- Higher temperature causes decomposition. The ammonia, which is evolved, causes the pH of the remaining ammonium nitrate to drop, leading to greater detonation sensitivity.
- High temperature decomposition can lead to bubbles in the molten ammonium nitrate, which reduces the density of the liquid and hence increases sensitivity to detonation.

Confinement makes ammonium nitrate more sensitive to detonation as detailed below:

- Confinement of molten ammonium nitrate increases the sensitivity to detonation by restraining the decomposition gases.
- For ammonium nitrate, typically 80 atmospheres are required for detonation.

Contamination makes ammonium nitrate more sensitive to detonation as detailed below:

- As a pure compound, ammonium nitrate is less sensitive to detonation than if it is contaminated. At 1% contamination with hydrocarbons (eg. oils / diesel, etc.), it is at its most sensitive.
- Other impurities, such as some metals, acids (or low pH from decomposition) and salts, have a strong catalytic effect on the decomposition of ammonium nitrate and hence increase its sensitivity to detonation.

Interactions between heat, confinement and contamination combine together to increase the detonation sensitivity of ammonium nitrate, often resulting in an impact greater than their individual effects.

A III.8.2 Factors Influencing Ammonium Nitrate Explosions

Without any of the three variables previously discussed being present, ammonium nitrate requires a strong initiation charge to detonate. This scenario represents a malicious activity (such as terrorism) which is not assessed numerically as part of a Quantitative Risk Assessment (QRA). The threat of malicious activity is best assessed and mitigated through security assessments and control measures.

There is little value in attempting to quantify the risk of malicious activities due to the uncertainty involved in estimating the frequency of persons being sufficiently disgruntled with an organisation (or the connections to an organisation a disgruntled person may perceive to exist) to actively damage facilities or harm personnel. It should be noted that there may be a portion of the historical accident events included in the data sets used in this study which were malicious activities where the cause was not accurately identified.

Once intentional detonation of ammonium nitrate is excluded from the QRA, only accidental scenarios remain to be assessed for credibility. Assessing the credibility of accidental scenarios is carried out to ensure that alarmist or excessively conservative scenarios are not modelled and that those scenarios that are modelled are considered to be as realistic as possible and reflect the historical record. Accordingly, the characteristic of such accidental detonations is usually the presence of all three contributors; heat, confinement and contamination.

Detonation from Heat

Heat alone has never been recorded to cause detonation of ammonium nitrate, which is not confined or contaminated. However, heat can lead to ammonium nitrate melting and flowing to areas where confinement or contaminants may also be contributors. There, toxic gases can also be emitted due to heating of ammonium nitrate.

A vehicle fire on its own in the ammonium nitrate Bulk Store is unable to cause an ammonium nitrate explosion. However, if burning fuel from the vehicle were to mix with molten ammonium nitrate and an explosion from the vehicle caused high-velocity shrapnel to impact the molten contaminated ammonium nitrate, an explosion is possible, an event borne out by the historical record [Shah, 1996 - Table 4, No. 24].

Detonation from Confinement

Confinement alone has never been recorded to cause detonation of ammonium nitrate, which is not heated or contaminated. However, heated ammonium nitrate will decompose and release vapours which if confined leads to increased pressure and greater sensitivity to detonation. While the pressure required is 80 atmospheres, this can be reduced by the presence of contaminants. This can reduce the pressure required for detonation to 20 atmospheres.

The historical record shows several fatalities caused by maintenance work on screw conveyor shafts, which have become filled with ammonium nitrate over time. The heat from welding causes decomposition of the trapped ammonium nitrate, the pressure increases leading to detonation and injuries or fatalities [Shah, 1996 - Table 4, No. 6, 10, 25, 29, 31, 61].

Detonation from Contamination

Contamination can lead to catalytic decomposition of ammonium nitrate and can also (if a combustible material) lead to fire, which adds heat to the scenario. Accordingly, Australian Standard “AS 4326-2008: The storage and handling of oxidizing agents” directs that the storage of ammonium nitrate be free of contaminants and details the housekeeping requirements to ensure this. In the instance that ammonium nitrate solution is stored in acidic conditions, the decomposition can lead to bubbles forming in the solution. With heating, these bubbles may lead to detonation [Shah, 1996 - Table 4, No. 48, 60, 69].

A III.8.3 Credible Detonation Scenarios

Appendix II details the significant ammonium nitrate inventories on site. Each one is assessed for credible scenarios leading to detonation. Note that potential fire or fumes as an outcome is not detailed here, only detonation. Consequences of an ammonium nitrate explosion were determined according to the following steps.

The plume of combustion products resulting from an ammonium nitrate fire in previous studies (eg. Bunbeg Harbour, etc.) have been shown to be buoyant due to the high temperatures involved, and disperse to non-hazardous concentrations before returning to grade. On this basis, toxic effects from ammonium nitrate fires are excluded from the analysis.

Proportion Sensitised to Detonation

The proportion of material sensitised to detonation helps define the consequences of an explosion. As detailed in Section A III.8.2, the action of higher temperature, confinement and contaminants sensitise ammonium nitrate to explosion. However, the effects of heat, confinement or contamination may not extend to the entire inventory.

Explosion of ammonium nitrate in storage could lead to offsite effects. Bulk ammonium nitrate prill is stored in freestanding piles, hence it is difficult for the influence of heat, confinement and contaminants to carry over the entire inventory. A review of all the known significant ammonium nitrate accidents between 1961 to the present [Shah 1996 and GHD Review] has only resulted in two cases where bulk prill has exploded. These are the Toulouse incident [Dechy, 2004, event occurred in 2001] and the Cherokee incident [Shah 1996, Table 4, Entry 24, event occurred in 1973]. The Toulouse incident involved contamination of prill and the Cherokee incident involved a fire with a front-end loader. In both cases only a small proportion of the ammonium nitrate present was detonated. The proportion of material involved in the explosion is taken in the model as a realistic proportion of the total present.

A III.8.4 Overall TNT Equivalence

The Overall TNT Equivalence of ammonium nitrate provides an estimate of the blast energy of ammonium nitrate relative to TNT, best represented by the following equation:

Overall TNT Equivalence = Chemical TNT Equivalence x Explosive Yield

The Chemical TNT Equivalence is a ratio based on the relative thermodynamic properties of the two chemicals. Published values ranges from 55% to 32%, depending on the thermodynamic method used. Orica has adopted an "industry" value of 32% chemical equivalence (as referenced e.g. in the Queensland Explosives Inspectorate Information Bulletin 53).

The estimate of Explosive Yield is based on expert judgement within Orica Mining Services (via the Orica AN Expert Panel).

While there are several categories of ammonium nitrate products, the predominant type produced at Orica's Kooragang Island facility is low-density (i.e.< 0.92 g/cc), porous prills/granules, often referred to as technical grade ammonium nitrate (TGAN). For this material, Orica proposed three distinct explosion scenarios, with the corresponding estimates of Overall TNT Equivalence:

- High energy decomposition due to chemical contamination, 16% Overall TNT Equivalence;
- Molten AN decomposition from radiation and confinement, 5% Overall TNT Equivalence;
- Detonation from high energetic impact, 32% Overall TNT Equivalence.

The equivalency and efficiency used in this QRA mutually agreed between Orica and NSW Department of Planning are listed below. These figures are considered more conservative than those figures originally proposed by Orica.

Table AIII-2: Overall TNT Equivalency Values used in QRA

	Bags	Bulk in Bays	Bulk in free Stockpiles
Fire	20%	15%	10%
Contamination	20%	15%	10%
Projectile	32%	32%	32%

A III.8.5 Thermal Decomposition of AN

Fire involving ammonium nitrate and thermal decomposition results in the release of toxic fume, which contains NO_X, typically nitric oxide (NO) and nitrogen dioxide (NO_2). NO_2 gas is considered more toxic than NO.

There is limited published data on NOx generation from AN fires. The investigation completed by W. D. Adams for UK HSE estimated NO_2 releases for:

1. Externally applied heat to AN in a pile produced NO_2: 3g/s/m^2 floor space. This is applied to the Bulk Store fire and thermal decomposition.
2. Fire involving AN in bags stacked on timber pallets produced NO_2: 10 g/s/ per 250kg bag AN. This is applied to Bag Store fire and thermal decomposition.

References

AIHA, Emergency Response Planning Guidelines, AIHA, Akron, 1989.

Chamberlain, G. A., 1987, Developments in design methods for predicting thermal radiation from flares, Chem. Eng. Res. Des. v65 (1987).

Cox, A., Lees, F., and Ang, M., Classification of Hazardous Locations, Institute of Chemical Engineers, Warwickshire, 1990.

Daubert, T.E. and Danner, R.P. 1989, *Physical and thermodynamic properties of pure chemicals,* Data compilation by Design institute for physical property data and American institute of chemical engineers, Hemisphere Publishing Corporation.

Dechy, N & Mouilleau, Y, 2004, Damages of the Toulouse Disaster, 21st September 2001, 11th International Symposium Loss Prevention 2004, 2004

Det Norske Veritas 1990, Port Risks in Great Britain from Marine Transport of Dangerous Goods in Bulk: A Risk Assessment, The Health and Safety Executive, DNV C1216, 1990,

Hazardous Industry Planning Advisory Paper No. 6 “Guidelines for Hazard Analysis”, NSW Department of Planning. 1992.

Lees, F.P., "Loss Prevention in the Process Industries", Vol 2, Butterworth Heinemann, Oxford, United Kingdom, 1996.

Médard, L. and Thomas, M., 1953, Heats of Combustion and Formation of AN, *Materials Propertie*s, vol. 35, pp. 155, 160 & 172, quoted in Fedoroff, *et.a*l.

Mellor J.W 1967, *Mellor's comprehensive treatise on inorganic and theoretical chemistry, vol.* 8(2) Nitrogen Part II, Longmans London, quoted in Daubert and Danner.SAFETI (Software for the Assessment of Fire Explosion and Toxic Impact) v6.4.2 help file.

SAFETI Modelling Software User Manual, DNV, 1995.

Shah, K.D. (1996), “Safety of Ammonium Nitrate Fertilisers”, Proceedings No. 384 of The International Fertiliser Society.

Ten Berge, W.F. Swart, A, Appelman, L.M. ‘Concentration – Time Mortality Response Relationship or Irritant and Systematically Acting Vapours and Gases, *Journal of Hazardous Materials*, (1986), 301 – 309.

TNO Yellow book, 2nd edition, TNO, The Netherlands (1992).

Wiltox, H.W.M. and Holt, A., “A unified model for jet, heavy and passive dispersion including droplet rainout and re-evaporation’, CCPS 1999 ADM paper.

DCMR Steering Committee, Study into the Risks from the Transportation of Liquid Chlorine and Ammonia in the Rijnmond Area. Selection of Probit Equations for Acute Toxic Gas Exposure, F291 Memo, Technica Ltd, July 1984.

van Heemst V., Estimating Chlorine Toxicity Under Emergency Conditions, Chlorine Safety Seminar, Brussels, November 14-15, 1990.

Appendix IV – Assumptions

(Refer to Appendix I in 2009 PHA report Rev 8)

APPENDIX IV

A IV Key Modelling Assumptions

In the process of undertaking the quantitative risk assessment of Orica's Kooragang Island facility, a number of key modelling assumptions have been identified that are critical to the risk results. This appendix lists the key modelling assumptions along with their assumed operating parameters.

The majority of modelling assumptions are associated with risk mitigation measures and are presented here as essential requirements to the design and operation of the facilities. These measures were developed through discussions with Orica engineers, safety and operations specialists. GHD has recorded these key mitigation measures here to ensure that the operation and performance of key mitigation measures is clearly defined as a key input into the risk results.

A IV.1 General Assumptions

The following assumptions are applicable to the risk modelling of all facilities.

- For vessels not connected to a dump system, leaks continue until the whole inventory is lost, but subject to a maximum time limit of 60 minutes. Within a 60 minute period all releases will have reached a steady state in term of hazard distance and potential fatal impacts. Therefore the modelling of consequences beyond the 60-minute period is not required. This assumption is not critical to the risk analysis.
- The study focus is on release events capable of producing an offsite fatality risk and injury / irritation risk; events that pose only an on-site risk are not modelled.
- The time to detect, investigate and isolate a process leak (other than for the ammonia transfer pipeline) using remotely operated valves (ROVs) has been (conservatively) assumed and modelled as ten minutes. The ten-minute response time is estimated from Orica response systems based on the following information from Kooragang Island Operations Specialists: Within two minutes of a major release in the processing plant a leak will be detected. The operators wearing appropriate PPE will investigate the indicated area and identify the point of leakage and initiate the necessary isolation measure(s). The time required for this operation is estimated to be eight minutes.
- Under Orica's operating philosophy, in the event of gas detection, the appropriate response will be decided by the operators on a case-by-case basis. Training in the selection of the appropriate response to different release scenarios is provided to all operators on a regular basis.
- Natural gas is imported to the site via a buried cross-country pipeline. The natural gas feeds the Ammonia Plant.
- The major plant equipment items and vessels containing significant inventories of hazardous materials are modelled. Minor lines and fittings are not modelled, as the consequences of failures of such items will be included in the failure scenarios for the major plant equipment items.
- The compositions of streams in the plant are simplified. For example, this enables natural gas streams typically comprising 90% methane, 8% ethane, 1.5% propane and 0.5% heavier components to be modelled as pure methane, which simplifies the analysis but does not affect the results of the modelling.

A IV.2 Ammonia Plant

- Liquid ammonia (99.88% concentration) is transported via pipeline to the Ammonia Storage Tank. The ammonia transfer pipelines can by isolated remotely by actuated valves. For the base case (existing operation) in the event of loss of containment from the pipeline ammonia will be released for up to 30 minutes at the normal production feed rate.
- A major leak in the Ammonia Plant will be detected and isolated in 10 minutes.
- The failure of the flash drums and receiver containing ammonia in the Ammonia Plant will result in loss of total inventory of the vessel involved.

A IV.3 Ammonia Transfer and Storage

- The atmospheric Ammonia Storage Tank, V101, is surrounded by a bund (4m in height) designed to contain the full content of the tank. The bund will not fail during rupture of the tank.
- In the event of a release of refrigerated ammonia within the storage tank bund, the spill surface temperature will drop rapidly as the cold ammonia moves across the surface.
- All potential liquid spills from the tank and associated plant equipment are located within the bund.
- In the event of a release of ammonia from the tank all liquid droplets are assumed to be contained within the bund.
- The ammonia pipeline from the ship is mostly underground. Pipe failure and ammonia release is considered only for the exposed section of the pipeline. The underground section 100m approx is located within a secondary containment pipe – a failure from NH3 pipe in this section could result in NH3 emitting from either end of the containment pipe.
- An ammonia release at the wharf involving the pump or pipe is assumed to result in 50% of the ammonia falling into the water and 50% onto dry land. Ammonia ending up in the water is assumed to result in 60% of ammonia being absorbed by the water and 40% evolved into the air.
- Ammonia bullets supply the Nitric Acid and Ammonium Nitrate Plants.
- In the event of a major leak involving the ammonia transfer pipeline from Ammonia Plant to other users, the time to detect and isolate the pipeline is estimated to take 30 minutes for the Existing case. There will be some delay in isolating the pipeline including the time it takes to detect the leak depending upon the location of the leak. Currently there are no gas detectors to warn the control room in the event of a leak.
- For the ammonia transfer pipelines for the Expanded Facility the time to detect and isolate a leak has been assumed to be 5 minutes based on appropriate means of leak detection (combination of gas detection and flow detection). Trevor Kletz in Lees Vol 2, page 17/154, suggests that ‘if a remotely controlled emergency isolation valve is fitted, it may be assumed that it will be operated within 5 minutes’.

A IV.4 Ammonium Nitrate Production and Storage

- Explosions of ammonia nitrate (AN) have been identified as a hazard associated with the production and storage of ammonium nitrate.

- Explosions involving AN solution is considered for solutions greater than 85% strength. Explosions involving AN solution lower than 85% strength is considered extremely unlikely and has not been modelled.
- Explosion involving dry ammonium nitrate in production is considered for the unit operations with greater than 1 tonne inventory.
- The separation distance, to be determined by Orica, between the bulk stock piles in the Bulk Store and bag stacks in the Bag Store are assumed to be sufficient to prevent sympathetic explosion.

Reference:

1. Lees F.P, Loss Prevention in the Process Industries, Hazard Identification, Assessment and Control, Vol 2, 2nd Edition, 1996.

Appendix V – Consequences

This Appendix has been withheld from the publicly exhibited Environment Assessment as it is an "exempt document" for the purposes of the Government Information (Public Access) Act 2009 (NSW).

Appendix VI – Frequency Analysis

This Appendix has been withheld from the publicly exhibited Environment Assessment as it is an "exempt document" for the purposes of the Government Information (Public Access) Act 2009 (NSW).

Appendix VII – Methodology

(Refer to Appendix I in 2009 PHA report Rev 8)

APPENDIX VII

A VII Individual Fatality Risk

Location Specific Individual Risk (LSIR) is a measure of the level of risk an individual would be exposed to, if continuously present in a particular location for a whole year (or for the full duration of the activity). It does not take into account any actions that people might take in the area to escape from an event, or the actual time that people are present. It is also independent of land use and exposed population type. The risk exposure is calculated for all relevant hazards and summed to give the overall level of risk in each location.

The LSIR for any given location, failure case and associated consequence outcomes (e.g. pool fire, jet fire, flash fire, vapour cloud explosion (VCE), toxic exposure) can be represented as:

$$\text{LSIR} = R \times I \times \sum (M \times C \times F)$$

where:

$\sum$ = Sum of probability of fatalities for each alternate type of consequence (jet fire, toxic release etc) for the location for which the LSIR is calculated.

R = Release frequency.

I = Ignition probability (not relevant for toxic releases).

M = Fractional probability of each alternate type of consequence occurring (governed by the SAFETI MPACT parameter file(s)).

C = Consequence result for each type of consequence in terms of level of toxic gas, radiant heat or explosion overpressure, experienced at the location.

F = Fractional probability of fatalities for each alternate type of consequence result, based on exposure level / event duration, experienced at the location.

The total LSIR at any location may be calculated by summing the frequency of fatalities for all release events and consequence outcomes for that location.

NSW Individual Risk Criteria

The New South Wales Government requires that new potentially hazardous developments comply with the risk criteria defined and published by NSW DoP *Hazardous Industry Planning Advisory Paper No. 4 – Risk Criteria for Land Use Safety Planning* (HIPAP 4). The criteria covers public fatality, injury, and irritation risk criteria to which all new potentially hazardous industrial developments must adhere. The fatality criteria are summarised in Table AVII-1.

Table AVII-1: Risk Criteria published in HIPAP 4

Exposure Type	**Risk Levels**
Hospitals, schools, child-care facilities and old age housing developments	Half in a million per year (0.5 x 10^{-6} per year)
Residential developments and places of continuous occupancy (hotels/resorts)	One in a million per year (1 x 10^{-6} per year)
Commercial developments, including offices, retail centres, warehouses with showrooms, restaurants and entertainment centres	Five in a million per year (5 x 10^{-6} per year)
Sporting complexes and active open space areas	Ten in a million per year (10 x 10^{-6} per year)
Industrial sites	Fifty in a million per year (50 x 10^{-6} per year)

The risk contours generated by SAFETI provide a means to determine whether the risk presented by the facility exceeds any of the defined criteria.

For an industrial site, the risk of fatality should, as a target, be contained within its boundary at a level of fifty-in-a-million (50×10^{-6}) per year. HIPAP 4 does however allow for some flexibility in the interpretation of this criterion. In particular, it indicates that “where an [adjacent] industrial site … involves only the occasional presence of people, such as in the case of a tank farm, a higher level of risk may be acceptable”. The neighbours around the KI facility that would meet this definition are:

- Grain storage with occasional presence of people;
- Vacant space that could be occupied in the future;

A VII Societal Risk

Societal risk sets out how risks to the public vary with changing levels of hazard severity. It is generally represented graphically as a curve on log-log axes, called an FN-curve, with the frequency (F) on the vertical axis plotted against the cumulative fatalities (N) on the horizontal axis.

The FN-curve is often plotted against two regulatory risk limits; the unacceptable and tolerable risk limits, therefore defining three zones on the FN-curve. By convention, the tolerable risk limit is taken as two orders of magnitude below the unacceptable risk limit.

The three risk zones defined on a typical FN-curve are:

a) Above the upper risk limit, where the risk level is unacceptable;

b) Between the upper and lower risk limits, where the risk level is deemed tolerable . In this zone, the risk level should be "as low as reasonably practicable" (ALARP), i.e. any further risk reduction is not commensurate with the cost of achieving that risk reduction. The ALARP principle arises from the fact that it would be possible to spend an inordinate amount of time, effort and/or money attempting to reduce a negligible risk to near to zero.

c) Below the lower risk limit, where the risk level can be considered to be acceptable and therefore there is no need to consider any risk reduction measures.

By applying tests (a), (b) and (c), a series of tolerability limits can be proposed for incidents involving a defined number of casualties.

FN-curves allow a visual interpretation of the effectiveness of proposed risk reduction measures as significant changes in the frequency of large-fatality events may not easily be detected in risk assessments due to high frequency / low impact events dominating an analysis.

International Experience

Major hazardous incidents involving multiple fatalities (e.g. Seveso 1976, Flixborough 1978 and Bhopal 1984) were key drivers for the development of societal risk criteria. Leaders in the development of criteria for societal risk have been the UK, Netherlands and Hong Kong.

The UK HSE (UK Health and Safety Executive) has undertaken fundamental development work over many years in establishing appropriate values of societal risk. The UK HSE work has been used as the basis for developing societal risk criteria in some other European countries and in other parts of the world.

Guidance on societal risk was first developed in the province of Groningen in the Netherlands, primarily in response to several major hazardous incidents in Europe. In the Asian region, societal risk criteria have been published in Hong Kong and it is understood that these are based on modification of the UK criteria. The development of societal risk criteria in Hong Kong was proposed as a result of pressure for residential developments close to petrochemical facilities.

Australian Experience

The values for the societal risk limits were established by DNV (Det Norske Veritas) in 1984 (believed to be based on work from the Netherlands).

The NSW Department of Planning has published FN criteria for societal risk assessment in its Land Use Planning Safety Studies for Port Botany (1996) and for the Botany Randwick Industrial Area (2001), and the values are given in Table AVII-2 below. These were a ‘composite of some typical criteria adopted elsewhere.’

Table AVII-2: Published DoP FN-Curve Limits

Number of Fatalities	Frequency of N or more fatalities	Frequency of N or more fatalities
10	$1x10^{-4}$	$1x10^{-6}$
1000	$1x10^{-7}$	$1x10^{-9}$

A VII Fatality Impact Levels

A VII.1 Heat Radiation Criteria

The heat radiation fatality probability is based on the effects of heat radiation in the *Hazardous Industry Planning Advisory Paper (HIPAP) No's 4 and 6* by the NSW Department of Planning. Table AVII-3 is an extract from the HIPAP 4 and 6 guidelines.

Table AVII-3: Effects of Thermal Radiation

Heat Radiation kW/m^2	Effect
1.2	Received from the sun at noon in summer
2.1	Minimum required to cause pain in 1 minute
4.7	Will cause pain in 15 – 20 seconds and injury after 30 second exposure (2nd degree burns)
12.6	Significant chance of fatality for extended exposure. High chance of injury. After long exposure causes the temperature of wood to rise to a point where it can be readily ignited by a naked flame. Thin steel insulation on the side of the fire may reach a thermal stress level high enough to cause structural failure.
23	Likely fatality for extended exposure and chance of fatality for instantaneous exposure. Spontaneous ignition of wood after long exposure. Unprotected steel will reach thermal stress temperatures which can cause failures. Pressure vessel needs to be relieved or failure will occur.
35	Cellulosic material will pilot ignite within one minutes exposure. Significant chance of fatality for people exposed instantaneously.

SAFETI uses a probit function to calculate the fatality rate from thermal radiation. The probit function uses exposure time and thermal radiation level to estimate a fatality rate. The probit function used for the KI model is:

$$Y = -36.38 + 1.56 \ln(I^{1.33} \times t)$$

Where I = thermal dose in W/m^2 and t is time in seconds.

This probit is used for pool fires, jet fires and fireballs from explosions or BLEVES.

A VII.2 Flash Fire Criteria

In terms of consequence criteria the hazard distance relating to the dispersion distance is taken at less than the Lower Flammable Limit (90% of LFL). This distance defines the size of the flash fire engulfed region from which escape is not possible, ie 100% fatality inside this envelope. Modelling flammable clouds to 90% LFL is conventionally assumed to account for longer than anticipated dispersion anomalies (incomplete mixing, ground effects, building wake effects etc). Outside the cloud the fatality probability is assumed to be zero.

A VII.3 Boiling Liquid Evaporating Vapour Explosion (BLEVE) / Fireball Fatality Criteria

Exposure to a thermal dose of 250 kJ/m^2 is taken to be fatal. For a radiant heat level of 23 kW/m^2 this would correspond to a duration of 11 seconds.

A VII.4 Explosion Overpressure Fatality Criteria

The explosion overpressure fatality rate criteria used is also based on the only consequence effects publicly documented in Australia, the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6, by the NSW Department of Planning. is an extract from the HIPAP guideline.

Table AVII-4: General Overpressure Consequence Levels

Overpressure level (kPa)	Consequence of Overpressure
3.5	90% glass breakage. No fatality and very low probability of injury from overpressure.
7	Steel frame of a clad building slightly distorted. Associated with an injury probability of 10%, but a 0% chance of fatality.
14	Partial collapse of timber framed buildings. Buildings may become uninhabitable (again no fatalities are expected).
21	Storage tanks may buckle and fail. Can result in a 20% chance of fatality among people in a building but still no fatalities among those outside.
35	Timber framed buildings become uninhabitable, plant items may be overturned. There is a 50% chance of a fatality for a person in a building and 15% chance of a fatality for a person in the open.
70	100% chance of fatality for a person in a building or in the open. Complete demolition of buildings.

From the above table of overpressure effects, consequence impacts were assumed based on the level of overpressure received. Therefore the assumed fatality levels were conservatively assumed and used in the risk assessment as follows:

- At 70 kPa overpressure, 100% chance of fatalities for outdoor population.
- At 35 kPa overpressure, 15% chance of fatalities for outdoor population
- At 21 kPa overpressure, 1% chance of fatalities for outdoor population.

A VII.5 Toxic Criteria

If the release is a toxic material, it is necessary to attempt to relate the specific atmospheric concentrations and durations of exposure following a release to the level of toxicity produced within the surrounding population. The impact is determined from reports of accidental single exposure of humans to the airborne substance, or generated in single exposure inhalation studies in animals. All the data available in this area relates to toxic effects, which become apparent soon after exposure (acute impact).

Other effects, including mutagenicity, carcinogenicity and teratogenicity, may also arise as a result of a single exposure. These chronic impacts are not considered in this study.

For most substances, existing reliable data on acute effects arising from a single exposure in humans are sparse. For a few substances some information is available from their use in warfare (e.g., chlorine). Nevertheless, for most substances the data is limited to a few reports of accidental exposures, often involving only a few people and rarely containing accurate measurements or even estimates of exposure concentrations and times.

Consequently, heavy reliance needs to be placed on the results of experiments on animals, in attempting to predict the responsiveness of a human population. In general, extrapolation from laboratory animals to humans with any degree of accuracy and reliability is difficult, principally because of the inadequate information. Even so, for most substances it is necessary to make the assumption that results from animal experiments will be representative of effects on the human population, in terms of both the nature of the effects produced and the dose-effect relationships observed.

For some substances the scarcity of toxicity data will make any analysis extremely tenuous, and in these situations further experimental work by manufacturers or their trade associations would be advisable if important decisions depend on the results. For Orica, the public domain information available for the toxic materials assessed is suitable to base this study on.

Toxicity of a material can be measured against criteria for either fatality or survivability. Fatality criteria can be presented in terms of probits or dangerous dose. A probit is a mathematical system for estimating the probability of fatality based on the concentration and time exposed to a particular material. A dangerous dose is a single criterion that defines a certain level of dosage received over any time period that will result in fatality. Survivability criteria are those that, if a person is exposed to levels below the criteria, there is strong confidence that he or she will survive. There can be considerable separation between survivability and fatality criteria, which makes them difficult to compare.

A VII.6 Ignition Probabilities

Ignition can be either immediate or delayed. This section discusses the ignition probabilities for both immediate and delayed ignition.

A VII.6.1 Immediate Ignition Probability

Immediate ignition and explosion probabilities are used in this study. These are derived from Cox, Lees and Ang data (1990). Cox Lees & Ang ignition probabilities are based on historical offshore data, in particular the North Sea and Gulf of Mexico data (i.e. process leaks, blow-outs etc). The likelihood of immediate ignition takes into account all causes including the initiating mechanism for a release. Table AVII-5: shows, the immediate ignition probability as a function of the phase of the material released (liquid or gas / aerosol) and the release rate.

Table AVII-5: Immediate Ignition Probabilities

Release	Immediate Ignition Probability	
	Gas / Aerosol	Liquid Spill (pool evaporation)
Small	0.5%	3%
Medium	4%	4%
Large	10%	6%
Full-bore	30%	8%

A VII Injury and Irritation Risk Assessment Methodology

Different people have different levels of tolerance to toxic chemicals depending upon the physiological condition, weather condition, exposure level and duration. The exposure levels that can cause injury or irritation are reported in various sources, some of the common exposure levels reported are given in Appendix I.

The toxic risk criteria of NSW DoP as given in the 'Hazardous Industry Planning Advisory Paper HIPAP No 4' for injury risk requires assessment for:

1. Injury Risk:

   Toxic concentrations in residential area 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.

2. Irritation Risk:

   Toxic concentrations in residential area 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.

This section describes the criteria adopted for the assessment of injury and irritation risk associated with toxic chemicals.

A VII.1 Acute Exposure Guidelines Limits (AEGL)

The US EPA have developed the AEGL primarily to provide guidance in the event of accidental exposure to a particular chemical from the release or spill of a particular chemical that can involve the general public. They are designed to protect the general population including the elderly and children.

The AEGL have been developed for short term exposure to the hazardous chemicals. The AEGLs are defined as:

AEGL-1: is the airborne concentration (expressed as parts per million or milligrams per cubic meter (ppm or mg/m^3)) of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

AEGL-2: is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

AEGL-3: is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

AEGLs are defined for 10 minute, 30 minute, 60 minute, 4 hour and 8 hour exposures.

A VII.2 Emergency Response Planning Guideline (ERPG)

The Emergency Response Planning Guideline (ERPG), developed by AIHA Emergency Response Planning Committee, are based on concentrations at which some adverse effect on people can be expected. ERPG are based on exposure for 1 hour duration. The definitions of ERPG are:

> ERPG-1: is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing other than mild transient adverse health effects or perceiving a clearly defined, objectionable odour.
>
> ERPG-2: is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr 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: is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

The ERPG approach is based on 1 hour exposure duration whereas the NSW DoP HIPAP No 4 injury risk criteria requests assessment based on short term exposure.

A VII.3 UK HSE

The UK HSE has developed a method, Specified Level of Toxicity (SLOT), for assessing the exposure to toxic material for land use planning (LUP). UK HSE has defined SLOT as:

- Severe distress to almost every one in the area;
- Substantial fraction of exposed population requiring medical treatment;
- Some people seriously injured, requiring prolonged medical treatment;
- Highly susceptible people possibly being killed.

SLOT is based on concentration and exposure time given by the formulae:

SLOT = C^nT

Where:

- C =concentration in ppm;
- T = time in minutes.
- n = constant specific to each material (can be obtained from the UK HSE website)

SLOT values for:

- Ammonia: 3.78×10^8 ppm^n.min (n=2);
- Chlorine: 1.08×10^5 ppm^n.min (n=2); and
- Nitrogen Dioxide: 9.6×10^4 ppm^n.min (n=2).

The SLOT approach is on the borderline of fatality and does not meet the NSW DoP injury and irritation risk criteria.

A VII.4 Method Selected

The AEGL approach developed by the US EPA has been selected to assess the injury risk and irritation risk for Kooragang Island plant expansion.

- The 10 minute AEGL-1 will be used to assess the off site irritation risk from exposure to ammonia (30 ppm), chlorine (0.5 ppm) and nitrogen dioxide (0.5 ppm).
- The 10 minute AEGL-2 will be used to assess the off site injury risk from exposure to ammonia (220 ppm), chlorine (2.8 ppm) and nitrogen dioxide (20 ppm).

The main reasons for selection are:

- The definition of AEGL-1 is reasonably similar to the definition of the HIPAP 4 irritation criterion, in particular odour is not included, but is conservative compared to HIPAP4 in that it does not refer to 'coughing' or 'acute physiological responses'. The HIPAP 4 definition also does not mention the AEGL-1 phrase 'transient and reversible';
- The definition of AEGL-2 is reasonably similar to the definition of the HIPAP 4 injury criterion, taking 10 minutes as 'a relatively short period of exposure'. It may be conservative for some chemicals in that it also includes the phrase 'or the impaired ability to escape' which is not specifically mentioned in the HIPAP4 injury definition;
- It is specifically developed for assessing the risk to the general population including sensitive (susceptible) individuals, the elderly and children;

It should be noted for the three toxic materials considered here, the AEGL-1 values are constant with time ie AEGL-1 (10 minutes) is the same AEGL-1 (8 hours).

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