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Perdaman Chemicals & Fertilisers

Collie Urea Project

Preliminary Risk Assessment

July 2009

INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

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Executive Summary

The purpose of this report is to describe the methodology and findings from Preliminary Risk Assessment (PRA) conducted to assess the offsite hazards and risks from Perdaman Chemicals' proposed urea plant at Collie in WA. The report outlines the assessment approach applied; including the key assumptions and data used, and presents Individual Risk predictions, supported by societal risk predictions expressed as f-N curves. Comparative risk metrics are also presented, along with 'wind affected' Individual Risk contours, which account for the expected wind speeds and direction spectra applicable to the selected site.

Key findings from the risk assessment will be published in the documentation submitted to EPA. In addition, the EPA may stipulate that all or parts of any risk assessment are made public. This Preliminary Risk Assessment and its outcomes are therefore considered an important part of the Public Environment Report (PER).

Although there has been no formal HAZID process, due to the early development stage of the project; the expected hazards present at the facility has been examined and discussed between the risk analyst, GHD and Perdaman Chemicals and Fertilisers Pty Ltd. The nature and probable scale of hazards was addressed during the risk assessment workshop, which provided much of the base information required for the assessment of offsite risks. This information and the risk assessment results will be useful for Perdaman Chemicals to understand the level of risk associated with the development, which will assist submissions to interested parties and with the facilitation of stakeholders' engagement sessions.

It was concluded that the dominant hazard would be large or continuous emissions from the ammonia storage area and associated plant. No other significant offsite hazards were identified. Perdaman Chemicals and Fertilisers Pty Ltd is committed to the effective management and will conduct a series of Safety in design reviews throughout the design project, including a formal HAZID workshop at the appropriate time.

The PRA has examined three characteristic storage tank hazards and assessed their consolidated impacts and risks. Three separate offsite risk metric have been assessed and compared – the findings from each of these are summarised below.

Individual Risk (IR) Contours

The extent of Individual Risk contours from 1x 10^{-5} per year to 1x 10^{-12} per year has been assessed by the study. It is predicted that the 1x 10^{-7} per year contour will be within a 1 km radius of the plant boundaries and that the area within this 1 km zone does not encompass any residential developments or sensitive developments.

Societal risk, f-N curve

The societal risk assessment has predicted an f-N curve which is comfortably within typical risk tolerability thresholds. Societal risk has been calculated making conservative population and manning assumptions; with a maximum of up to 116 persons present within 4.5 km of the proposed plant.

Scaled Risk Index (SRI)

This third risk measure has been applied as a sense check to the IR contours and f-N curve, societal risk calculation. The SRI also indicates a suitable site location with respect to offsite hazards and risks.

Abbreviations and Definitions

Table 1-1 Abbreviations

Abbreviations	
ACH	Air Changes per Hour, ventilation rate
ALARP	As Low As Reasonably Practicable
C, C_0	Concentration (volumetric)
D5	Wind condition – atmospheric condition D, 5 m/s average wind speed
EPA	Environment Protection Authority
F2	Wind condition – atmospheric condition F, 2 m/s average wind speed
f-N	frequency-Number, societal risk metric
FESA	Fire and Emergency Services
HAZID	Hazard Identification
IR	Individual Risk, measure of off-site risk
IRPA	Individual Risk per Annum, measure of personal risk exposure. Note: IRPA is a different metric to Individual Risks required by the EPA.
LC_{50}	Lethal concentration resulting in 50% fatalities for corresponding exposure durations
LEL	Lower Explosion Limit
LUSP	Land Use Safety Planning
MAE	Major Accidental Event
MSDS	Material Safety Data Sheet
MX	Motocross
PER	Public Environment Report
PHAST	Proprietary consequence modelling software (DNV supply)
PLL	Probable Loss of Life (fatalities per year)
ppm/ PPM	Part per million (by volume)
PRA	Preliminary Risk Assessment

^{PQ}RISK	Risk assessment software
QRA	Quantified Risk Assessment
SQRA	Semi Quantified Risk Assessment
SRI	Scaled Risk Integral
TC_0	Lowest published toxic concentration
te	Metric tonnes
tpd	Tonnes per day
UK HSE	United Kingdom Health & Safety Executive
ZOFE	Zone of flow establishment
λ	Air changes per unit time (mins or hours)
Pr, a, b, C, n t	Constants in Individual probit formulations
ά, a, b, P_f	Constants in Individual Risk calculation

Definition of terms

Hazard and Risk

A hazard is an item of equipment or process which could lead to harm, i.e. it is the thing which presents the risk, e.g. a fuel tank or pipeline containing a hazardous substance.

Risk is a measure of the specified level of harm occurring or being realised. Risk is a numerical measure; such as the chance of fatality per year.

Individual Risk

Individual risk is a measure of the chance of a particular individual incurring a specified level of harm (e.g. fatality). For onshore, Land Use safety Planning purposes, Individual Risk is generally calculated assuming hypothetical individuals at any and all population centres, such as a member of a residential population.

Individual Risk Per Annum (IRPA) refers to the risk carried by individual Worker Groups occupied at particular work locations and with a particular risk exposure cycle. IRPA is usually expressed a fatalities/ year for a particular Worker Group.

Societal Risk

Societal risk is a more complex measure, which reflects the likelihood of numbers of persons (beyond the operating plant limits) being affected in a particular event. The societal risk can be characterised in a number of ways:

f-N curve – A graph which shows the cumulative frequency (f) of all events that could lead to N or more people being affected. The graph is interpreted by considering Tolerable and Intolerable threshold. the band between these regions in known as the ALARP region.

Potential Loss of Life (PLL) – PLL is the average number of people affected per year (fatalities/ year) and is useful for assessing the Implied Cost of Averting Fatalities and for Cost Benefit Analysis (CBA). PLL is used as a metric for both onsite and offsite risk

Scaled Risk Integral (SRI) – SRI is a ready reckoner measure of societal risk devised by the UK HSE for considering specific land use and developments. The measure takes account of the number of persons potentially exposed to hazards, the risk of exposure and the land area of a development. SRI is a useful comparator for other societal risk metrics.

1. Introduction

1.1 Development

Perdaman Chemicals and Fertilisers Pty Ltd (PCF), Perdaman) propose to establish a state of the art Urea Production Plant at the proposed Shotts Industrial Park, approximately 7.5 km east of Collie. The urea produced will be railed, twice daily for export from Bunbury Port.

The Project involves converting mined Collie coal from the Griffin coal mine, situated north of the Shotts Industrial Park, to urea and transporting the final product by rail to the Bunbury Port for export. The project is being developed on a commercial basis using proven technology units and scale. The overall project consists of the following facilities:

The proposed Urea Production Plant;

- A coal conveyor connecting the plant and the Griffin Coal Mine;
- Water supply pipeline to supply water from Wellington Dam and other sources to the Plant.
- A rail spur within the project site to facilitate loading of urea connected to the existing rail network; and
- A storage shed, railcar unloading facilities, conveyor and ship loading facilities at Bunbury Port.

The PRA has considered the offsite hazards and risks resulting from normal operation of the Urea Production Plant located at the Shotts Industrial Park location.

1.2 Plant capacity

- The following plant and storage capacities have been assumed:
- Ammonia storage: 10,000 tonnes capacity, on site, in a single refrigerated tank
- Gasification Plant: 2.6 Mtpa of coal gasified
- Ammonia Plant: 3,500 tpd nominal capacity
- Urea Plant: 6,200 tpd nominal capacity, granulated product
- Site area approximately 120 hectares
- Coal storage: approximately 7 days supply stored on site

1.3 Airborne emissions

The following routine airborne emissions are expected:

- Oxides of nitrogen (NO_x) (mostly NO_2)
- Carbon dioxide (CO_2) vented to atmosphere
- Sulphur dioxide (SO_2)

- Hydrogen (H2)
- Methane (CH_4 - traces)
- Ammonia (NH_3)
- Urea Dust
- Methanol

Apart from major Ammonia emissions, no chemical emissions are anticipated also to represent major hazard chemicals.

1.4 Objective of PRA

The objective of the Preliminary Risk Assessment (PRA) process is to identify expected major hazards and risks associated with normal operation of the proposed urea plant located Shotts Industrial Park. The risk assessment is intended to generate risk measures which can be compared with established guidance to enable a supportable judgement to be made of the acceptability of the plant at the proposed location. In addition, the risk assessment is expected to identify the key factors affecting offsite risk such that these issues are given suitable prominence and visibility during subsequent design and planning phases.

The calculation of Individual Risk for Land Use Safety Planning does not strictly require the identification of specific offsite population centres or an understanding of the onsite manning populations and worker groups. Nevertheless, societal risk in form of f-N curves has been considered to provide additional insight into the nature of hazard and will assist Perdaman Chemicals to use this data during stakeholders' engagement sessions.

1.5 Planning requirements

The EPA requires that a preliminary risk assessment is conducted to determine off-site individual risk and that the results comply with prescribed Individual Risk criteria, set by EPA, for developments in populated areas. The EPA has set the following off-site individual risk criteria for hazardous industrial plant:

A risk level in residential areas of one in a million per year or less is so small as to be acceptable to the EPA.

A risk level in "sensitive developments", such as hospitals, schools, child care facilities and aged care housing developments, of one half in a million per year or less is so small as to be acceptable to the EPA.

In the case of risk generators within the grounds of the "sensitive development" necessary for the amenity of the residents, the risk level can exceed the risk level of one half in a million per year up to a maximum of one in a million per year, for areas that are intermittently occupied, such as garden areas and car parks.

Risk levels from industrial facilities should not exceed a target of fifty in a million per year at the site boundary for each individual industry, and the cumulative risk level imposed upon an industry should not exceed a target of one hundred in a million per year.

A risk level for any non-industrial activity or active open spaces located in buffer areas between industrial facilities and residential areas of ten in a million per year or less is so small as to be acceptable to the EPA.

A risk level for commercial developments, including offices, retail centres, showrooms, restaurants and entertainment centres, located in buffer areas between industrial facilities and residential areas, of five in a million per year or less, is so small as to be acceptable to the EPA.

2. Risk Assessment Approach

2.1 Scope and objectives

The scope of the study is to assess and report the offsite risk in form of individual risk contours. The study has additionally assessed societal risk. The societal risk is depicted in form of f-N curves. These additional outputs will be useful for Perdaman Chemicals in understanding the level of risk associated with the development and will also help Perdaman Chemicals in facilitating stakeholders' engagement sessions.

2.2 Hazard Identification

Perdaman Chemicals provided a list of the Hazardous chemicals that will be stored and handled at site. It was agreed by the study, and confirmed at the risk assessment workshop, that ammonia storage represents the dominant major hazard and that any sustained loss of containment event resulting in a significant spill of anhydrous ammonia could present a major risk to the workforce and areas adjacent to the proposed plant.

Due to high minimum ignition energy (100 MJ), ignition of ammonia is unlikely; the study has therefore considered the hazard consequences from ammonia releases to only have toxic effects.

The severity of consequence, once the released has occurred the severity will depend on the size of the leak.

The hazardous properties of anhydrous ammonia are summarised in Appendix A.

2.3 Risk Assessment Software

The PRA has been conducted using PHAST hazard consequence modelling software combined with an in-house GHD risk assessment technique termed ^{PQ}RISK+.

2.4 Characteristic hazards

The risk assessment approach applied for the PCF plant has considered the total plant risk to be a combination of three characteristic hazards:

2.4.1 MAE 1

Major failure from bottom outlet flange (300 mm diameter emission) of 10,000 tonne ammonia storage tank:

Entire tank inventory drains out, no isolation possible

Pool spreading, flashing and dense gas dispersion close to point of release

No bund provided, site kerbing will provide containment to prevent offsite spills

Fatalities due to toxic effect of ammonia

No ignition unlikely due to cold temperatures, high LEL and large minimum ignition energies

Release continues until tank empties; partial flashing resulting in vapour/ liquid aerosol which is initially denser than air and slumps to ground close to the release point. Gas disperses as neutral density or marginally lighter-than-air plume beyond zone of flow establishment (ZOFE).

Dispersion modelling conducted using PHAST (Process Hazard Analysis Software Tool) Version 6.53.

2.4.2 MAE 2

25 mm equivalent diameter release, e.g. small pipe work leak, pump seal failure or accident following shutdown and inspection

25 tonne loss of containment.

Release results in onsite gas plume which maintains a toxic concentration at population centres for more than 10 minutes

Flashing and spray close to release source; small running pool for larger emissions, potential for asphyxiation close to source of release

Ammonia released as cold flashing gas with liquid drop out, gas disperses as dense, ground hugging cloud

Dispersion modelling conducted using PHAST (Process Hazard Analysis Software Tool) Version 6.53

2.4.3 MAE 3

Instantaneous loss of contents from ammonia storage tank ; wholesale rupture of vessel due to major quality/ manufacture defect or mechanical impact event:

Rapid loss of entire tank inventory drains, 10,000 tonnes

Pool spreads to margins of plan

Fatalities due to toxic effect of ammonia

Partial flashing resulting in vapour/ liquid aerosol which is initially denser than air and slumps to ground close to the release point; gas disperses as denser than air, ground hugging cloud.

Dispersion modelling conducted using PHAST (Process Hazard Analysis Software Tool) Version 6.53.

2.5 Non-Major hazards

Onsite risk and non-major hazards and risks, such as workplace and transport risks, were not quantified by the study. These risks can be assessed when the project is further developed.

2.6 Probits

The software includes probit techniques for Explosion, Fires, Toxic Dispersion and other miscellaneous hazards, such as mechanical impacts and pressurised releases. Only toxic dispersion probits were required for the Perdaman ammonia risk assessment.

Probits are further described in Section 5.0 and Appendix B.

2.6.1 Risk assessment workshop

Initiating event frequencies and parts count estimates were allocated and calculated addressed during the risk assessment workshop, with the agreement of all attendees. Agreed frequencies were estimated using a combination of qualitative and quantitative techniques; including comparisons with case histories and parts count estimates combined with generic failure rate data.

2.6.2 Generic failure rate data

Table 2-1 Generic failure rate data

Leak	Leaks/ year Per leak source
Catastrophic failure (whole vessel, > 150 to 200 mm diameter)	3.42E-06
Large releases (50 to 150 mm diameter)	1.14E-05
Moderate releases (15 to 50 mm diameter)	1.69E-05
Small releases (5 to 15 mm diameter)	1.90E-05
Minor releases (< 5 mm diameter):	5.29E-05

2.6.3 Modification of generic data

The software allows data "multipliers" to be applied to generic data to account for factors such as ageing, the use of low integrity fittings such as flexible pipework, hoses and bellows, exposure to aggressive and hot fluid or any other factor which could increase the likelihood of an incident above that predicted using generic data. These issues were raised during the risk assessment workshop and it was agreed not to modify the generic data for the new Perdaman plant.

Data applied by the study are indicated in risk model; which is available for review; other source data and records of workshops discussions are contained in the risk model.

2.7 Event Trees

The risk assessment applied Event Trees to account for incident mitigations with the potential to result in non-hazardous outcomes; the following mitigation branches were defined for each characteristic hazard:

Hazard mitigated by high rainfall or high wind speed: wind speed dilutes release below fatal concentration or dispersion prevented by extreme rainfall event

Hazard mitigated by active barrier, e.g. deluge

Site response team arrests leak by Vetter bags

Other Mitigations: e.g. ventilation dilution, forestry barrier

Te likelihoods/ effectiveness of mitigations was addressed during the risk assessment workshop and allocated with the agreement of all attendees. Data applied by the study are indicated in risk model; which is available for review. Other potential mitigations, such as terrain and building ventilation were considered, although no allowance for these was made in the risk assessment.

No allowance has been made for reduced societal risk as a result of effective emergency responses; it has been assumed that all affected persons offsite would be exposed for a minimum of 10 minutes.

2.8 Onsite population and manning density

The expected onsite plant operations team sizes, as well as their expected exposure to hazardous areas, was defined by discussion with Perdaman and agreed at the risk workshop. Three worker groups were defined and an allowance made for a 4 yearly 400 person shutdown team.

Two-shift roster with 20 field operators, 20 control room operators and 40 administration staff; administration staff work single 8 hour shifts, plant operations work 2 x 12 hours shifts.

Shutdown crew comprising 400 people, for 3 weeks every 4 years, was considered in addition to the normal manning.

The following Worker Groups were defined:

Field operators

Control room operators

Admin/ support staff

Maintenance shutdown team

Plant operations will comprise two back to back teams, each with equal exposure. An 80 person day shift and 80 persons night shift is anticipated; with a 25% staffing allowance required for holiday cover, etc. An average of 5 shutdown days per annum was assumed.

The risk assessment software allows factoring to account or an increased likelihood of accidents when persons are present. This is commonly applied where cyclic manning occurs, or where traffic incidents are considered a probable cause of accidents. Neither of these was considered relevant to the Perdaman plant and, for all accident scenarios, the likelihood of incidents is considered independent of manning levels.

2.9 Offsite populations

2.9.1 Population centres

Offsite populations at risk from major ammonia releases were defined by reviewing site drawings and various published information, and by discussion with Perdaman operations; these were discussed and agreed at the risk workshop and confirmed by subsequent research. The following population centres were defined:

Griffin ash dumping station at 600 metres from coset plant boundary: intermittent trucking over assumed 24 hour operation. Dumping station located on hill, which is expected to reduce the likelihood of exposure to dense, ground hugging gas cloud. (This has been accounted for in the allocated likelihood of exposure to incidents).

Bluewater's power station is at 4,500 metres from closest plant boundary. 24 hour manning, all year round.

Fore MAE 3 only (due to distance from site); Collie town outskirts at 7 kilometres from the closest plant boundary. The North end of Collie is not exposed, even to the most massive emission resulting from instantaneous loss of vessel contents. In addition, the instantaneous release creates a low ground hugging cloud which would be impaired from dispersing by terrain, woodland and buildings.

Premier coal handling, including administration/ head office located at 2.2 kilometres from the closest plant boundary.

The risk assessors were informed that there is a resident "Hermit" living in the vicinity of the plant. This 24 hour presence of a single person has been considered by inclusion as an additional person present in the vicinity of the Premier site.

Stockton lake recreational area at 1 kilometre from the nearest plant boundary. Transient population with peak numbers at weekends and in the summer; lake used for water skiing and other water sports. Manning assumed as weekend/ summer: 50 to 60 persons; 10 - 20 persons during week days, all year round. These estimates included local pedestrian traffic throughout the year.

2.9.2 Estimated offsite populations

Table 2-2 Estimated offsite populations

Griffin ash dumping station	
Distance from closest site boundary	600 metres
Maximum manning level	5 persons
24-hour average manning	2 persons
Bluewater's' Power Station	
Distance from closest site boundary	4500 metres
Maximum manning level	20 persons
24-hour average manning	10 persons
Premier Coal Handling	
Distance from closest site boundary	2200 metres
Maximum manning level	30 persons + 1 hermit
24-hour average manning	10 persons
Stockton Lake Recreational Area	
Distance from closest site boundary	1000 metres
Maximum manning level	Appendix C
24-hour average manning	Appendix C
Collie outskirts (MAE 3 only)	
Distance from closest site boundary	7.5 km
Maximum manning level	2000 persons
24-hour average manning	1500 persons

2.9.3 Risk of exposure to major hazards

Table 2-3 Summary of population centre exposure risk

Location	Likelihood of incident affecting population		
	MAE 1	MAE 2	MAE 3
Griffin ash dumping station;	10%	1%	15%
Bluewater's power station	10%	0.5%	15%
Premier coal handling	15%	2%	15%
Stockton lake recreational area	25%	5%	15%
Collie outskirts	No risk	No risk	15%

2.10 Offsite fatal risk assessment

Offsite fatalities have been assessed by estimating firstly, the likelihood that each populating is exposed to an ammonia hazard; based on dispersion modelling; each exposed population is divided into different "Hazard Zones" (70 to 100% fatality, 7% to 70% fatality, 1% to 7% fatality and less than 1% fatality.). Three measures of offsite risk have been assessed:

Individual Risk contours; including wind-affected risk contours

Societal risk, expressed as an f-N curve, compared with accepted tolerability criteria

Scaled Risk Integral (SRI)

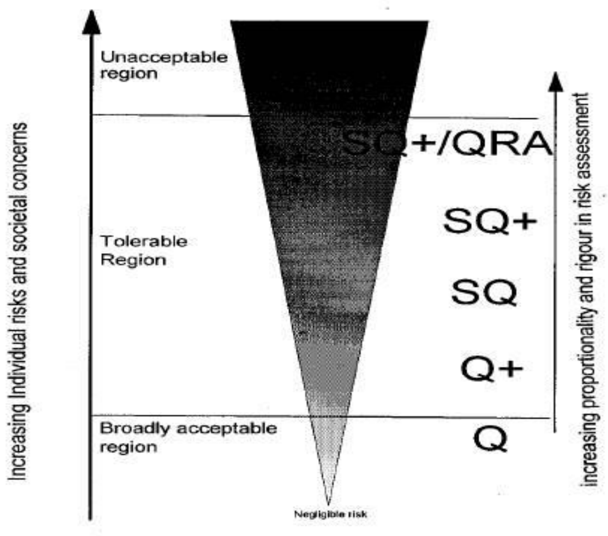
The three measures are checked against each other to ensure a consistent understanding of the impact of the ammonia plant hazards and risks. No assessment has been made of onsite risk exposure or non-major risks.

2.11 Dispersion modelling and hazard ranges

Hazard ranges for each MAE have been derived using combination from the combination of consequence modelling to estimate the concentration at a given distance and use of probits for estimating the fatality likelihood. Dispersion modelling was completed using PHAST software, supplied by DNV, with special attention given to the dispersions distances relating to ground or centreline concentrations of 10,000 ppm, 6500 ppm and 4500 ppm.

2.12 Guidance on offsite fatal risk assessment approaches

The following diagram is presented as guidance for selecting the correct risk assessment technique, based on the hazards and risks presented by a facility.



Where

Q = qualitative

SQ = semi quantitative

QRA = quantitative RA

The '+'sign reflects increasing depth of analysis or quantification, e.g. Q+ is somewhere between the expectation for Q and SQ levels

Table 2-4 Risk assessment technique guidance

Type of risk assessment*	**IR public (fat/yr)**	**IR Worker (fat/yr)**	**SRI**
Full QRA Full options analysis Risk reduction required	>1e--4	>1e-3	>500,000
QRA/SQ+	1e-5 to 1e-4	1e-4 to 1e-3	500000
SQ+	3e-5 to 1e-5	3e-5 to 1e-4	200000
SQ	3e-6 to 3e-5	1e-5 to 3e-5	20000

Q+	1e-6 to 1e-5	1e-6 to 1e-5	5000
Q	< 1e-6	< 1e-6	<2000

The Perdaman risk assessment is fully quantitative and based on detailed hazard consequence modelling. Offsite fatalities per year are estimated to be in the range 1e-5 to 1e-6 fatalities per; and an SRI of less than 50,000 is predicted for the offsite populations assumed.

From the table above; this infers that the most appropriate technique for risk assessment would be semi quantitative, with major hazards addressed quantitatively if needed to verify risk tolerability. Using this guidance, the Perdaman risk assessment more than satisfies the minimum requirements. In addition, the project is committed to the ALARP principal and will develop the project with a view to minimising both onsite and offsite hazards and risks.

3. Incident Frequency Assessment

3.1 Characterisation of Hazards

The incident definition stage involved the characterisation of worst case and typical hazard scenarios for a plant or operation; including the absolute worst case involving instantaneous loss of full ammonia storage tank contents (MAE 3). The definition of hazard cases applied the principles of 'reasonableness' and 'foresee-ability' and took account of industry experience and published case histories for similar plants.

Worst case hazards

The risk assessment process assumes that the total fatal risk for the facility can be assessed as the sum of risks from the characterised scenarios. The definition of scenarios took place at the risk assessment workshop for the project where the following rules were applied to define worst case hazards:

Assume catastrophic failure of most significant hazardous inventory or failure of large import/ export line

Assume primary inventory isolation device fails (i.e. secondary inventories involved)

No risk reduction benefit from fire fighting or inventory blowdown systems

All emergency responses effectively deployed

The definition of scenarios took place at the risk assessment workshop for the project where the following rules were applied to define worst case hazards:

Typical hazard scenarios

The following rules were applied at the risk assessment workshop to define the typical major hazards with offsite implications.

Characteristic release size: typically 20 mm to 50 mm equivalent diameter, with some contribution from small, high inventory emissions; plus all emissions in excess of 50 mm

Breaching of layers of protection if they are not considered reliable or high integrity.

Primary inventory isolation successfully deployed

Accident escalation prevented by foam blanketing and adjacent area fire protection, where appropriate

All emergency responses effectively deployed

3.2 Qualitative Estimate of Occurrence Frequencies

Prior to the quantitative estimate based on equipment parts counts and generic data, the risk assessment team were prompted to estimate the likelihood of occurrence of defined events; drawing on their collective experience and, wherever possible, using estimates which account for industry experience and case histories for similar systems. The following prompts were used by the workshop leader:

How many equivalent incidents have occurred?

How many similar facilities have been in operation and what is the cumulative experience in plant-years?

What is the cumulative plant-years with no record of incidents?

Based on these responses and, where necessary, the application of rare event statistical assessment (e.g. Poisson distribution), a qualitative estimate was made by the workshop team members.

3.3 Quantitative Estimate of Occurrence Frequencies

3.3.1 Use of Quantitative Estimator

The risk assessment approach applied included a facility which enables fully quantitative estimates to made, which are then compared with qualitative predictions. This is achieved using generic failure data and an estimate of the number of leak sources with the potential to create a defined hazard. This comparison can be applied to process systems where the hazard involves loss of containment from an enclosed system. The quantitative prediction is treated as a comparator to the occurrence likelihood allocated from team experience.

Either prediction or some intermediate value is then selected.

3.3.2 External Multipliers

The frequency assessment allows the selective allocation of 'external multiplier' factors, to take account of any specific features of the plant and operations which make the likelihood of occurrence '*more likely than the recorded historical experience'* for process plant facilities similar to those under consideration. This factor applies to risk raising issues which are not directly related to the design integrity or operation of the plant – such as ground subsidence or transport risk.

Different multiplier values can be applied to Worst case and Most Typical hazards. 'External Multipliers' are used either as reference for further risk assessment, or to condition quantitative estimates.

3.3.3 Design or Operational Multipliers

The frequency assessment also allows the selective allocation of 'design or operational multiplier' factors to account for any specific features of the plant and operations which make the likelihood of occurrence '*more likely than the recorded historical experienc*e' for process plant facilities similar to those under consideration.

This factor applies to risk raising issues associated with the design and operation of the plant, such as any features which increase the loss of containment likelihood (e.g.

materials, aggressive fluids, high vibration loads or the use of lower integrity pipework and fittings such as bellows or flexible connectors.)

Generic data applied by the assessment typically refers to high integrity pressurised containment, pipework and fittings. Flexible joints and hoses have an inherent failure rate typically between 10 to 100 times that for fixed pipework. Where these connectors are used it is recommended that specific failure histories and failure rates are investigated and applied in the risk assessment.

3.3.4 Generic data

Generic data used in the risk assessment is presented in Section 2.0 – these data are the 'default' values, based on a survey of multiple data sources, Ref. [1]. Alternative data can be applied if available, as agreed with the risk assessment workshop team.

3.4 Occurrence frequency data used in the risk assessment

Table 3-1 Incident frequency summary table

	Qualitative	Quantitative	Estimated
	Mean Time Between Incidents (years)		
MAE 1	60,000	87,719	75,000
MA E 2	2,000	711	1,000
MAE 3	150,000	292,398	150,000

4. Dispersion Modelling

4.1 Overview

The dispersion modelling was carried out using the PHAST (Process Hazard Analysis Software Tool) Version 6.53, which is part of the SAFETI package of risk assessment tools.

The dispersion modelling approach and results were discussed with Perdaman operations throughout the study, with a number of technical memoranda prepared and issued for comment. Comments raised by the client have been investigated and incorporated as appropriate. These memoranda are identified on the project file, but have not been reproduced in this report.

4.2 Basis of dispersion modelling

Three hazard scenarios were modelled: 50 mm, 300 mm leak and instantaneous loss of full 10,000 tonnes refrigerated ammonia storage tank contents. Both ground level and plume centreline concentrations were modelled, with particular attention paid to gas concentrations at offsite population centres and at threshold concentrations of 10,000 ppm, 6,500 ppm and 4,500 ppm.

Basic information is summarised in Tables 5 to 7 below.

Table 4-1 Ammonia storage tank conditions

Material	Anhydrous ammonia
Inventory	10,000 tonnes
Temperature	-33°C
Pressure	300-400 mm WC (Atmospheric tank)
Liquid head	20 m
Bund	No bund

Table 4-2 Release parameters

Parameter	**Estimate**	**Notes**
Elevation of release	1 m	
Direction of release	Horizontal	Conservative as a horizontal release produces the greatest consequence distances.
Toxic Averaging time	600 s	The toxic averaging time is used to calculate the concentration
Release size	50 mm and 300 m	Representative leak sizes for the storage tank.

Table 4-3 Release sizes

	Release size	
	50 mm	**300 mm**
Inventory	25 tonne	10,000 tonne
Pressure	10 barg	Atmospheric

4.3 Meteorological Conditions

The following ambient atmospheric conditions have been used for this study.

4.3.1 Atmospheric Pressure

1.01 x 10^5 N/m^2; Atmospheric pressure used to determine the properties of the atmosphere, for the discharge and subsequent dispersion calculation.

4.3.2 Atmospheric Temperature

22.5°C for day, Daytime atmospheric temperature used to determine the properties of the atmosphere for the dispersion and discharge calculation. This is the recorded mean temperature at Collie.

4.3.3 Air Surface Temperature

22.5°C for day; Daytime air surface temperature used to calculate how much heat is transferred from the air surface into the gas cloud; this is the recorded mean temperature at Collie.

4.3.4 Ground Surface Temperature

27.5°C for day, Daytime Ground surface temperature used to determine the heat transferred from the ground surface to the liquid pool, and hence the vaporisation rate. Due to heating during the daytime, the ground surface temperature for day is assumed to be 5°C warmer than atmospheric temperature.

4.3.5 Atmospheric Humidity

60% to 65% Relative humidity is used to determine the properties of the atmosphere in all discharge and dispersion calculation, especially materials that react with H_2O. 61% is the average relative humidity for Collie. The PHAST model can be highly sensitive to relative humidity values; to prevent spurious results a number of sensitivity runs were executed to ensure a consistent trend in results with changing humidity values.

4.3.6 Solar Radiation Flux

0.5 kW/m^2, solar radiation flux represents the amount of heat radiation received by a liquid pool from the sun for the pool vaporisation calculation. A typical sunny day in Australia produces a solar radiation flux of approximately 0.5 kW/m^2.

4.3.7 Surface Roughness Factor

0.5 m, Surface roughness describes the roughness of the surface over which the cloud is dispersing (i.e. Greater roughness, more resistance to dispersion). For this study, the surface roughness value of 0.50 m (for parkland, bushes; numerous obstacles) was used to describe the topography around the Shotts Industrial park.

4.3.8 Wind speed [6]

2 m/s and 5 m/s, wind speed is used to determine the properties of the atmosphere for the dispersion calculation. 2m/s and 5 m/s are typically used to represent 'calm' and 'moderately windy' conditions. The Collie wind rose indicates predominantly low wind speeds in the area, with only very few high wind days.

4.3.9 Pasquil Stability

F and D, Pasquil stability classes used to describe the amount of turbulence in the atmosphere, which dictates the dispersion coefficients used by PHAST. Class D describes windy, overcast daytime or windy night time. Classes F and D correspond to wind speeds 2 m/s and 5 m/s respectively; i.e. F2 and D5 conditions.

4.4 Offsite gas dispersion behaviours

Refer also to Appendix B.

Ammonia gas upon release will chill and slump before it is heated by the surrounding environment and become lighter than air. As such, an ammonia cloud is expected to lift up to the atmosphere upon becoming lighter than air. For a large leak of 300 mm at 1 m release height (MAE 1), the ammonia cloud slumps to the ground at approximately 4.5 to 5 metres from the source of release. Upon being heated by the surrounding environment, the cloud disperses in the far field as a lighter than air gas plume.

For a medium size leak of 50 mm (MAE 2) at a height of 1 m, the ammonia cloud edge touches the ground at approximately 12 m. With a release inventory of 25 tonnes, the release duration is approximately 480 s with a release rate of 52 kg/s. With a smaller release at high pressure (10 barg), the cloud continues to disperse at a distance closer to the ground level. MAE 2 acts as a dense gas cloud.

The instantaneous loss of contents case is a complex combination of pool vaporisation, flashing gas and droplets. The cloud is predicted to disperse offsite as a denser than air ground hugging cloud. The concentrations of ammonia reported at the cloud centreline in the event of a release from the storage tank are presented in presents the downwind distances at the concentrations of interest. These results are based on a horizontal release where the cloud is not impeded by any equipment or objects.

4.5 Exposure time

Onsite fatalities were calculated using a maximum exposure time of 90 seconds; on the assumption that all site personnel would readily be notified of an incident and that prolonged exposure would be avoided by protective breathing apparatus and safe emergency responses.

The average toxic exposure time for persons exposed offsite has been estimated accounting for following:

Delays due to eye irritation, breathing problems and disorientation

Physical pain resulting from ammonia contact ammonia contact with the skin

Time taken to select the correct route for escape from a gas plume

An average exit speed, by walking, of approximately 1.0 to 1.2 m/s

Ammonia gas plume width, at ground level of 400 metres to 600 metres

Guidance is provided by the FESA discussion paper [6], which indicates a typical public response time to emergencies of 25 to 30 minutes – which is assumed to include a stage which involves decision making and responses to escape from immediate danger.

The risk assessment has conservatively assumed a 600 second (10 minute) exposure time at the same toxic gas concentrations; with no allowance for reduced concentrations at the margins of gas clouds. The 600 second exposure time is consistent with the SAFETI risk assessment software default "averaging time" used for ammonia releases.

4.6 Summary of results used for risk modeling

4.6.1 Probit results

For the Perdaman risk assessment; this Probit equates to the following toxic concentration thresholds for a 10 minute exposure period:

2,310 ppm for 10 mins = 1% fatality

3,800 ppm for 10 mins = 7% fatality

15,500 ppm for 10 mins = 70% fatality

4.6.2 Distance to fatal concentration zones

Table 4-4 Summary of MAE 1 results, plume centreline

Gas plume centerline			
PPM	**MAE 1 - distance from source (m)**		
	F2	D5	Averaged
15500	< 500 m (300)	< 500 m (300)	300 m
3800	900 m	900 m	900 m
2310	2000 m	1450 m	1725 m

Table 4-5 Summary of MAE 1 results, ground level

Ground level			
PPM	**MAE 1 - distance from source (m)**		
	F2	D5	Averaged
15500	< 500 m (100)	< 500 m (100)	100 m
3800	< 500 m (300)	650 m	500 m
2310	< 500 m (400)	1000 m	1000 m

The risk assessment conservatively assumed that all exposure would be to gas plume centreline concentrations.

Table 4-6 Summary of MAE 2 results, plume centreline

Gas plume centerline/ ground level			
PPM	**MAE2 - distance from source (m)**		
	F2	D5	Averaged
15500	< 500 m (300)	< 500 m (200)	300 m
3800	900 m	< 500 m (200)	800 m
2310	1300 m	~ 400 m	1200 m

Table 4-7 Summary of MAE 3 results, plume centreline

Gas plume centerline/ ground level			
PPM	**MAE 3 - distance from source (m)**		
	F2	D5	Averaged
15500	2100 m	< 500 m (200)	2000 m
3800	> 5000 m	2900 m	4500 m
2310	~ 8000 m	4400 m	8000 m

4.6.3 Hazard ranges

The following hazard ranges relate to an exposure time of 600 seconds; these ranges have been applied by the risk assessment to identify offsite populations at risk:

Table 4-8 MAE 1 Hazard ranges

		% fatalities	Distance from source (m)
MAE 1	Zone 1	70% to 100%	300
	Zone 2	7% to 70%	900
	Zone 3	1% to 7%	1725
	Zone 4	< 1%	

Table 4-9 MAE 2 Hazard ranges

		% fatalities	Distance from source (m)
MAE 2	Zone 1	70% to 100%	300
	Zone 2	7% to 70%	800
	Zone 3	1% to 7%	1200
	Zone 4	< 1%	

Table 4-10 MAE 3 Hazard ranges

		% fatalities	Distance from source (m)
MAE 3	Zone 1	70% to 100%	2000
	Zone 2	7% to 70%	5000
	Zone 3	1% to 7%	8000
	Zone 4	< 1%	

5. Selection of Ammonia Probit

5.1 Probit Methodologies

Refer to Appendix for details of the derivation and application of Probits. The hazard and risk assessment approach applied has estimated fatality likelihoods using the probit technique

$Pr = a + b \ln [C^n t]$

where,

Pr = Probit value

C = Concentration of interest (ppm or mg/m3)

t = time exposed to concentration (mins)

a, b, n = constants specific to each material

The risk model used allows sensitivity runs to be conducted to determine the most appropriate probit model. Over 10 different published Ammonia Probits were compared to determine the most appropriate model for the assessment of offsite toxic risk. This comparison identified a wide fluctuation in the results produced by different equations.

Table 5-1 Alternative ammonia Probits

Probit constants a, b, n	Reference
-9.82, 0.71, 2	DCMR (Dutch Government Environmental Protection Agency) Steering Committee. As used for Kwinana risk study
-35.9, 1.85, 2	I Chem E 1986
-49.54, 2.3, 2.02	Ten Berge 1986
-49.03, 2.205, 2.75	Canvey 1978 (supplied by GHD, original source not identified)
-12.2, 0.8, 2	ACDS 1992
-15.8, 1, 2	de Weger 1991/ Green Book16
-9.82, 0.71, 2.75	SAFETI recommendation (similar to DCMR)
-35.9, 1.85, 2	FP Lees
1.14, 0,782, 2.75	Canvey 1978, FP Lees
-7.41, 2.205, 2.75	Canvey 1978, FP Lees

5.2 Comparison with experimental results and published data

Table 5-2 Second Canvey report, no probit formulation proposed

Time (mins)	ppm at LC_{50}
1	Not possible
5	7000 to 9800
10	3500 to 4900
30	1200 to 1680
60	500 to 700

Table 5-3 Guidance from AS/NZS 2022:2003 [8]

PPM range	Exposure period (mins)	Description of consequence
25	8 hrs	Odour, detectable, no health risk
100	long periods	No adverse effect, average worker
400	> 1 hour	No serious effect 30-60 mins (Assume serious at 7200 secs)
700	> 1 hour	No serious effect 30-60 mins, (Assume serious at 7200 secs)
1700	> 30 mins	Could be fatal after 30 mins
2000 to 5000	> 15 mins	Could be fatal after 15 mins
5000 to 10000	Within minutes	Rapid, 100% fatalities

Table 5-4 Extract from FESA Guidance [9]

ppm	Exposure period (mins)	Description of consequence
5000	1 or 2 breaths	Rapid, 100% fatalities
17	1 hour	No adverse effect, average worker

Table 5-5 Material Safety Data Sheet (MSDS)

ppm	Exposure period (mins)	Description of consequence
5000	5	TCL_0 - lowest published toxic concentration
Molecular formula: NH3, CAS No: 7664-41-7 EC No: 231-635-3, Annex I Index No: 007-001-00-5		

5.3 Comparison between published Ammonia toxicity data and Probits

Summary of published data findings - LC_{50} thresholds:

2 to 5 mins exposure at 5000 to 10000 ppm

Approx 15 mins exposure at 2000 to 5000 ppm

Approx 30 mins exposure at 1700 to 2000 ppm

This published data conflicts with many of the probit formulations, which indicate 30 Min LC_{50} values between 2200 and 23000 ppm; the probit formula proposed for the Kwinana cumulative risk study, for example, equates to a 30 Min LC_{50} at 6200 ppm. However, there is also disagreement between published hazard thresholds, with 5000 ppm considered to result in '*almost certain'* fatalities from "*a few breaths*" to 15 minutes or greater.

5.4 Conclusion

The Kwinana cumulative risk Probit appears to underestimate the AS2022:2003 stated risk of "*1700 ppm could be fatal after 30 mins*"; where, for this one criterion, the Probit predicts a fatality risk of < 1% compared with up to 8% for the most conservative probit formulation. However, the estimates for "*2000 to 5000 ppm could be fatal after 15 mins*" from the same publication are a good match, with fatality predictions in the range 2% to 21%.

The most conservative Probit formulation aligns well with the MSDS TCL_0 - lowest published toxic concentration - and with the FESA discussion paper note of "*rapid fatality within 1 or 2 breaths at 5000 ppm*". The MSDS and FESA toxic expectations, however, do not appear consistent with other data and are an over estimate of the Australian Standard guidance.

For these reasons, the following Probit, which has been applied by GHD for the Kwinana industries cumulative risk modelling, has been applied to the Perdaman Ammonia risk assessment.

$$Pr = -9.82 + 0.71 \, Ln \, [C^2 \times t]$$

6. Event Tree Analysis

6.1 Introduction

Fault tree analysis (FTA) and Event tree analysis (ETA) techniques were developed to enable probabilistic assessments of equipment performance, where different outcomes are possible depending on specific combinations of circumstances. Fault trees are logical diagrams which show the relationship of specific fault conditions leading to undesirable outcomes.

Event trees are similar to faults trees and show the relationship between specific error conditions, such as failed mitigation measures and undesirable hazardous outcomes.

6.2 Ammonia release Event Trees

The risk assessment has developed Event Trees to account for incident mitigations with the potential to result in non-hazardous outcomes; the following mitigation branches were defined for each hazard:

Hazard mitigated by high rainfall or high wind speed: wind speed dilutes release below fatal concentration or dispersion prevented by extreme rainfall event

Hazard mitigated by active barrier, e.g. deluge

Site response team arrests leak by Vetter bags

Expected of effected of other mitigating factors such as terrain and forestry barriers

Te likelihoods/ effectiveness of mitigations was addressed during the risk assessment workshop and allocated with the agreement of all attendees. Data applied by the study are indicated in risk model; which is available for review.

No allowance has been made for reduced societal risk as a result of effective emergency responses; it has been assumed that all affected persons offsite would be exposed for a minimum of 10 minutes.

No allowance has been made for ventilation dilution of protected buildings adjacent to the Shotts Industrial Park.

6.3 Mitigation by high wind speeds or rainfall

6.3.1 Source reference

Refer to Wind roses; attachment 5 to "NWCF Basis of Design - Collie coal to urea project", dated: June 2008 [6].

Table 6-1 Wind velocity distribution - extract from [6]

km/h	m/s	9:00 am	3:00 pm
0 to 10	0 to 2.78	84.00%	64.00%
10 to 20	2.78 to 5.56	10.00%	20.00%
20 to 30	5.56 to 8.33	5.00%	10.00%
30 to 40	8.33 to 11.11	1.00%	5.00%
>40	>11.11	0.00%	1.00%
		100.00%	100.00%

Table 6-2 24 -hr Average (assume 50% 9 am and 50% 3 pm)

km/h	m/s	Average
0 to 10	0 to 2.78	74.00%
10 to 20	2.78 to 5.56	15.00%
20 to 30	5.56 to 8.33	7.50%
30 to 40	8.33 to 11.11	3.00%
>40	>11.11	0.50%
		100.00%

6.3.2 Wind conditions relevant to characteristic releases

Table 6-3 MAE 1; 300 mm release, 10,000 tonne

km/h	m/s	Potential for fatal concentration	Below fatal concentration
0 to 10	0 to 2.78	100.00%	0.00%
10 to 20	2.78 to 5.56	100.00%	0.00%
20 to 30	5.56 to 8.33	90.00%	0.75%
30 to 40	8.33 to 11.11	0.00%	3.00%
>40	>11.11	0.00%	0.50%
			4.25%

Table 6-4 MAE 2; 50 mm release, 25 tonne

km/h	m/s	Potential for fatal concentration	Below fatal concentration
0 to 10	0 to 2.78	100.00%	0.00%
10 to 20	2.78 to 5.56	75.00%	3.75%
20 to 30	5.56 to 8.33	0.00%	7.50%
30 to 40	8.33 to 11.11	0.00%	3.00%
>40	>11.11	0.00%	0.50%
			14.75%

Table 6-5 MAE 3; Instantaneous loss of contents, 10,000 tonne

km/h	m/s	Potential for fatal concentration	Below fatal concentration
0 to 10	0 to 2.78	100.00%	0.00%
10 to 20	2.78 to 5.56	100.00%	0.00%
20 to 30	5.56 to 8.33	100.00%	0.00%
30 to 40	8.33 to 11.11	100.00%	0.00%
>40	>11.11	100.00%	0.00%
			0.00%

6.3.3 Event tree branch probabilities

Table 6-6 Hazard mitigated by high rainfall or high wind speed

	Estimated branch probabilities		
	Expected Wind dilution	Extreme rainfall	Event Tree Branch A
MAE 1	4.25%	1.00%	5.25%
MAE 2	14.75%	3.00%	17.75%
MAE 3	0.00%	0.00%	0.00%

6.4 Mitigation by active barriers

Table 6-7 Hazard mitigated by active barriers

	Estimated branch probability
MAE 1	10%
MAE 2	20%
MAE 3	0%

6.5 Mitigation by site response team (e.g. Vetter bags)

Table 6-8 Hazard mitigated by site response team

	Estimated branch probability
MAE 1	10%
MAE 2	20%
MAE 3	0%

6.6 Mitigation by terrain and forestry barriers

Table 6-9 Hazard mitigated by terrain and forestry barriers

	Estimated branch probability
MAE 1	0%
MAE 2	80%, dense gas cloud
MAE 3	80%, dense gas cloud

6.7 Gas plume dilution in sheltered buildings

6.7.1 Explanation

Protected buildings adjacent to the Perdaman site may be protected from toxic gas effects if the buildings can be sealed to provide a safe refuge. This will allow protection for the period from initial exposure to the gas plume until the gas concentration within the building reaches fatal levels as a result of ventilation air and ingress due to seepage.

6.7.2 Perfect mixing model

Gas concentrations in sheltered areas can be estimated using the "perfect mixing" equation:

$C_0 = C * 1\text{-}e^{(\lambda \times Time)}$

Where:

C_0 External gas concentration

C Concentration in sheltered area

λ Air changes per unit time (mins or hours)

Time Exposure time of sheltered area

6.7.3 Examples

C_0 2000 ppm and 5000 ppm

C See tables below

λ 6 Air Changes per Hour (ACH), typical for light industry

10 ACH, allowing for time to close doors, windows and non-industrial building air tightness

Time see tables

Table 6-10 C0 - 5000 ppm

Time (mins)	**Concentration in refuge, C**	**Concentration in refuge, C**
	ACH = 6	ACH = 10
5	1967	2827
10	3161	4056
20	4323	4822
30	4751	4966
60	4988	5000

Table 6-11 C0- 2000 ppm

Time (mins)	Concentration in refuge, C	Concentration in refuge, C
	ACH = 6	ACH = 10
5	787	1131
10	1264	1622
20	1729	1929
30	1900	1987
60	1995	2000

6.7.4 Conclusion

No credit is taken for possible protection provided by sealed buildings which could be used as refuges during an offsite ammonia incident

Buildings would need to be made air tight

All external openings would need closing within a few minutes

The emergency response advice would be to evacuate to a safe area away from the gas plume

This assumption can be revised as the project develops and more information becomes available about adjacent units

7. Risk Assessment Results

7.1 Individual Risk Contours

7.1.1 Introduction

The Preliminary Risk Assessment has predicted fatal Individual Risk contours using the following formula; refer to Refs. [2] to [4] for derivation and explanation and the methodology:

$R (IR) = 2/ ά \times Ln \{3 \times IR / (2 a \times b \times p_f)\}$

Where:

ά Constant; measure of the rate of decay of a hazard (m^{-1}) – a value of 0.015 is typical for chemical hazards

a constant, 2 in all cases (dimensionless)

b is constant, typically 0.15 (dimensionless) tor chemical hazards, but the prediction is insensitive to the variations in b in the range 0 to 1

p_f Probability of failure killing at least 1 person offsite

7.1.2 Assessment of wind effects

Risk predictions have also taken account of the collie area wind direction profile indicated in the basis of design document [6].

The sensitivity to wind speed distribution has been assessed using guidance provided in Tables 25a and 25 b: 'Severity 6' is considered highly sensitive to wind speed; 'Severity 0' is considered insensitive to wind speed.

Table 7-1 Source parameters affecting sensitivity to wind directions

Severity	Hazard type	Toxicity	Dispersal	Source quantity
6	Toxic release.	Extreme	Slow	Large
5	Toxic release	High	Slow to moderate	Large
4	Toxic release	Moderate	Slow to moderate	Moderate to large
3	Toxic release	Moderate	Moderate	Moderate to large
2	Toxic, major VCE or flash fire	Minor to moderate	Moderate to rapid	Moderate
1	Toxic, VCE, flash fire	Minor	Rapid	Minor to moderate
0	Fire, explosion, release of pressure, mechanical	None	Any	Any

Table 7-2 Environmental parameters affecting sensitivity to wind directions

Severity	Wind speeds	Direction'	Terrain	Buildings	Weather, climate	Flora
6	High	Very directional, distinct channels	Flat, no barriers	None	Fine, sunny	Grass, low shrubs
5	High	Very directional	Some slopes	No large buildings	Fine, sunny	Grass, low shrubs
4	High to moderate	Very directional	Some hills or valleys	No large buildings	Mostly fine	Shrubs, low trees
3	Moderate	Directional	Undulating	Some buildings	Some rain	Some trees
2	Moderate	Some distinct directionality	Hilly areas	Some buildings	Some fog	Woodland
1	Low to moderate	Typical	Any	Any	Any	Any
0	Low to moderate	Typical	Any	Any	Any	Any

7.1.3 Results

Table 7-3 Results

__________	1.0 x 10^{-7} per year
__________	1.0 x 10^{-6} per year
__________	1.0 x 10^{-5} per year

Figure 1 - Wind affected IR contours

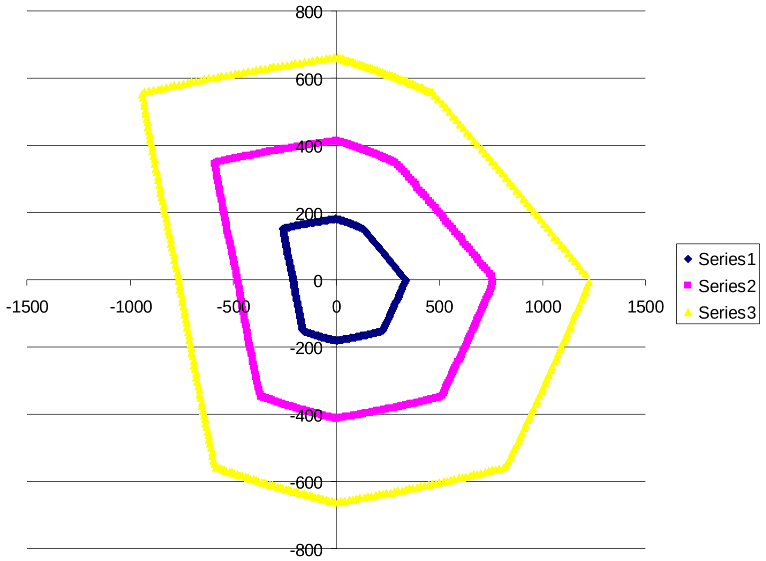


Figure 2 - IR contours – not wind affected

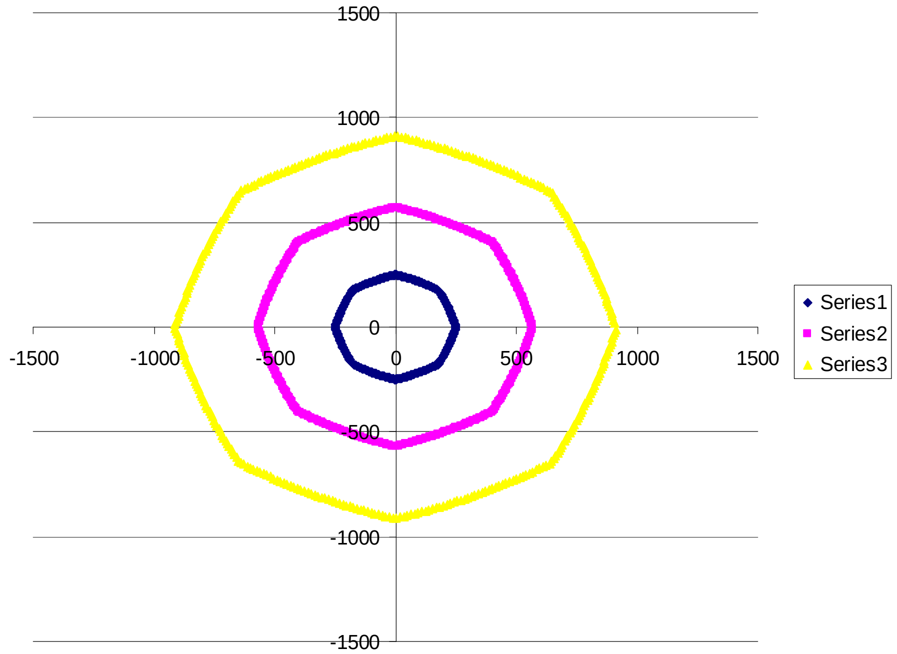


Figure 3 - IR contours – maximum wind effect

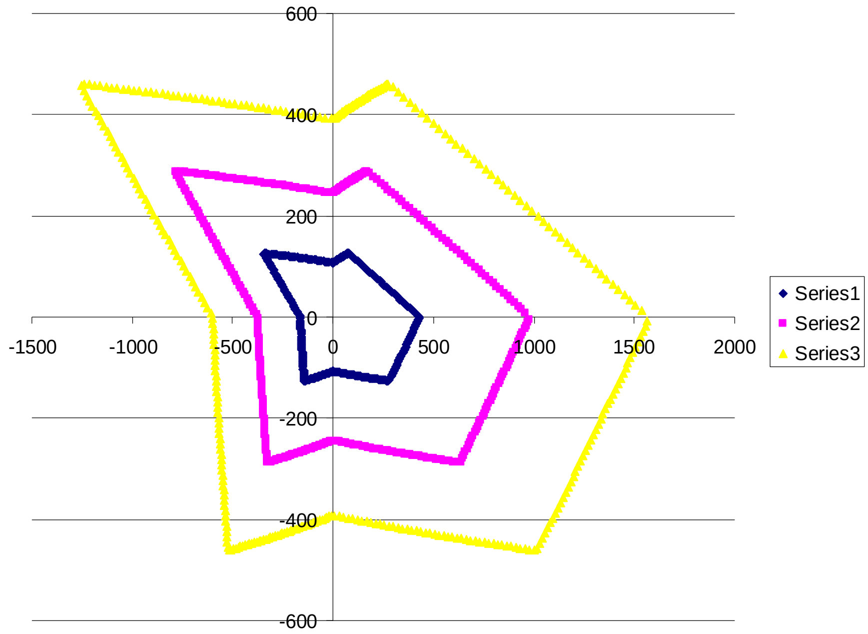
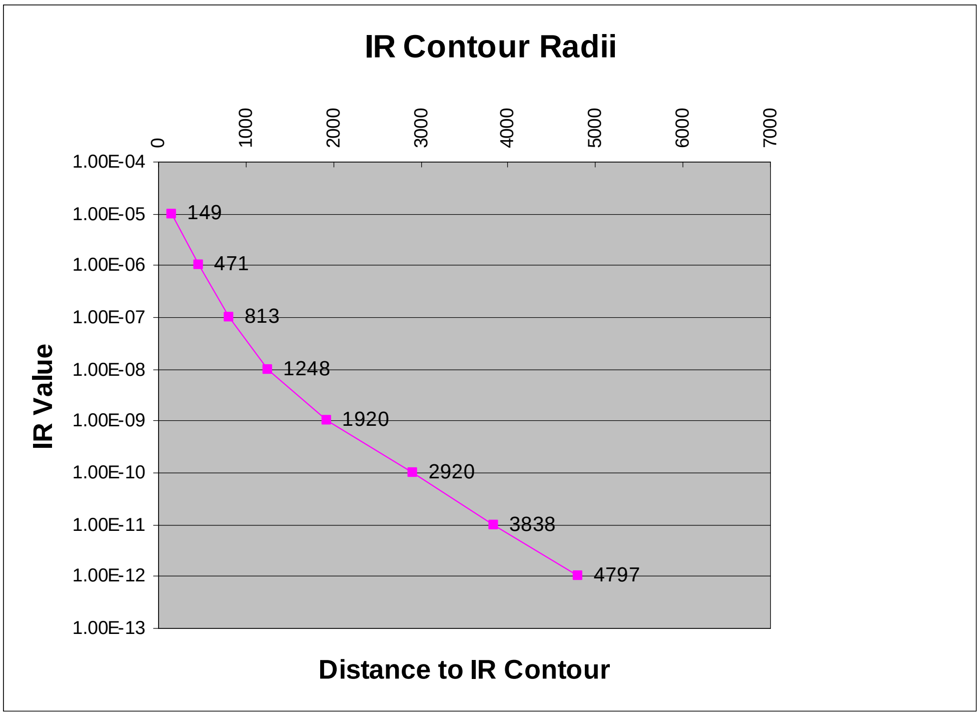


Figure 4 – Distance to IR contours



7.1.4 Interpretation of results

The EPA has set the following off-site individual risk criteria for hazardous industrial plant:

0.5 x 10^{-6} per year

A risk level in "sensitive developments", such as hospitals, schools, child care facilities and aged care housing developments, of one half in a million per year or less is so small as to be acceptable to the EPA

0.5 x 10^{-6} to 1.0 x 10^{-6} per year

In the case of risk generators within the grounds of the "sensitive development" necessary for the amenity of the residents, the risk level can exceed the risk level of one half in a million per year up to a maximum of one in a million per year, for areas that are intermittently occupied, such as garden areas and car parks.

1x 10^{-6} per year

A risk level in residential areas of one in a million per year or less is so small as to be acceptable to the EPA.

5 x 10^{-6} per year

A risk level for commercial developments, including offices, retail centres, showrooms, restaurants and entertainment centres, located in buffer areas between industrial facilities and residential areas, of five in a million per year or less, is so small as to be acceptable to the EPA.

10 x 10^{-6} per year

A risk level for any non-industrial activity or active open spaces located in buffer areas between industrial facilities and residential areas of ten in a million per year or less is so small as to be acceptable to the EPA.

50 x 10^{-6} per year

Risk levels from industrial facilities should not exceed a target of fifty in a million per year at the site boundary for each individual industry.

100 x 10^{-6} per year

The cumulative risk level imposed upon an industry should not exceed a target of one hundred in a million per year.

7.1.5 Conclusion

The extent of Individual Risk contours from 1x 10^{-5} per year to 1x 10^{-12} per year has been assessed by the study. It is predicted that the 1x 10^{-7} per year contour will be within a 1 km radius of the plant boundaries and that the area within this 1 km zone does not encompass any residential developments or sensitive developments.

The hazard ranges, represented as IR contours, are not greatly affected by the annual wind condition directions.

7.2 Societal risk (f-N curve)

7.2.1 Introduction

Societal risk can also be presented in the form of an 'f--N curve', which expresses the predicted frequency of occurrence (f) of a range of incidents with different magnitudes (N) of offsite fatalities. f-N curves express societies' aversion to single incidents resulting in large numbers of fatalities (e.g. rail crashes, building collapse), compared to more frequent fatal incidents (notably traffic incidents).

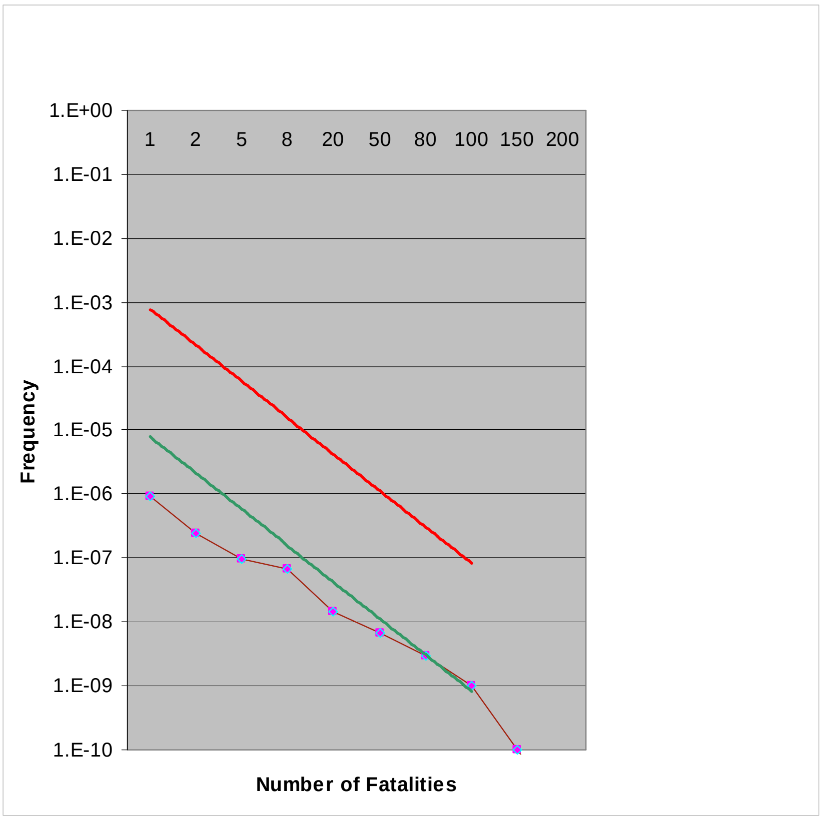
Societal risk has been calculated as described in Sections 2.0 to 6.0 of this report.

7.2.2 Results

________	Intolerable band§
________	Broadly tolerable band§
________	Prediction

§ The area between these bands is the ALARP region

Figure 5 – f-N curve for proposed Perdaman site



7.2.3 Conclusion

The societal risk assessment has predicted an f-N curve which is comfortably within typical risk tolerability thresholds. Societal risk has been calculated making conservative population and manning assumptions; with a maximum of up to 116 persons present within 4.5 km of the proposed plant.

The f-N curve flattens towards the right hand side, beyond the 8 to 20 person group fatality bands. This 'flattening' reflects the low risk of exposure of larger populations towards Collie as a result of the extreme hazard case of instantaneous loss of full vessel contents. Nevertheless, the risk is predicted to be broadly acceptable even though the hazard assessment has made a series of highly conservative assumptions.

His result demonstrates that the offsite risk to populations is not sensitive to individual assumptions regarding population numbers and hazard consequences.

The calculation of Individual Risk for Land Use Safety Planning does not strictly require specific offsite population centres to be considered; however, societal risk in form of f-N curves has been considered to provide additional insight into the nature of hazard and will assist Perdaman Chemicals to optimise safe operation of the plant and during stakeholder engagements.

7.3 Scaled Risk Index (SRI)

7.3.1 Introduction

The UK HSE has defined a coarse estimator for societal risk known as the Scaled Risk Integral (SRI). The SRI calculation is intended as a screening tool, for use at the very early stage of project planning, prior to engineering development. One application of SRIs is to give guidance on qualitative estimates, such as those allocated during early safety in design activities such as HAZID. Although SRI is a simple metric, the HSE refers to SRI predictions in Land Use Safety Planning (LUSP) documentation and provides guidance concerning the calculation methodology and interpretation of results. Refer to reference [2].for further details of the SRI process and its application.

7.3.2 Formulation

$SR = P \times IR_{HSE} \times T/ A$

Where:

P Population factor, defined as (N + N2)/ 2

N Number of persons affected by a development - can be estimated as: number of residential units x 2.5, plus 0.25 x commercial and industrial workers impacted by a development

IR_{HSE} Fatalities per million years due to major hazard exposure

T Proportion of time development is occupied by N persons

A Surface area affected by major hazard (km^2)

7.3.3 Typical interpretation

SRI	Guidance
<30000	Will not take steps to prevent development proceeding
30000 to 100000	May advise against development but will not take steps to prevent
100000 to 500000	Not unreasonable, further safety justification required
500000 to 750000	Very likely to be considered intolerable
>750000	Intolerable

7.3.4 Perdaman study

There are a number of interpretations and approaches for estimating SRIs. The assessment below has been used because offsite populations have been defined.

An alternative approach, where offsite populations are undefined, is to assume rural and urban area population densities, for example:

Rural area ~ 100 persons per km^2

Urban areas ~ up to 5000 persons per km^2

Base case (current case)

"Affected population" assumed to be all residences and businesses within 5 km of the proposed site. Estimated as 116 persons, including Stockton lake recreational area, say 120 persons

P = (120 + 1202) / 2 = 7260

IR = 4.38e-6/ year (MAE1 and MAE2) + 5.16e-5/ year (MAE3) = 56.5 per million years

T = 30%, from offsite manning assumptions

A = Area within 1e-6 contour; say 1 km radius ~ 3.2 km2

SRI (120 persons) = 7260 x 56.5 x 0.3 / 3.2 = **38,500**

Sensitivity case (1000 persons)

Assume risk scaled up with population

P = 500,500

IR ~ 56.5 x 1000/120 = 471 per million years

A ~ assume 5 km^2 for increased population

SRI (1000 persons) = 500,500 x 471 x 0.3 / 5 = **14,144,000**

7.3.5 Conclusion

The site location is satisfactory - in accordance with UK HSE planning guidelines, for the current population density surrounding the plant. Risk and safety measures, and ultimately the location of the plant, would need to be re-assessed with any significant increase (200 to 250 persons or more) in residential development within 1 to 2 km of the plant. This conclusion agrees with the findings from the offsite IR calculation and with societal risk, f-N curve.

7.4 Comparison of risk results

All risk measures are in reasonable agreement and indicate that, with the current expected offsite population centres, the Shotts Industrial Park location is a suitable site with respect to offsite hazards and risks.

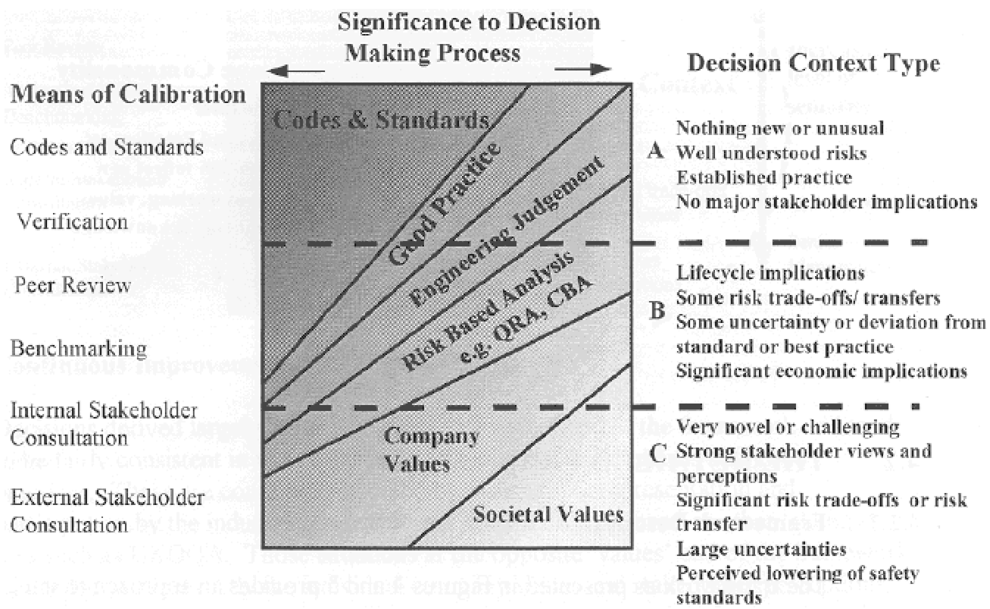
8. Demonstration of ALARP

ALARP – As Low As Reasonably Practicable

Although the likelihood of a major hazard at any specific location should be very low it can never be zero; such that some level of risk has to be tolerated where an industrial development exists. There is no simple determinant for measuring safety or for demonstrating that an operation is "safe enough".

Hazard identification and risk assessment are vital parts of any demonstration, but it is also necessary for a project to be conducted in a way which allows the benefits from good risk management practices to be realised.

The following ALARP demonstration approach, based on a framework proposed by UKOOA (UK Offshore Operators Association), is proposed for the project once sufficient design development gas been conducted.



The ALARP demonstration draws on many of the findings from the risk assessment and was conducted following the team based sessions, using information collected during the risk workshops.

Perdaman Chemicals and Fertilisers Pty Ltd is committed to the effective management and will conduct a series of Safety in design reviews throughout the design project, including a formal ALARP workshop at the appropriate time.

9. Conclusions and Recommendations

9.1 Conclusions

The PRA has determined that the dominant hazard from the proposed plant would be large or continuous emissions from the ammonia storage area and associated plant. No other significant offsite hazards were identified.

The risk assessment has postulated three characteristic storage tank hazards and assessed their consolidated impacts and risks using comprehensive dispersion modelling and the quantification of three separate offsite risk measures. All risk measures indicate that the Shotts Industrial Park location is a suitable site with respect to offsite hazards and risks.

9.2 Recommendations

Effective risk assessment is likely to facilitate the identification of opportunities for risk reduction, including measures which are essential to achieve an acceptable risk. This consideration of safeguards and improvement measures is an essential element in the demonstration that hazards and risks have been controlled to levels which are ALARP.

At an appropriate stage in the project Perdaman Chemicals and Fertilisers Pty Ltd will embark on a formal risk reduction process identifying opportunities which can:

Remove hazards entirely?

Reduce the likelihood of occurrence?

Reduce hazardous consequences?

Minimise exposed populations (on-site and off-site)?

Reduce the risk of fatality of an exposed person?

All actions raised will be recorded and managed in accordance with appropriate action tracking and project change management procedures.

No design recommendations, other than essential requirements inferred by the risk results, were raised during the PRA.

10. References

{1] "Failure frequencies for major failures of high pressure storage vessels at COMAH sites: a comparison of data used by HSE and the Netherlands"

Various subsidiary references, including:

UK HSE guidance on assessment of COMAH safety cases

Scooby and Tolchard

O'Donnel et al

TNO review (1998)

Smith and Warwick data 1981

Spouge (2005), high quality data collected from UK offshore

Canvey Island and COVO study

FP Lees

Phillips and Warwick (1968)

ABMA (Marx, 1973)

Kellerman and Siepel (1967)

[2] Carter J and Riley N: "The role of societal risk in land use planning near hazardous installations and in assessing the safety of the transport of hazardous materials at the national and local level. Published as "Quantified societal risk and policy making", Kluwer academic publishers, 1998

[3] J K Vrijling, W van Hengel and RJ Houben and P H A J M van Gelder, “A generalized approach for risk quantification and the relationship between IR and SR"

[4] S N Jonkman, J K Vrijling and P H A J M van Gelder “A framework for risk evaluation”. Journal of hazardous materials 43 (1995) 345-261

[5] Yu. N. Shebeko, A. Ya. Korrolchenko, A.P. Shevchuk, V. A. Kolosov, I. M. Smolin “Fire and Explosion Risk Assessment for LPG storages. Fire Science and Technology Vol 15, Nos 1 and 2, 1995

[6] Wind roses; attachment 5 to "NWCF Basis of Design - Collie coal to urea project", dated: June 2008

[7] Various ammonia probits, including:

DCMR (Dutch Government Environmental Protection Agency) Steering Committee; probit used for Kwinana risk study

I Chem E, 1986

Ten Berge, 1986

Canvey island trials, 1978 (supplied by GHD, original source not identified)

ACDS, 1992

de Weger 1991/ Green Book 16

SAFETI recommendation (similar to DCMR)

Information extracted from FP Lees handbook – e.g. accident case histories, summary of Canvey island trials 1 and 2

[8] AS/NZS 2022:2003 - "Anhydrous ammonia, storage and handling", Table A1

[9] FESA discussion paper, title: "Protect-in-place". Prepared by Leith Higgins, Scientific Officer; organisation: FESA Operational resourcing. Date of issue: 19th January 2006.

[10] Second Canvey report, 1988 (sourced through FP Lees handbook)

[11] Material Safety Data Sheet (MSDS) for anhydrous ammonia: Molecular formula: NH3, CAS No: 7664-41-7, EC No: 231-635-3, Annex I Index No: 007-001-00-5

[12] Various correspondences: Perdaman and GHD: dispersion modelling results and subsequent dialogue. Initial dispersion result – GHD memo dated 29th May 2009

Appendix A

Properties of Anhydrous Ammonia

Properties of Anhydrous Ammonia

Chemical Name: Ammonia, Anhydrous COMPOSITION: 99+% Ammonia.

Synonyms: Ammonia Liquefied. CAS REGISTRY No. 7664-41-7

Chemical Family: Ammonia formula: NH_3 Moll. Wt. 17.03 (NH_3)

Properties

Physical data boiling pt: -33°C

Freezing pt: -78ºC

Vapour density (Air=1): 0.6

Vapour density (AIR=1): 0.596 @ 0°C

Vapour pressure: 10 atm @ 25.7ºC

Solubility in water:: 89.9 g/100 cc @ 0ºC 7.4 g/ 100 cc @100ºC

Specific gravity (H_2O=1): 0.682 @ 4°C

Evaporation rate (Water=1) - Faster than water

Appearance & odour: Colourless gas/liquid and pungent odour

Chemical Reactivity

Stable at room temperature; Ammonia will react exothermically with acids and water.

Avoid mixing with sulphuric acid or other strong mineral acids

Avoid mixing with hypochlorite (chlorine bleach) or other halogens and sodium hydroxide

Avoid contact with galvanized surfaces, copper, brass, bronze, aluminium alloys, mercury, gold, silver, and strong oxidizers

Avoid heating.

Hazardous Decomposition Products - Hydrogen and Nitrogen gases above 450ºC

Health Effects

Irritant and corrosive to skin, eye, respiratory tract and mucous membranes

May cause severe burns, eye and lung injuries

Skin and respiratory related diseases aggravated by exposure

Not recognized as a carcinogen

Eye damage: lachrymation, oedema, blindness

Skin: irritation, corrosive burns, blister formation

Contact with liquid will freeze tissue and cause caustic burns

Heavy, acute inhalation exposure may result in severe irritation of the respiratory tract, glottal oedema, bronchial spasm, pulmonary oedema and respiratory arrest. Lung injury may appear as delayed phenomenon, pulmonary oedema may follow chemical bronchitis.

Extreme exposure (5000 ppm) can cause immediate death from spasm, inflammation or oedema of larynx.

Fire and Explosion and Special Hazards

Not generally a fire hazard

Combustion may form toxic nitrogen oxides

If relief valves are inoperative, heat-exposed storage containers may become explosion hazards

Ammonia contact with chemicals such as mercury, chlorine, iodine, bromine, silver oxide, or hypochlorite can form explosive compounds.

Reacts with chlorine to form chloramines gas

Appendix B

Probit Analysis

Use of Probits in Hazard Consequence Analysis

Dispersion Dynamics

For a dense gas release from a pressurised storage vessel (note: ammonia is stored at atmospheric pressure); a gas release will initially be momentum driven with an orientation dependent on the location of an incident. Figure B1 represents a gas release directed upwards. Beyond the momentum driven diffusion zone, the direction of dispersion is likely to be dictated by wind effects. Five emission and dispersion zones are identified in Figure B1 below:

Emission from source (near field effect)

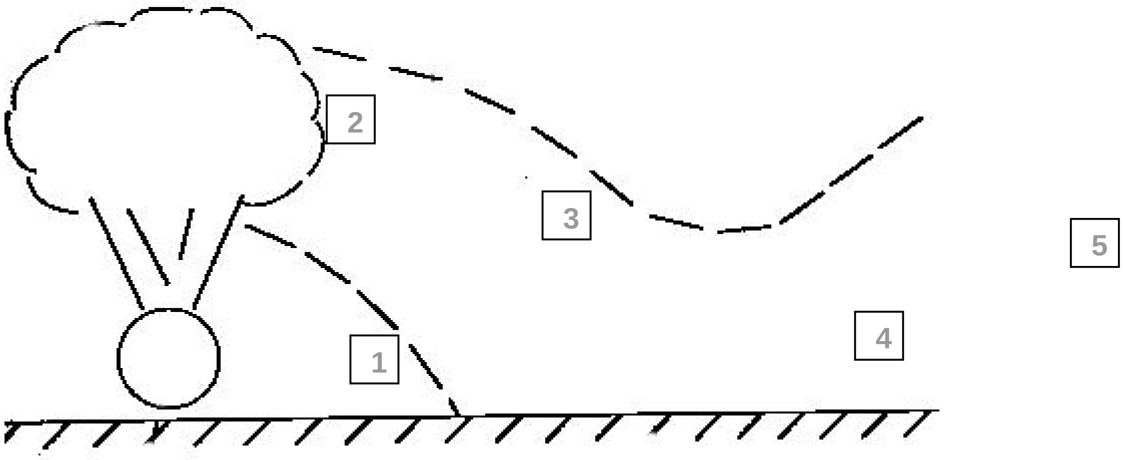
Initial acceleration and diffusion (near field effect)

Negative buoyancy, denser than air zone, with gas cloud slumping to ground

Transition to neutral density or lighter than air dispersion

Neutral density or lighter than air dispersion (far field effect)

Figure B1: Emission and Dispersion Zones



The risk to individuals on the ground will depend on their location and the direction and elevation of gas at toxic concentrations. For Figure B1, the greatest impact is likely to be in zone 4, where the gas reaches ground level. Dispersion modelling identifies, for different materials and release conditions, the distance at which a dense gas cloud reaches ground level.

Ammonia plant

Hazard consequence modelling, using PHAST software has evaluated both the "plume centre-line" and "ground level" gas concentration profiles for three release cases:

MAE 1 represented as - 300 mm rupture from base of storage tank

MAE 2 - 25 mm release from peripheral equipment

MAE 3 – Instantaneous loss of full vessel contents

The modelling has identified that MAE 2 and MAE 3 behave as dense, ground hugging gas plumes in the far field; such that there is minimal difference between "cloud centreline" and "ground level" concentrations. MAE 1 is found to slump close to the point of release and to disperse as a neutral density, slightly lighter than air gas plume in the far field.

A "rule of thumb" for lighter than air gas plumes in the far field is that gas concentrations at the margins of a plume are approximately 10% of the maximum cloud centre line concentrations.

Typical Dose Responses

Figure B2 illustrates the typical lethal response (numbers of fatalities) to doses of toxic chemicals. The y-axis indicates the response; the x-axis indicates the logarithm of the dose.

Figure B2: Typical dose response (toxic hazard)

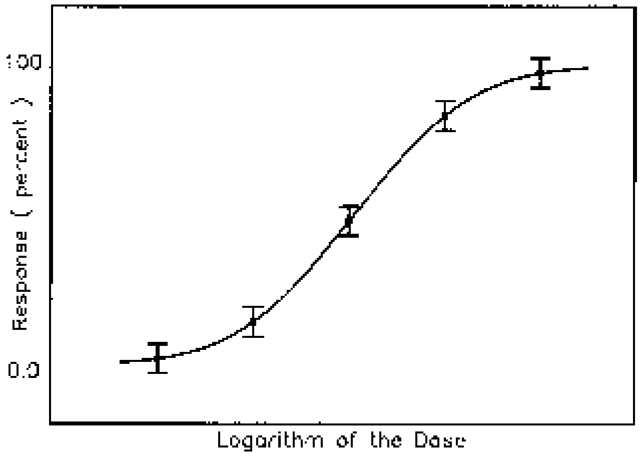
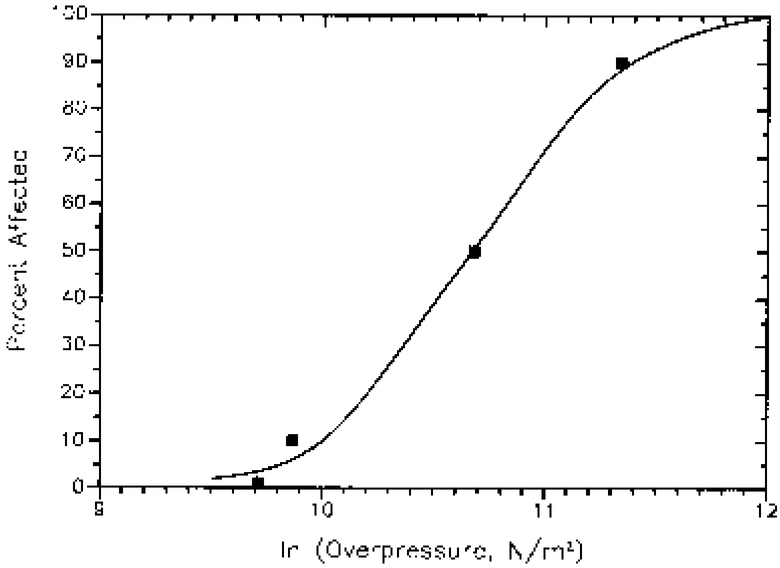


Figure B3 illustrates the lethal response in terms of the number of persons affected by explosion overpressure hazards. The y-axis indicates the effect (such as the percentage of individuals affected); the x-axis is the logarithm of the over pressure. The shapes of figures B2 and B3 are similar and could be represented using a similar mathematical equation.

Figure B3: Typical dose response (explosion hazard).



Probit function

Probit functions can be considered as a transformation between exposure dose and percentage of populations affected – related to the physical or chemical consequences of a hazard. Probits are derived empirically and take the form of Figure B4; the y-axis represents the probit function, the x-axis represents the percentage of a population affected by a physical hazard.

Figure B4: Physical response to hazard consequences

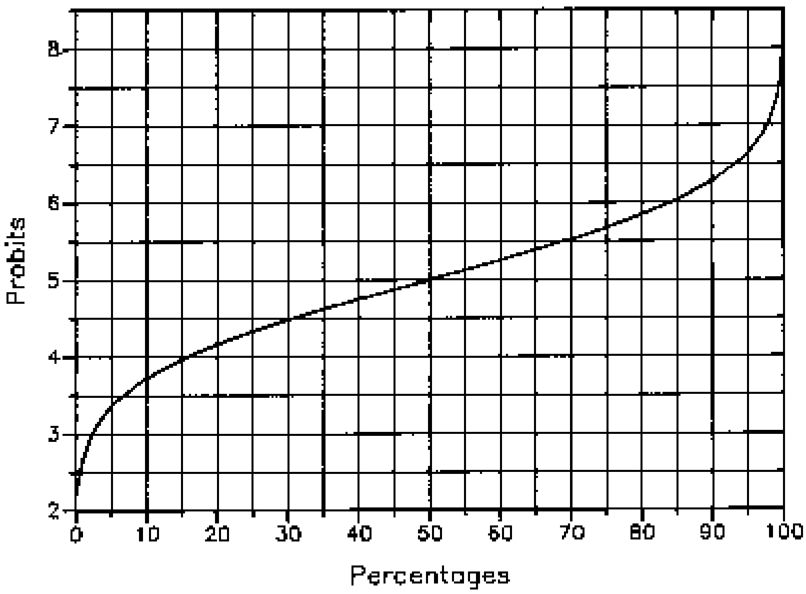
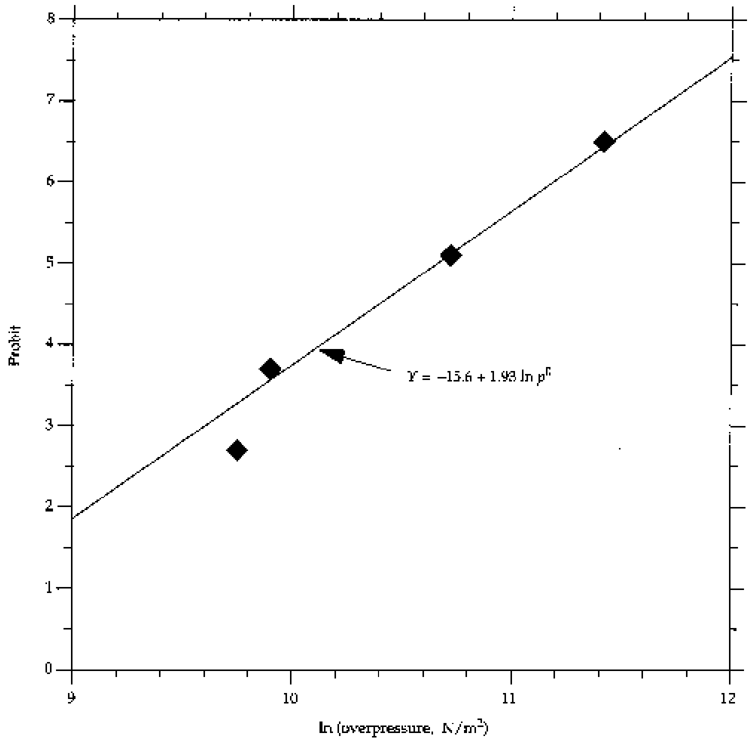


Figure B4, the probit function, is applied to transform the typical dose curve into a probit v. dose curve. This allows percentage fatality or injury rates to be estimated for typical populations. Probit functions are a mathematical formulation termed "Error function (Erf); Erfs can be solved analytically, but are usually solved by reference to a look up table – see Table B1 below.

Figure B5 shows the result of the transformation; where the Probit v. Ln (dose) curve is now linear. This straight line is a different realisation of Figure B3; but, being linear, the impact and relation can more easily be described and represented. Using these forms, a variety of events can be expressed using linear equations.

Figure B5: Physical response to hazard consequences



From Figure B5; the defining equation for probits representing toxic hazards is shown to be:

$Pr = a + b \{Ln (C^n t)\}$

Where

Pr - Probit value

C – Concentration, usually in ppm

N – Concentration exponent, typically in the range 0.6 to 3

T - Exposure time (usually minutes)

a and b - Probit constants representing chemicals

Example toxicity probits are indicated below; for reference the probit applied for the Perdaman facility ammonia hazard is:

$Pr = -9.82 + 0.71 \ Ln \ [C^2 \times t]$

Selected Probits for other toxic chemical are indicated in Table B2 – original reference: Louvar, J.F. and Louvar, B.D., 1998, publication: “Health and Environmental Risk Analysis: Fundamentals with Applications”.

The values for constants a and b are mostly derived from experiments with animals, scaled up to represent the human body. Although there is considerable research in this field, only a limited number of toxic materials consequence models have been developed. One problem is the scarcity of information from which good predictive models are developed, especially for acute toxic exposure. Data transformation from oral intoxication data to inhalation toxicity criteria is sometimes necessary.

Table 10-1 Example toxicity probits

Material	a	b	n
Acrolein	-9.93	2.05	1.0
Acrylonitrile	-7.81	1.00	1.3
Ammonia	-16.14	1.00	2.0
Benzene	-109.78	5.30	2.0
Bromine	-10.50	1.00	2.0
Carbon Disulfide	-46.58	4.20	1.0
Carbon Monoxide	-7.25	1.00	1.0
Carbon Tetrachloride	-6.29	0.41	2.5
Chlorine	13.22	1.00	2.3
Hydrogen Chloride	-6.20	1/00	1.0
Hydrogen Cyanide	-9.68	1.00	2.4
Ethylene Oxide	-6.19	1.00	1.0
Hydrogen Sulphide	-11.15	1.00	1.9
Nitrogen Dioxide	-17.95	1.00	3.7
Phosgene	-27.20	5.10	1.0
Propylene Oxide	-7.42	0.51	2.0
Sulphur Dioxide	-1.22	1.00	2.40
Tetraethyl Lead	-1.50	1.00	1.0
Toluene	-6.79	0.41	2.50

For situations where personnel are exposed to different concentrations (or different chemicals) for different times; the usual approach is to treat exposure in "batches" and to integrate the constituent exposure doses over the full exposure duration; i.e.

$C^n t = \Sigma C^n \times \Delta t_i$

Example

The following example refers to a scenario involves a community of 1000 persons of which 200 are exposed to toxic chlorine gas due to a truck accident. The Chlorine probit applied is taken from Table B1:

$Pr = -13.22 + (1.00) \, Ln \{\Sigma(C^{2.3} \Delta t)\}$

Table 10-2 Example calculation

People Subjected	Exposure Time (mins)	Concentration (ppm)	Pr
200	150	200	3.60
	150	300	5.20
	200	150	3.98

Solution:

a) $-13.22 + (1.00) \, Ln \{\Sigma(200^{2.3} \times 150)\} = 3.98$

b) Refer to Table B3

c) Pr 3.60 = 8% fatalities

Pr 5.20 = 58% fatalities

Pr 3.98 = 15% fatalities

Table 10-3 Probit function look up table

%	0	1	2	3	4	5	6	7	8	9
0									3.59	
10						3.96				
20										
30										
40										
50									5.20	

60										
70										
80										
90										
%										
99										

Results

d) For 200 persons

8% x 200 persons exposed = 16 fatalities

58% x 200 persons = 116 fatalities

15% x 200 persons = 30 fatalities

Conclusion

Probit Analysis is a methodology which transforms the complex percentage affected v. dose response into a linear relation of probit v. dose response. The probits can then be translated into percentages. The method is useful because of the typical curve shape found in the dose response curve. The method is approximate but it does allow quantification of consequence due to exposure.

Refer to Section 5.0 of the risk assessment report “Selection of ammonia probit”.

Appendix C

Stockton Lake Occupancy Estimate

Motorcycle/ motocross events at Stockton Lake

The Collie Motorcycle Club comprises senior, junior and vintage motocross riders, Enduro and Trail riders. The club hosts a number of major events, such as the "Griffin Coal junior and senior motocross (MX) challenge" over the Easter long weekend, as well as one of the "Honda Country Pony Express Series" state round endurance trials and other state round motocross events; although not all of these take place at Stockton Lake. The Vintage MX Club of WA utilizes the circuit for two of their events each year

In addition to these, there are a number of inter-club competitions with other South West clubs, club member trail rides and general fun days.

The Stockton Park circuit is approximately 1.8 km long and consists of sand, gravel and clay and is a preferred track for hosting events during the dry seasons due to the availability of the water.

The Collie club is affiliated to "Motorcycling WA" (MWA), the sports' governing motorcycle body. As with most motocross circuits, the track is essentially under lock and key and closed for riding except for practice days, club days and organised events.

Estimated usage - Motocross annual events

1. Long Easter weekend - Griffin Coal Junior and Senior MX Challenge; group size: 200 to 2000
2. Local MX competitions - Collie MX versus other MX clubs; group size: 100
3. Vintage MX club of WA; group size: 200 to 500
4. Honda country pony express series; group size: 200 to 1000
5. State wide MX events; group size: 100 to 200
6. Other public events and fun days; group size: 100 to 200
7. Club trail rides (Collie MX club only); group size: 20 to 30

Estimated usage (Motocross and related events)

Ref.	Group size	Exposure (hrs)	Occurrences per year	Total hrs
1	2000	12	1	24,000
	1000	12	1	12,000
	500	12	1	6,000
	200	12	1	2,400
				44,400
2	100	24	6	14,400
	200	24	2	9,600
	500	24	2	24,000
				33,600
3	200	8	1	1,600
	400	8	1	3,200
	600	8	1	4,800
	800	8	1	6,400
	1000	8	1	8,000
				22,400
4	100	24	6	14,400
	100	36	6	21,600

Ref.	Group size	Exposure (hrs)	Occurrences per year	Total hrs
				36,000
5	100	24	3	7,200
	100	48	3	14,400
				21,600
6	30	12	5	1,800
	20	36	5	3,600
7				5,400

Ref.	Total exposure	% Total
1	44,400	19.7%
2	14,400	6.4%
3	33,600	14.9%
4	22,400	9.9%
5	36,000	15.9%
6	21,600	9.6%
7	5,400	2.4%
	177,800	78.7%

Other Stockton Lake usage

Apart from motorcycle and motocross events, Stockton Lake is freely accessible to the public and is used for walking, camping, day and weekend visits, water skiing and swimming.

8. Non MX event weekends (21 per year); group size: 10 to 20
9. Long weekends (2 per year); group size: 50
10. School vacation (20 days per year); group size: 30 to 50 persons
11. Mid week days (20 per year); group size: 10
12. Week day use (250 days/ year); group size: 1 to 5 persons

Ref.	Group size	Exposure (hrs)	Occurrences per year	Total hrs
8	10	36	15	5,400
	20	36	6	4,320
				9,720
9	50	48	2	4,800
				4,800
10	30	24	10	7,200
	50	24	10	12,000
				19,200
11	10	12	20	2,400
				2,400
12	20	5	70	7,000
	20	2	70	2,800
	10	2	110	2,200
				12,000

Ref.	Total exposure	% Total
8	9,720	4.3%
9	4,800	2.1%
10	19,200	8.5%
11	2,400	1.1%
12	12,000	5.3%
	48,120	21.3%

Summary of Stockton Lake estimated usage

			Hours per year		
Refs.	Total exposure	24-hr population (persons)	> 50 persons	> 200 Persons	> 500 persons
1 to 7	177,800	20.44	292	136	84
8 to 12	48,120	5.53	72	None	None
	225,920	25.97	364	136	84

Source references:

Various email correspondence (unreferenced): Landcorp and PCF

Various public information, example **http://www.motorcyclingwa.org.au**

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Document Status

Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
0	D Allen	A Khandelwal		S Kamper		2/07/09
1	D Allen	A Khandelwal		S Kamper		24/07/09