

**Table 9 Moranbah Weather Categories (%)**

Wind Stability Category	Wind Speed (m/s)	Wind Direction Probability (%)															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
		360	20	50	70	90	110	130	160	180	200	230	250	270	290	310	340
F	1	0.6%	0.0%	0.0%	0.6%	5.8%	5.2%	13.0%	0.2%	0.6%	0.0%	0.4%	0.0%	0.0%	0.4%	3.9%	1.1%
D	3	1.3%	0.5%	1.9%	1.8%	8.2%	5.4%	7.7%	0.5%	0.4%	0.1%	0.8%	0.0%	1.0%	0.2%	3.5%	0.6%
B	3.3	1.9%	0.3%	2.7%	1.9%	10.5%	4.4%	3.1%	0.4%	1.8%	0.6%	2.1%	0.3%	1.7%	0.3%	1.5%	0.5%

**Table 11 Moranbah Weather Station Air Properties.**

Property	Day	Night
Air Temperature	29 °C	18 °C
Relative Humidity	34 %	80 %

### 3. Hazard Identification, Impact and Risk Criteria

#### 3.1 Hazardous Material Identification

Hazardous materials identified as being either produced or consumed in the Ammonia, nitric acid, Ammonium Nitrate, and/or emulsion plants are presented in Table 13.

**Table 13 Hazardous Materials addressed in the AN and AN Emulsion Facilities**

Ref No.	Hazardous Material <sup>9</sup>	Phase <sup>10</sup>	Produced/Use	Maximum Quantities in Assessed Sites on the AN & AN Emulsion Facilities
1	Anhydrous Ammonia	Liquid and Gas	Produced at the Ammonia plant and consumed in both the AN and Nitric acid plants for the production of acid and AN.	Storage of up to 5000 tonnes.
2	Ammonium Nitrate	Solution, Prill, and Emulsion	Produced in AN plant. Facility end product	Storage of up to 12,000 tonnes of prill and emulsion (this includes material moving through the process on site).
3	Nitrogen oxides (monoxide, dioxide, tetroxide, nitrous)	Intermediate Gas	Produced and consumed in Acid plant for the production of acid.	In-situ usage. No storage of gas.
4	Nitric acid	Liquid	Produced in Acid plant and consumed in AN plant to produce AN.	Storage of up to 2000 tonnes
5	Alkyl amine (coating agent)	Liquid	Consumed in AN plant for prill stabilisation.	Storage of up to 100 tonnes
6	Emulsion agents (oils, diesel)	Liquid	Consumed in emulsion plant.	Storage of up to 200 tonnes
7	Steam	Gas	Produced and consumed by Ammonia, Ammonia	No storage of steam

<sup>9</sup> The typical MSDS's for these chemicals can be found in Appendix E.

<sup>10</sup> See Table 35, Table 37 and Table 39 for further details.

Ref No.	Hazardous Material <sup>9</sup>	Phase <sup>10</sup>	Produced/Use	Maximum Quantities in Assessed Sites on the AN & AN Emulsion Facilities
			nitrate and nitric acid plants.	
8	Nitrogen	Pressurised Liquid and Gas	Consumed by both plants as purge.	Storage of up to 300 m <sup>3</sup>

Of the materials mentioned above, only Anhydrous Ammonia, Nitrogen Oxides and Ammonium Nitrate were considered capable of having an offsite safety risk impact. These materials are discussed in turn in the following sections. The remainder of materials mentioned above is considered to only have localised effects, as discussed below:

- ▶ Nitric acid and Steam will cause severe burns with bodily contact however will not travel sufficient distances upon release to atmosphere to affect an offsite populations.
- ▶ The coating agent (alkyl amine) and emulsion agents (process oils, diesel) will cause localised pool fires, if they become ignited, 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 a potential asphyxiation and frostbite hazard to personnel however all Nitrogen releases will rapidly disperse, to safe concentrations, before reaching the site boundary.

These items will therefore not be discussed further within this report.

### 3.2 Consequence Impact Criteria

Impact criteria were established for the assessment of hazardous event consequences (dispersing gas cloud, explosion, etc)<sup>11</sup> on humans and buildings. Explosion overpressure criteria are well-defined and used throughout industry / military as considerable information has been made available from reputable sources (Table 19). Explosion overpressure criteria (AN) are based on the impact the overpressure can cause to buildings and infrastructure, and also impact to humans. The relationship between overpressure and fatalities is complex and for the purposes of this study, the criteria quoted in the NSW Hazardous Industry Planning Advisory Paper (HIPAP) No. 4 [Ref 8], have been used, as detailed in Table 19. This criteria is widely accepted throughout Australia.

<sup>11</sup> The impact of a fire onsite was considered at the Ammonia plant, but ultimately the consequences do not contribute to the offsite risk profile.

Toxic exposure criteria (Ammonia and  $\text{NO}_x$ ) can be presented in terms of probits or dangerous doses. Probit calculations relate the probability of fatality to a probit coefficient that is determined from an exposure dose to a particular material [Ref 3]. Modern consequence modelling packages use probit calculations to generate fatality probability footprints suitable for creating reasonable risk measurements. A dangerous dose is a single criterion that defines a certain dose that will result in a certain probability of fatality. Details of the Probits used for Ammonia and Nitrogen Dioxide release are presented in Appendix C, Table 41.

### **3.3 Ammonia**

Ammonia is a toxic gas, which while also flammable, it 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. The ignition of Ammonia is discussed further in Appendix A.

Although Ammonia is lighter than air, a pressurised or cold release of Ammonia may form a dense cloud (due to low temperature) after expansion to atmospheric pressure or form a fog. Ammonia can be readily detected in the atmosphere by smell at concentrations as low as 5 ppm. It is a powerful irritant to eyes and mucous membranes of the respiratory tract. Inhalation of high concentrations of the vapour may cause pulmonary oedema, which may be fatal. 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. The toxicity of Ammonia is reported in Table 15.

**Table 15 Toxicity of Ammonia**

Concentration (ppm)	Exposure Effects	Exposure Duration
5	Odour detectable by most people.	Prolonged repeated exposure produces no injury.
100	No adverse effects for average workers.	Maximum allowable concentration for 8-hour working day.
300-700	Nose and throat irritation. Eye irritation with tearing.	Infrequent, short (1 hr) exposures typically produce no serious effects.
2000-3000	Convulsive coughing, severe eye irritation.	No permissible exposure.
5000-7000	Respiratory spasm, rapid asphyxia.	No permissible exposure. Rapidly fatal.

The toxicity levels and exposure effects are based on the de Weger / TNO Green Book [Ref 4] probit for determining Ammonia fatalities. The ERPG-3 concentration for anhydrous Ammonia is 750 ppm.

### 3.4 Nitrogen Oxides

Nitrogen oxides (nitrogen monoxide, dioxide, tetroxide, nitrous oxide, etc) are produced in the nitric acid plant for the production of acid. Nitrogen dioxide (NO<sub>2</sub>) is the most toxic. NO<sub>2</sub> is a respiratory irritant, however its main danger lies in the delay before its full effects upon the lungs are shown by feelings of weakness and coldness, headache, nausea, dizziness, abdominal pain and cyanosis. In severe cases, convulsions and death by asphyxia may follow. Table 17 overviews the toxicity of nitrogen dioxide [Ref 5]. This study used the Harris DSM78 probit for determining nitrogen dioxide fatalities. The ERPG-3 concentration for nitrogen dioxide is 30 ppm.

**Table 17 Toxicity of Nitrogen Dioxide**

Concentration (ppm)	Exposure Effects
0.1	Odour perception. Short-term impairment of night vision.
0.2	Odour threshold for 100% recognition.
3	Recommended TLV for continued workplace exposure with no adverse effect.
90	Lowest toxic concentration for humans. Causes pneumonia and bronchitis after 40 minutes exposure. Moderate irritation

Concentration (ppm)	Exposure Effects
	to eyes and nose
200	Lowest lethal concentration for humans after one-hour exposure.
250	Acute exposure. Concentration may result in coughing, fever, vomiting and death.

Nitrous oxide (N<sub>2</sub>O) is a non-toxic anaesthetic however may cause fatality due to an asphyxiation effect by displacing oxygen. Personnel exposed to nitrous oxide are likely to feel light-headed and anaesthetised before asphyxiation occurs, however concentrations of approximately 150,000 ppm of gas are required to displace of oxygen content of air to less than 18% which is considered a starting-point for asphyxiation [Ref 6]. Nitrous oxide was screened from the analysis, as concentrations leading to asphyxia will not be reached beyond the site boundary.

### 3.5 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. When subjected to heat, AN undergoes a series of complex decomposition reactions that produce low levels of toxic nitrogen oxides (namely nitrous oxide) at atmospheric pressure [Ref 7]. 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 the previous section.

The plume of combustion products resulting from an Ammonium Nitrate fire in previous studies (eg. Bunbergn 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 AN fires are screened out.

The sensitivity of Ammonium Nitrate to detonation is largely dependant on three variables; high temperature, confinement and contamination. Without any one of these being present, Ammonium Nitrate would require a strong initiation charge (i.e. high explosive) to detonate at all.

Variables in the calculation of overpressure consequences from an Ammonium Nitrate explosion include the proportion of material present that is sensitised to detonation, 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 and the scarcity of reliable information on the explosive nature of many other materials.

In this analysis, the impact criteria presented in the third column of Table 19 were used to define fatality envelopes (offset areas of the facility in which people present are expected to be killed) with their respective fatality probabilities. The criteria were chosen to provide conservative results appropriate for LUSP approval purposes. A detailed explanation of the Ammonium Nitrate explosion modeling conducted in this report is given in Appendix C.

**Table 19 HIPAP Overpressure Effects**

<b>Explosion Overpressure</b>	<b>Recognised Effects</b>	<b>Overpressure Criteria used in this Study</b>
3.5 kPa (0.5 psi)	90% glass breakage. No fatality very low probability of injury.	
7 kPa (1 psi)	Damage to internal partitions and joinery but can be repaired. Probability of injury is 10%. No fatality.	
14 kPa (2 psi)	Houses uninhabitable and badly cracked.	
21 kPa (3 psi)	Reinforced structures distort. Storage tanks fail. 20% chance of fatality for a person in a building.	Onset of Fatalities of people in the open, conservatively estimated at 10%
35 kPa (5 psi)	House uninhabitable. Wagons and plant items overturned. Threshold of eardrum damage. 50% chance of fatality for a person in buildings and 15% chance of fatality for a person in open.	Fatalities of people in the open conservatively estimated at 30%
70 kPa (10 psi)	Threshold of lung damage. 100% chance of fatality for a person in a building or in the open. Complete demolition of houses.	Fatalities of people in the open conservatively estimated at 100%

### 3.5.1 Ammonium Nitrate Prill

The proposed Moranbah AN storage facility will store a maximum 10,000 tonnes of AN Prill between four allocated storage areas (2 x 3,000 tonnes and 2 x 2,000 tonnes). The consequences from a 3,000 tonne AN Prill explosion (base case) are identified in Table 29.

One of the issues associated with AN Prill explosions is the quantity involved during an explosion. The quantity of AN Prill involved in an explosion can be determined through consideration of historical incidents. Essentially the Toulouse explosion [Ref 9] involved some 400 tonnes of contaminated AN material giving an overall TNT equivalence of between 20 to 40 tonnes (i.e. 5-10% equivalence). Note: This is fertilizer grade AN and is likely to have a lower equivalence than Technical grade AN. Queensland Guidance Note 4 (which references the COAG Guidelines), specifies an overall NEQ of 32% to be used for AN Prill. The COAG Guidelines forms the most conservative number used out of the three cases and will therefore be used as the “base case”.

### **3.5.2 Ammonium Nitrate Emulsion**

The proposed AN storage facility will store a maximum of 420 tonnes of emulsion in three storage tanks. The consequences from a 140 tonnes of AN Emulsion that will affect offsite populations are identified in Table 29. Note: The AN Emulsion tanks (3 x 140 tonne) will be provided with a concrete wall on three sides of the tanks. Each tank will be separated by 6m (dirt filled), to prevent any potential knock-on effects. The concrete walls reach a height of 1m above the emulsion tanks.

An explosion net equivalent quantity of 70%<sup>1</sup> (100% efficiency and 70% TNT equivalency) with 140 tonnes has been used as the base case in this study for AN emulsion that represents the total storage capacity within a single storage tank. This efficiency value assumes conservatively 100% of the emulsion is involved in the explosion.

### **3.6 Individual Risk Criteria**

As a part of the approval process for new industrial developments in Queensland, proponents are required to develop a risk assessment and compare the results with the individual risk criteria defined in the CHEM Services Hazardous Industry Planning for Safety guidelines as summarised below. The QLD Individual Risk Criteria are shown in Table 21.

Individual risk is defined by the I.Chem.E (1992) as the frequency at which an individual may be expected to sustain a given level of harm from the realisation of specified hazards. The purpose of criteria based upon this risk measure is to ensure that no single person is overexposed to risk. In this report it is taken to be the risk of death per year and is primarily reported in the form of an iso-risk contour plot.

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<sup>1</sup> For the purposes of this assessment an Net Equivalent (NEQ) factor of 70% were taken to represent the best estimated conservative number used for Ammonium Nitrate Emulsion based on discussions with Industry and the Regulators (WA).



**Table 21 Individual risk criteria based on QLD CHEM Services Limit of Tolerability Risk Criteria**

Development classification for Different Land Uses	(Fatalities per yr) (Scientific notation (Fatalities per yr)	Typical developments
Sensitive	0.5 in a million $5 \times 10^{-7}$	Hospital, school, Aged care centres.
Residential	1 in a million $1 \times 10^{-6}$	Residential housing
Commercial	5 in a million $5 \times 10^{-6}$	Shopping Centres, showrooms
Public	10 in a million $1 \times 10^{-5}$	Active open space, Sporting complexes
Industrial	50 in a million $5 \times 10^{-5}$	Refineries, Chemical Plants, Bulk storage

### 3.7 Societal Risk

Societal risk measures may be used to assess acceptability of risk to a specific population group (workforce, contractors, community etc). Societal risk measures relate the frequency of an incident occurring with the number of people affected. The purpose of criteria based on this risk measure is to control risk to society as a whole. In this report societal risk is reported in the form of Potential Loss of Life (PLL) values.

The Queensland Regulatory bodies have not yet specified any definitive criteria for the assessment of societal risk. HIPAP Advisory Paper No. 4 states that the two components of societal risk are:

1. The number of people exposed to levels of risk; and
2. The larger scale multiple fatalities.

Due to the isolated area at which the plant is located, and the vast separation of the plant from the community, the societal risk from the Moranbah Facility was not further investigated beyond calculating the potential loss of life (PLL) values for surrounding locations. This should, however, be addressed in the Major Hazard Facility Safety Case.

### 3.8 Major Accident Events (MAEs)

**Table 23 Major Accident Events**

No.	Major Accident Events	Cause(s)
1	Fire in AN storage area	1. Electrical failure. 2. Contamination of AN. 3. Front end loader operations in AN storage area. 4. Malicious third party interventions. 5. Unloading truck. 6. Lightning.
2	Deflagration event in AN storage area	1. Fire. 2. Malicious intervention. 3. Hydrocarbon contamination. 4. Product contamination. 5. Sympathetic detonation associated with explosive handling.
3	Fire impinged on AN emulsion tank	1. AN delivery truck collides with diesel vessels. 2. Diesel truck collision
4	Deflagration event in an AN emulsion storage tank	1. Lightning strike. 2. Malicious third party intervention. 3. Vehicle impact. 4. Bush fire. 5. Contamination.
5	Loss of containment of the Ammonia tank	Fitting failure Third Party Impact Missile Impact

All the MAEs described in Table 23 are reflected in the failure cases modeled for this study.

## 4. Hazardous Scenario Development

### 4.1 Screening of Hazards

Hazardous events were identified through analysis of descriptive information relevant to the facility made available in combination with the criteria (toxic, flammable and overpressure) established in the previous chapter.

The distance to site boundaries are shown in Table 25.

**Table 25 Distances from Plant to Site Boundaries**

South-West Boundary*	460m
North-East Boundary	640m
South-East Boundary	620m
North-West Boundary	860m

\* Directions are based on True North.

In each scenario, events not considered capable of reaching these distances in lethal effect (i.e. causing offsite fatalities) were screened out. A full list of the hazards and their detailed information is shown in Appendix A.

Overall, 18 events<sup>12</sup> were considered to have the potential to cause offsite fatalities through either toxic or overpressure effects and were therefore incorporated into a more detailed consequence and frequency analysis to determine the plants' offsite risk.

### 4.2 Natural Events

The following natural events were considered for the Moranbah area:

1. Cyclones;
2. Earthquakes;
3. Bush Fires;
4. Flooding; and
5. Lightning.

#### 4.2.1 Cyclones

The main risks to the plant in the event of a cyclone would be:

1. Wind loads, and
2. Flooding due to heavy rainfall.

<sup>12</sup> These events were taken from the list in Appendix, A which were not screened out.

The applicable code for wind loading (AS1170.2) indicates that Moranbah is not in a cyclonic zone. Moranbah is located in Region A4 - non cyclonic.

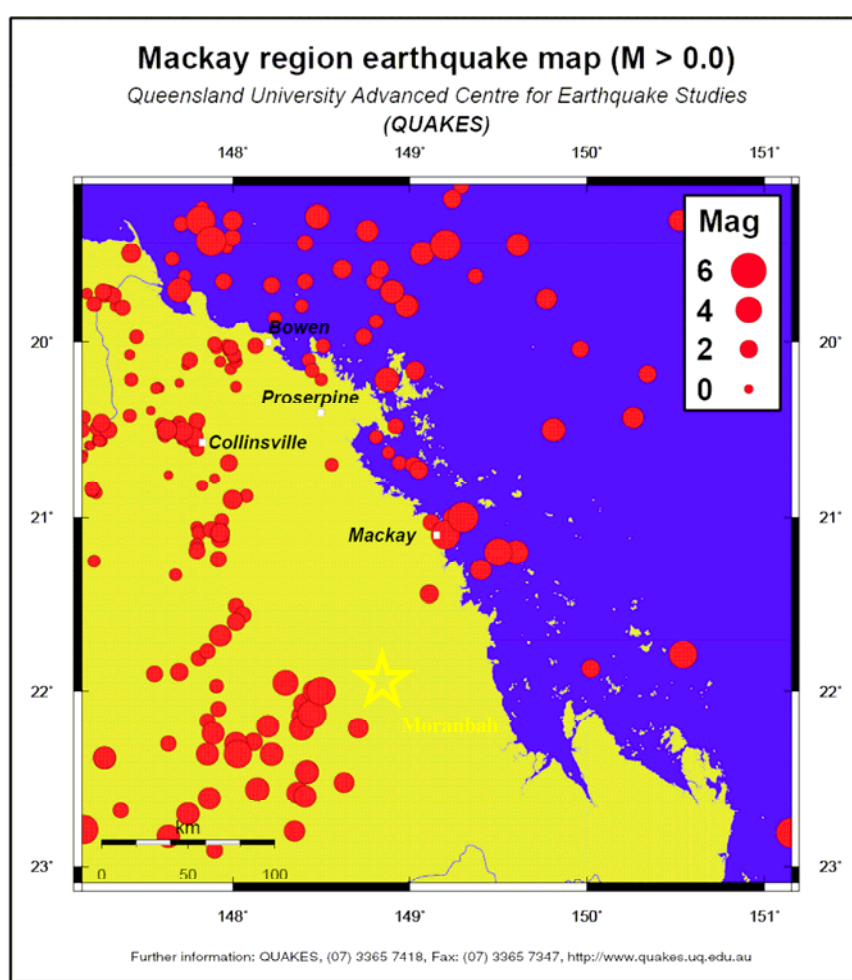
The Bureau of Meteorology advises the maximum wind speed ever recorded at Moranbah is 13.9m/s - well below any applicable design values.

The risk of flooding from a cyclone event (or rain bearing depression) is also low or 'insignificant' (see main body of EIS). The site storm drain system will be designed for the applicable rainfall event in accordance with the relevant Australian Standards.

#### 4.2.2 Earthquakes

As shown in Figure 9, there is no recorded history of earthquakes near Moranbah, Queensland. An earthquake does not present a credible risk scenario for the proposed facilities. Design will be in compliance with the Building Code of Australia, with respect to Earthquake protection.

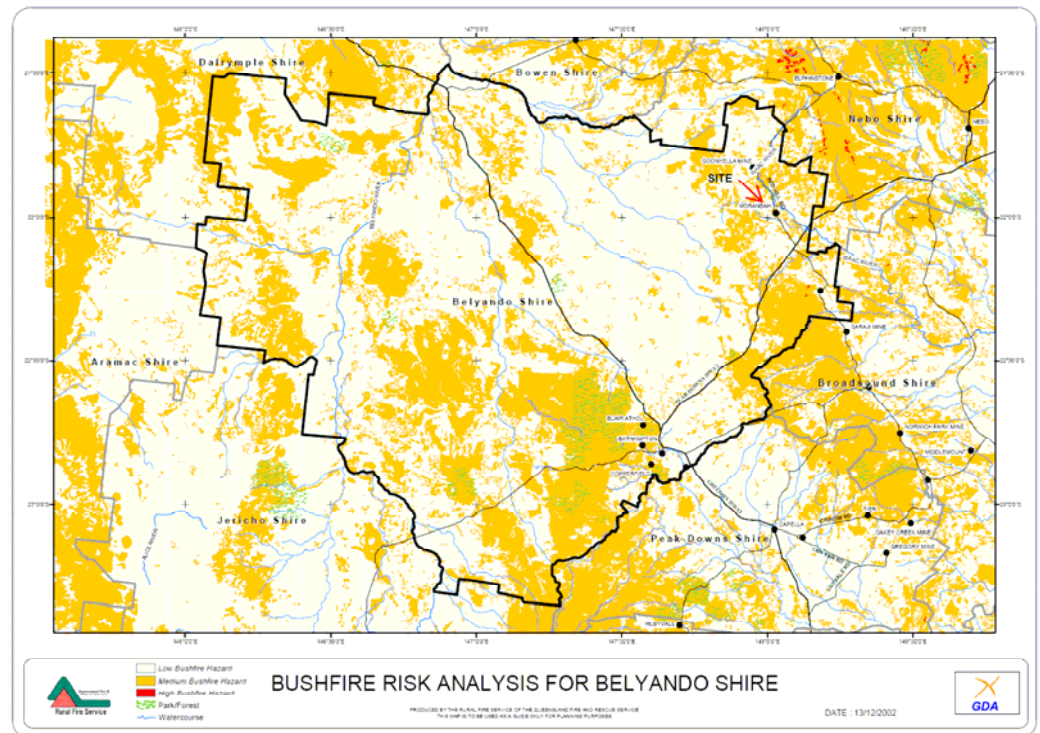
**Figure 9 Earthquake Map for the Mackay Area in Queensland**



#### 4.2.3 Bush Fires

As shown in Figure 10, there is a low to medium risk of a bush fire near Moranbah. The bush will be cleared to a specified distance (say 200 m) from the area of the main plant and evaporation lagoons but most would remain on the plot. Therefore, a bush fire causing impact onsite is not a credible scenario for this location.

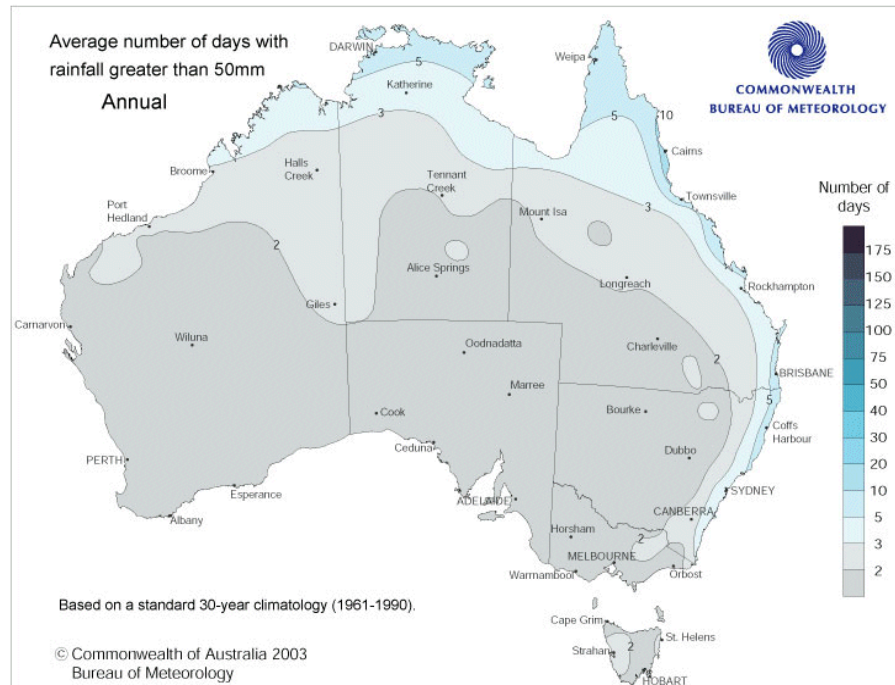
**Figure 10 Bushfire Risk Analysis for Belyando Shire**



#### 4.2.4 Flooding

As indicated by Figure 11, Moranbah experiences only 3 days per year when the rainfall total is above 50mm. The risk of a flood in the area is insignificant. It should also be noted that the plant lies on high ground (see Section 5.3) and would therefore not be susceptible to flooding.

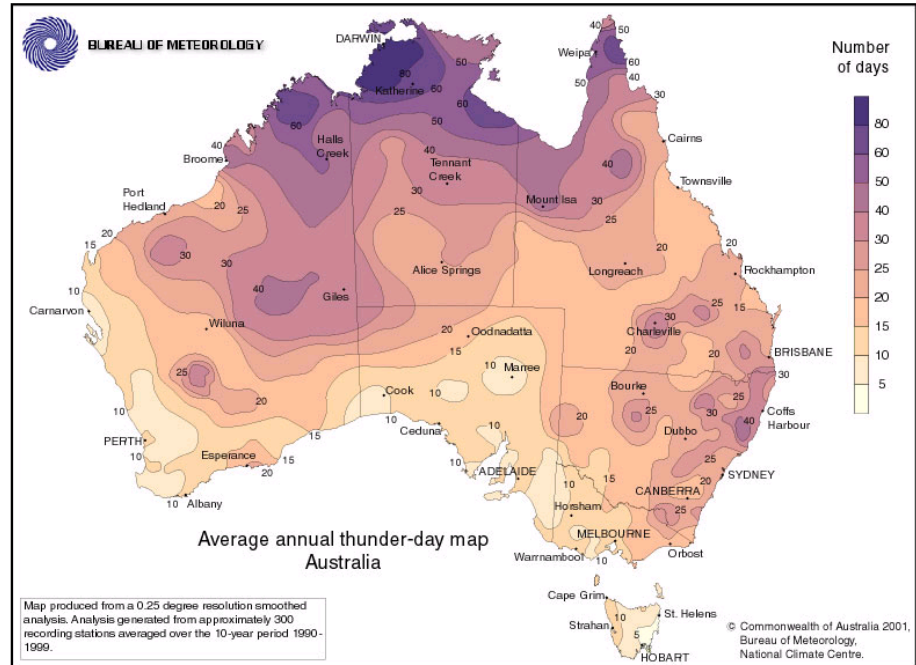
**Figure 11 Average Number of Days with Rain Greater Than 50mm**



#### 4.2.5 Lightning

The area surrounding Moranbah experiences 10-15 days of thunder per year, as shown in Figure 12. Though thunder and lightning are not mutually exclusive, the map does give an indication of the target areas for lightning. As long as all equipment is earthed and design to comply with AS 1768 (Lightning Protection), lightning should not be an issue onsite.

**Figure 12 Average Annual Day Map**



## 5. Consequence Analysis

### 5.1 Toxic Releases

Consequence modeling for the toxic release scenarios was conducted using PHAST (Process Hazard Analysis Software Tool). PHAST models the dispersion of vapour clouds to concentrations of interest and determines the toxic dose / loading over those areas. PHAST calculates the lethality of toxic doses using probit equations for Ammonia and Nitrogen Dioxide (refer to Table 41). Table 27 reports the distances to fatality rates. The distances quoted for the NO<sub>x</sub> Burner release cases relate to the nitrogen dioxide component of the gas.

**Table 27 Toxic Release Consequence and Likelihood**

Plant	Plant Iso-section <sup>13</sup>	Event Description	Material	Press. (bar <sub>g</sub> )*	Temp. (°C)	Inventory (kg) <sup>14</sup>	Distance (m) to 10% Fatality Rate	Distance (m) to 1% Fatality Rate	Frequency (per year) <sup>16</sup>	% of total toxic events frequency	% Freq breakdown per Iso-section
Ammonia Plant	Converter Effluent Gas	25 mm liquid leak	Ammonia	2	-11	<30,000	238	271	8.6x10 <sup>-3</sup>	30%	36%
		100 mm liquid leak	Ammonia	2	-11	<30,000	660	804	1.7 x10 <sup>-3</sup>	6%	
	Liq Ammonia	25 mm liquid leak	Ammonia	1	-33	<25,000	532	947	1.9 x10 <sup>-3</sup>	7%	8%

<sup>13</sup> An iso-section is a section of the process, which can be isolated by an automated valve, and therefore the maximum inventory to be lost per section is the volume between the automated valves.

<sup>14</sup> Inventories are based on the Hazard Identification information used in Appendix A.



Plant	Plant Iso-section <sup>13</sup>	Event Description	Material	Press. (bar <sub>g</sub> )*	Temp. (°C)	Inventory (kg) <sup>14</sup>	Distance (m) to 10% Fatality Rate	Distance (m) to 1% Fatality Rate	Frequency (per year) <sup>16</sup>	% of total toxic events frequency	% Freq breakdown per Iso-section
Nitric Acid Plant	Product Accumulator	100 mm liquid leak	Ammonia	1	-33	<25,000	838	1400	2.8 x10 <sup>-4</sup>	1%	
	Ammonia Tank	300 mm liquid leak	Ammonia	1	-33	<5,000,000	911	1450	6.0 x10 <sup>-5</sup>	0%	0%
	Ammonia Evaporator.	25 mm liquid leak	Ammonia	13	-11	< 750	241	300	1.7x10 <sup>-3</sup>	6%	11%
		100 mm liquid leak	Ammonia	13	-11	< 750	259	343	5.2x10 <sup>-4</sup>	2%	
		75 mm gas leak	Ammonia	13	90	< 250	<10	<10	9.7x10 <sup>-4</sup>	3%	
		200 mm gas leak	Ammonia	13	90	< 250	<10	<10	1.5x10 <sup>-4</sup>	0%	
	Downstream of the Burner	25 mm gas leak	10% NO <sub>x</sub>	9	100	< 1500	344	417	1.4x10 <sup>-3</sup>	5%	6%
		75 mm gas leak	10% NO <sub>x</sub>	9	100	< 1500	516	737	2.3x10 <sup>-4</sup>	1%	
	Absorption Tower.	200 mm gas leak	10% NO <sub>x</sub>	11	50	< 4500	440	833	3.7x10 <sup>-6</sup>	0%	

Plant	Plant Iso-section <sup>13</sup>	Event Description	Material	Press. (bar <sub>g</sub> )*	Temp. (°C)	Inventory (kg) <sup>14</sup>	Distance (m) to 10% Fatality Rate	Distance (m) to 1% Fatality Rate	Frequency (per year) <sup>16</sup>	% of total toxic events frequency	% Freq breakdown per Iso-section
Ammonium Nitrate Plant	Ammonium Nitrate Solution Tank and connected Evaporator equipment.	25 mm liquid leak	Ammonia	5	10	< 3500	<10	37.5	6.8x10 <sup>-3</sup>	24%	36%
		100 mm liquid leak	Ammonia	5	10	< 3500	<10	38.4	1.4x10 <sup>-3</sup>	5%	
		75 mm gas leak	Ammonia	5	50	< 3500	<10	34.5	1.2x10 <sup>-3</sup>	4%	
		200 mm gas leak	Ammonia	5	50	< 3500	<10	33.5	9.4x10 <sup>-4</sup>	3%	
Total									2.9x10 <sup>-2</sup>	100%	



The ERPG values were recorded for those events, which experience releases of ERPG 2 and 3 for a period greater than one hour. These distances represent social injury criteria as per HIPAP [Ref 8].

**Table 28 – Toxic Release Injury Consequences**

Plant	Plant Iso-section <sup>17</sup>	Event Description	Distance to ERPG-3 (m) in F-1m/s <sup>18</sup>	Distance to ERPG-2 (m) in F-1m/s <sup>19</sup>
Ammonia Plant	Converter Effluent Gas	100 mm liquid leak	1260	2800
	Liq Ammonia Product Accumulator	100 mm liquid leak	2680	6425
	Ammonia Tank	300 mm liquid leak	2500	5500
		Rupture	6500	13000

<sup>17</sup> An iso-section is a section of the process, which can be isolated by an automated valve, and therefore the maximum inventory to be lost per section is the volume between the automated valves.

<sup>18</sup> The ERPG-3 Ammonia concentration of 750ppm, is the maximum airbourne concentrate for which nearly all individuals can be exposed for up to 1 hr without experiencing or developing life threatening health effects.

<sup>19</sup> The ERPG-2 Ammonia concentration of 150ppm, is maximum airborne concentration below which, it is believed, nearly all individuals can be exposed for up to 1 hour without experiencing or developing irreversible adverse health effects or symptoms, which could impair an individual's ability to take protective action.

The inventory with the most significant consequence is the Ammonia Tank Storage. The tank is intended to be double walled, in order to provide secondary containment in the event of a crack or leak in the inner tank shell. One of the key issues with refrigerated storage tanks is the filling points. By installing an outlet pipe with pump to the base of the tank, the tank integrity is compromised as this places a piece of equipment more susceptible to leaks and failure at the base of the tank. Shutdown valves are located at the tank outlet to prevent loss of containment of the tank inventory.

A 150mm release from the tank would be due to an outlet pipework leak or connection flange leak. The line is able to be isolated in 30mins.

A rupture consists of a breakdown in the structural integrity of the tank and the tank liquid is retained by the bund; there is no containment of vapour.

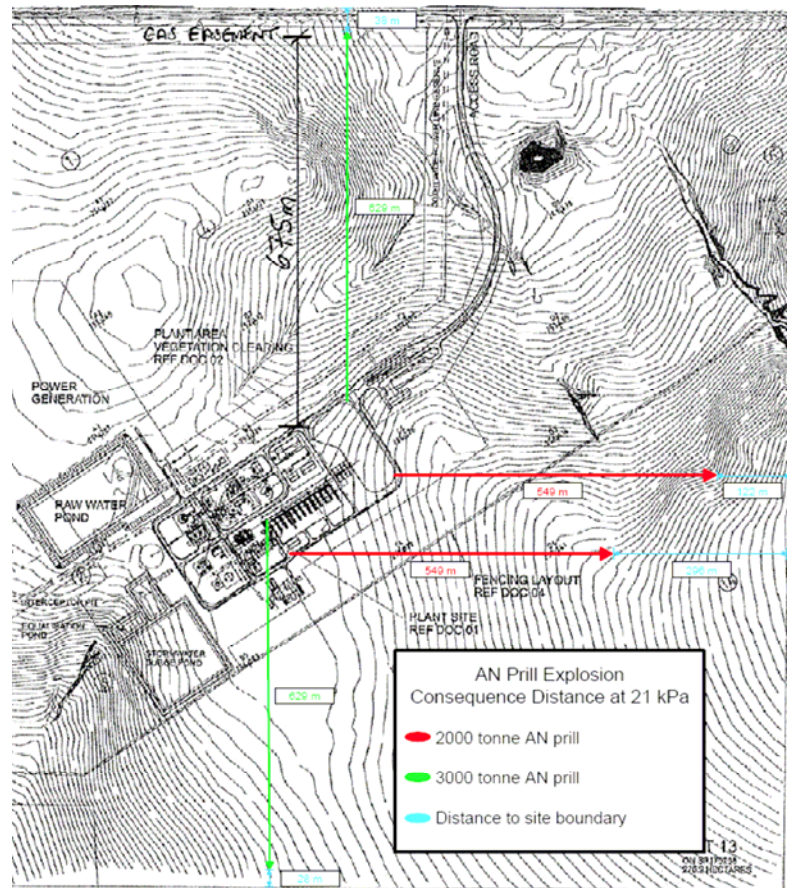
## **5.2 Explosion Events**

The quantity of AN involved in an explosion was determined through consideration of historical incidents. Essentially the Toulouse explosion [Ref 9] involved some 400 tonnes of off-spec / contaminated material giving an overall TNT equivalence of between 20 to 40 tonnes. The scenarios investigated in this study involve between 2000 to 6000 tonnes of uncontaminated material involving a limited / contaminated fraction (10% based upon the findings of the Toulouse study) with overall TNT equivalencies ranging between 70 to 330 tonnes of TNT.

It is acknowledged that the UK HSE specifies more severe ratios for the determination of an overall TNT equivalence however these are primarily based for the purposes of small scale stockpiling facilities with potentially less robust quality control mechanisms. Queensland Guidance Note 4 (which references the COAG Guidelines), specifies an overall NEQ of 32% to be used for AN Prill. This conservative number will be used as the “base case”.

The effect distances of Ammonium Nitrate explosions were calculated using the US Military TNT overpressure equation as detailed in Appendix C. The equation is based upon a robust empirical relationship and is appropriately conservative for the level of detail required in this H&RA.

**Figure 13 Distance of AN Prill Explosions to Site Boundary**



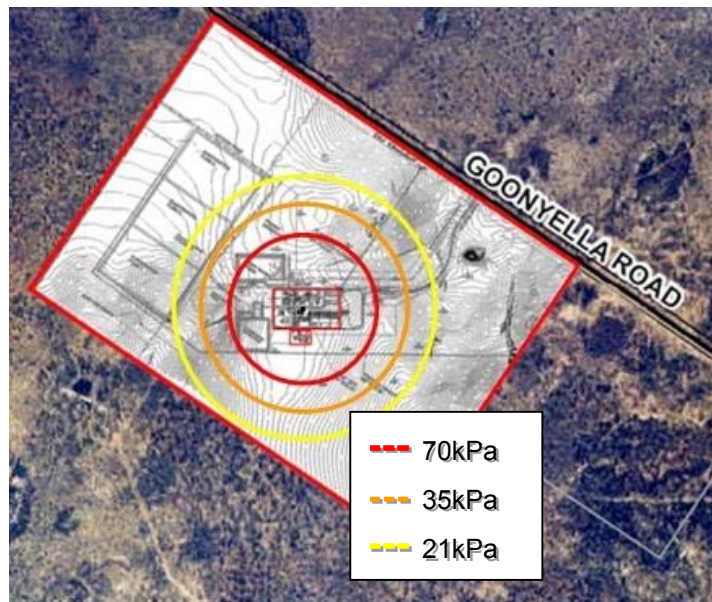
AN solution, AN Prill and emulsion explosions were screened from the offsite risk analysis during the preliminary consequence modelling stages of the study as mentioned in Appendix A and supported by the figures below. Nevertheless the implications of knock-on events between AN solution, AN Prill and emulsion explosions to the ammonia storage tank, resulting in toxic releases were considered in the consequence and offsite risk assessment. This was addressed by considering the explosion overpressure levels required to cause integrity failure of process equipment. An assessment of the AN prill and AN emulsion explosion overpressure distances at 21 kPa was made to estimate the extent of damage on the Ammonia storage tank. By factoring the initial AN explosion failure frequency into the toxic event failure frequency the risk of this potential escalation mechanism was considered within the total offsite risk profile.

The analysis did not look at sympathetic explosions between the AN storage container areas, or between the solution processing equipment as research by TNO [Ref 11] indicates that this event is not credible in the instance of separated unsensitised AN. Dyno Nobel Asia Pacific Limited will store the AN Prill in four allocated storage location, contained within shipping containers (in accordance with AS 4326) with adequate separation (as per discussions with DME) to prevent communication of the explosion from one storage location to the next.

Overpressure / impulse levels resulting in window / glass breakage and non-reinforced building collapse were not considered further as no continuously occupied or residential properties are located nearby. Additionally, the key assumption of calculating Location Specific Individual Risk revolves around the continuously present and vulnerable individual not being afforded any protection.

The detonation of an entire 3,000 tonne storage area of contaminated AN (worst case scenario on the site) was conservatively calculated to give overpressure levels sufficient to cause the death of 10% of outdoor human personnel and damage reinforced steel structures (21 kPa) at distances of up to 630 metres for the 3,000 tonnes AN Prill case, as shown in Figure 15.

**Figure 14 AN Prill (3,000 tonnes) Explosion Overpressures**



Two sensitivities were run using different efficiencies of AN (25%), in order to demonstrate the relationship between the efficiency of the explosion and the distance of impact. These sensitivities are shown in Table 29. The largest potential emulsion explosion would propagate 300m to the 21kPa overpressure mark, and the consequences are within the site boundary, as referenced in Figure 16.

**Figure 15 AN Emulsion (140 tonnes) Explosion Overpressures**





**Table 29 Explosion Consequence and Likelihood**

Plant	Area	Description	Mass of AN (te)	Efficiency (mass AN involved)	Equivalence (mass AN to Mass TNT)	Distance to overpressure envelope (m)				
						70 kPa	35 kPa	21 kPa	14 kPa	7 kPa
Ammonium Nitrate Bulk Storage Area	Modelled: Bulk storage pile	AN prill (3,000 tonnes)	3000	100%	32%	330	465	625	840	1525
		AN prill (1/4 full – 750 tonnes)	750	100%	32%	205	290	395	530	960
		AN Trucks (65 tonnes)	65	100%	32%	90	130	175	235	425
Sensitivity 1 (UK HSE)		AN prill (3,000 tonnes)	3000	25%	55%	250	350	475	635	1150
Sensitivity 2 (UK HSE)		AN prill (1/4 full – 750 tonnes)	750	25%	55%	155	220	300	400	725
AN Emulsion Storage	Storage Tanks	AN Emulsions (140 tonnes)	140	100%	70%	155	215	295	390	710
		AN Emulsions (1/4 full –35 tonnes)	35	100%	70%	95	135	185	245	450
		Emulsions Trucks (50 tonnes)	50	100%	70%	110	155	210	280	505

The sensitivities above show that the use of UK HSE 25% efficiency decreases the overpressure distance by 100-200m (depending on the overpressure level). None of the resulting overpressures of interest (including the sensitivity studies) reach outside of the site boundary with the exception of the 21kPa AN Prill explosion contour, which is an extremely conservative value, which allows for 100% mass of stockpile to explode and states that the stockpile is at 100% capacity.

In accordance with the AEMSC Code of Good Practice [Ref 13], the following distances are required from each storage area:

**Table 31 Required Distance to Vulnerable and Protected Works (Class A & B)**

<b>Material Stored</b>	<b>Net Explosive Quantity (NEQ)<sup>20</sup>, kg</b>	<b>Distance to Vulnerable Facilities<sup>21</sup></b>	<b>Distance to Protected Works (Class A)<sup>22</sup></b>	<b>Distance to Protected Works (Class B)<sup>23</sup></b>
Ammonia Nitrate Storage  (max of 3,000 tonnes, 32% Equivalence)	960,000	4380m	1460m	2190m
AN Emulsion Storage  (140 tonnes per tank, 70% Equivalence)	98,000	2050m	680m	1025m

In the area, there are only two sensitive land uses:

1. The residential areas of town (Protected Works – Class B); and
2. The Railway (Protected Works – Class A).

The nearest residential dwelling is 4.3km away from the site and the railway is 2.6km away from the site, therefore they are both compliant with the AEMSC Code of Good Practice.

<sup>20</sup> The total mass of an explosive unless it has been determined that the effective quantity is significantly different from the actual quantity (based on TNT).

<sup>21</sup> Vulnerable Facilities include: multistorey buildings, e.g. above 4 storeys; large glass fronted buildings of high population; large hospitals or schools; public buildings or structures of major historical value; major traffic terminals, e.g. railway stations, airports; major public utilities, e.g. gas, water, electricity works.

<sup>22</sup> Protected works – Class A: Public street, road or thoroughfare, railway, navigable waterways, dock, wharf, pier or jetty, market place, public recreation and sports ground or other open place where there public are accustomed to assemble, open place of work in another occupancy, river-wall, seawall, reservoir, above ground water main, radio or television transmitter or main electrical substation, a private road which is a principal means of access to a church, chapel, college, school, hospital or factory.

<sup>23</sup> Protected Works Class B: A dwelling house, public building church, chapel, college, school, hospital, theatre, cinema or other building or structure where the public are accustomed to assemble; a shop, factory, warehouse, store or building in which any person is employed in any trade or business; a depot for keeping of flammable or dangerous goods; major dam.

### 5.3 Missile Generation and Strike

As detailed in the Hazard Identification stage of the project, the potential for missile impact upon the Ammonia Storage tank was analysed. Details of assumptions made in conducting the missile impact analysis are presented in Appendix I.

The analysis considered the potential for missile impact upon the Ammonia Storage Tank, as an investigation into the Toulouse accident [Ref 9] identified five-metre sections of metal I-beam located up to 280 metres from the AZF site. Given the overall increase in power of a 3000 tonne prill explosion, projectiles were conservatively assumed to have the potential to impact up to 600 metres from the explosion epicentre. The Ammonia Tank is situated approximately 120m from the AN Prill Storage and has a diameter of approximately 20m. The probability of a 5-metre section of I-beam steel impact following an explosion is therefore calculated to be in the order of less than 3%, based on the maximum estimated exposed surface area vulnerable to missile impact.

It was conservatively assumed that three missiles of significant mass would be generated with the potential to impact the tank therefore giving an overall frequency of impact of less than a quarter-in-a-million per annum ( $4.6 \times 10^{-6}$  pa).

The frequency of missile strike upon individuals was not factored into the LSIR calculations as the area occupied by an individual is considered to be less than 5 metres in diameter and therefore presents a negligible increase in risk levels on a frequency basis alone.

### 5.4 Ground Shocks

Ground shock or vibration is generated when the ground surrounding an explosion is affected by the shock wave and overpressure and thus explosion energy is transferred into the ground and travels through the earth in wave form (amplitude). Generally the ground vibration impact is far less than the potential impact created from the blast overpressure and projectiles. Lees [Ref 3] states that “for an explosion at or near the surface damage by blast will extend to a much greater distance than damage by ground shock”. The effected area is therefore prescribed by the overpressure contours.

For the purpose of identifying the peak particle velocities at the nearby exposed facilities (Anglo Mine and Enertrade Natural Gas Pipeline), the following calculations were performed.

An analytical model [Ref 26] was used to predict the enhancement of ground shock waves produced by an AN Prill detonation, due to reflections from lower soil layer interfaces. Since it is possible to correlate the imposed deformation of structures directly to the ground particle velocity, a prediction model of these quantities can be used to establish the distances of separation required from an explosion to structures, by combining it with proposed ground motion failure criteria. Such criteria are the surface motion failure criterion of 50mm/s for above ground structures (Esparza, 1986) and the failure criterion of 127mm/s for steel pipelines (Siskind and Stagg, 1994, Siskind et al, 1994)

The peak particle velocity was calculated using the following formula:

$$ppv = \alpha f (R / W^{1/3})^{-n}$$

Where:

ppv = peak particle velocity (m/s)

$\alpha$  = variable coefficient,  $48.8 \times 0.252^{-n}$

W = TNT equivalent of explosive charge, 960 tonnes

n = attenuation coefficient of the soil type, 2.5 (Bulson, 1997) for “dense sand with high relative density” or “wet sandy clay with air voids” similar to the Moranbah location

f = ground shock coupling factor, 0.44 (Bulson, 1997)

R = distance to area of concern, 675m for pipeline, 1230m for mine site boundary.

The results were as follows:

	<b>Criterion for Surface Motion Failure (mm/s)</b>	<b>Calculated Peak Particle Velocity (mm/s)</b>
<b>Enertrade NG Pipeline</b>	127	17
<b>Anglo Mine Site</b>	50	4

Therefore the base case / worst-case scenario explosion onsite does not have any structure impacts the Enertrade natural gas pipeline or nearby Anglo mine.

## 6. Frequency Analysis

Frequency estimates for events modeled in the H&RA were determined using classical frequency assessment techniques however incorporated an additional measure of conservatism by accounting for the likelihood security related events in addition to historical events. The review of this frequency arises from the increased interest and knowledge among the public at large about the use of Ammonium Nitrate as an explosives precursor.

It is understood that the Ammonium Nitrate facilities will be built to accommodate production levels 185% greater than those of the jointly owned Moura plant in Queensland. As such, equipment and pipework data taken from design drawings sizes were scaled proportionally.

The increase in capacity is expected to decrease the frequency of equipment failures (as heavier large diameter pipes are more robust than thinner ones), however increase the consequences of failure (as large vessels hold a greater inventory). The difference in risk was not determined, as this would require the entire revision of the model, which was considered outside of the project scope. However, it is estimated using historical data that process equipment failures for the larger vessels may be up to ten percent less than those of a smaller capacity plant. Modern design techniques additionally limit the use of small-bore fittings, which aids in the management of plant integrity.

### 6.1 Toxic Release Events

The frequency analysis for the process release scenarios was completed by estimating the quantity of plant equipment containing hazardous material and comparing this against historical data for similar plant. The frequency data used in this study was obtained from the UK HSE and covers more than ten years of operating experience across the north-sea offshore industry. This data set is the most comprehensive data set currently available and is applicable for generating conservative estimates in that the operating conditions from which the data set was obtained are patently more severe. The data set details the number of leaks and their equivalent hole sizes and the quantity of equipment surveyed and operating life. Full details of the frequency analysis are provided in Appendix D. The frequency analysis conservatively concludes that the plant is expected to have an event with an acute toxic offsite impact approximately once every thirty-five years ( $2.9 \times 10^{-2}$  pa).

### 6.2 Ammonium Nitrate Explosion Events

Due to the fact that the consequence impacts do not reach the site boundary, the explosion events were screened from the risk analysis and therefore, no frequencies are required.

## 6.3 Security Vulnerability Impact on Frequencies

### 6.3.1 Terror Threat Groups

Threat groups and their capabilities were identified using a threat group assessment register during a Centre for Chemical Process Safety (CCPS), Security Vulnerability Analysis (SVA) and information made available by on the website of the Australian National Security Agency. Threat groups include the following:

- Activists (political, environmental, human rights),
- Terrorists (insurgents, international groups, proximity to other terrorist targets)
- Governments (coups, election violence, foreign intelligence/governments, war, corruption).
- Other threat groups (organised crime/mafia, local gangs, militia, deranged individuals).

Threats made by threat groups include the following:

- Threats against facility (toxic release, theft of materials, bombings, arson, sabotage, car/truck jacking).
- Against personnel (Kidnappings, extortion, assault)
- Information threats (hard copied information, electronic eavesdropping, information brokering, falsification of lab results).

The assessment characterises the threat groups using the following characteristics:

- Nature of assailants
- Motivations (damage, terror)
- Capability of assailants (physical/technical, determination, deception, infiltration)
- Nature of threats
- History of threats

### 6.3.2 Security Vulnerability

Accounting for the risks associated with security vulnerability will result in changes in event frequencies previously calculated. As a breach of security is considered credible, their impact will be considered in this assessment.

The probability of an employee intending to instigate an incident was determined using historical data. The instances of this nature occurring in the known 400 facilities over 40 years are given to be 0.7 events. Therefore, the likelihood is found to be once in 25, 000 years ( $4.1 \times 10^{-5}$  pa).

The frequency of a successful security related incidents also acknowledge individual ability to perform sabotage. Assuming individual access to restricted areas (50%), knowledge on how to exercise the activity (90%), and the ability to exercise the

initiating steps to propel the incident, such as manipulating equipment (50%), an overall estimate of once in 110, 000 years ( $9.2 \times 10^{-6}$  pa) was deducted.

The frequencies of toxic release and ammonium nitrate explosion events currently do not consider intentional damage, and will increase as a result of security vulnerability. The probability of security vulnerability is allocated to toxic release and ammonium nitrate explosion events as 5% and 95% respectively. The results of integrating security vulnerability is as follows:

- The event frequency of a toxic release resulting in an acute toxic offsite impact is currently once every thirty-five years ( $2.9 \times 10^{-2}$  pa). The security risk increases this amount by a negligible amount ( $4.61 \times 10^{-7}$  pa), remaining once in 35 years.
- Ammonium nitrate explosions were identified as occurring approximately once every seventeen thousand years ( $6.0 \times 10^{-5}$  pa). The security risk increases this amount by 14.6% to once in 15000 years ( $6.88 \times 10^{-5}$  pa).

## 7. Risk Analysis

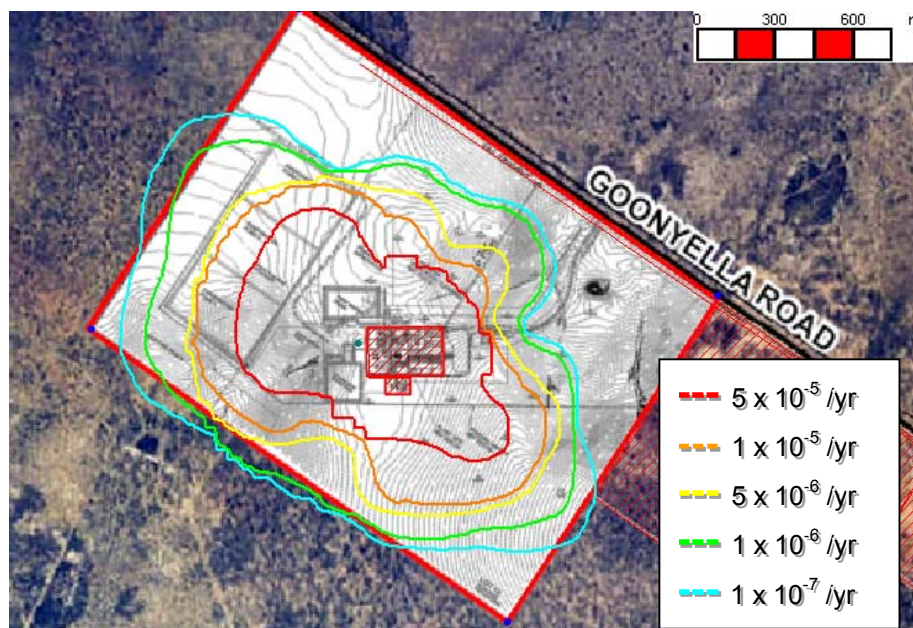
The scope of this H&RA is the assessment of offsite fatality risk in response to Land-Use Safety Planning (LUSP) requirements. The following sections present the risk analysis results against Individual Risk Criteria, and Societal Risk Criteria.

### 7.1 Offsite Location Specific Individual Risk

Figure 16 presents the offsite Location Specific Individual fatality Risk (LSIR) contours generated for the proposed Ammonia, nitric acid, Ammonium Nitrate plant, prill storage and emulsion plant. The LSIR contours shown in Figure 16.

indicates that the plants comply with all HIPAP offsite safety risk criteria. The contours show a prevailing wind in the North-West direction (from south-easterly winds), which accounts for the contour stretching a greater distance in this direction.

**Figure 16 Dyno Nobel Proposed Ammonium Nitrate Plant Individual Risk Profile**



An analysis of the risk drivers at the site boundaries is conducted in the following section. Toxic releases drive the risk profile, the major contributor being the release from the ammonia tank. The tank inventory (5,000 tonnes) means that the risk profile will always remain high. The ammonia tank leak frequencies used for this analysis were based on research into historical release frequencies for refrigerated storage tanks. The other significant contributor was releases from the Liquid Ammonia product accumulator iso-section.



## 7.2 Societal Risk Results

Since there is no societal risk criteria used to determine the acceptable level of societal risk in Queensland, the Potential Loss of Life (PLL) values were calculated at specific locations.

**Table 33 Potential Loss of Life Values**

Population of Interest	PLL (per year)
Grosvenor Creek (estimated picnic of 4 persons)	Not recordable <sup>21</sup>
Moranbah Township (closest point)	Not recordable <sup>24</sup>
Enertrade Proposed Facility	$2.50 \times 10^{-12}$
Transfield Proposed Power Station	$2.2 \times 10^{-9}$
Ergon Power Station	Not recordable <sup>21</sup>

<sup>24</sup> Value of Individual Risk Per Annum was less than  $10^{-12}$  and therefore did not produce a value in the SAFETI model.

## 8. Discussion

### 8.1 Toxic Release Scenarios

Ammonia is a toxic gas, which while also flammable, it is acknowledged to be extremely difficult to ignite. The ignition energy required to ignite Ammonia-air mixtures is up to 1000-times greater than that for typical hydrocarbon mixes. Considering this (and the fact that toxic Ammonia events will have greater effect distances than flammable events), the flammable effects of Ammonia were screened from the study with its toxicity being the principal issue considered in this assessment.

This is consistent with the findings of a study conducted by the UK HSE, in which of a total of 139 Ammonia-related incidents were assessed [Ref 10]. The study found that while all involved toxic exposure, none involved flammable effects. With respect to the assessment of offsite risk levels, the toxic effects of Ammonia have greater distances than thermal impacts and therefore the focus on toxic analysis is considered to give more conservative results (as ignited releases will not impact as far offsite).

Consequence modelling for the project indicates that large releases of liquefied Ammonia under typical wind / atmospheric conditions may result in the evacuation of personnel up to 6500 metres from the site, although this is considered unlikely. Ammonia upon release from a pressurised source will expand and chill to a temperature much cooler than air and as such is considered to show ground-hugging (slumping) behaviour, which may be subject to topographical guidance (whether ambient winds are also channelled by these features is also questioned). The same risk is also imposed by the refrigerated Ammonia, which makes up over 99% of the Ammonia produced on the site. Cold Ammonia clouds are also considered to react with ambient water vapour and form toxic fogs that are denser than the clouds modelled in this study. Ammonia reacts with water vapour and is essentially dissolved thus the Ammonia consequence distances indicated in this report are conservative.

Gas process inventories were determined from vessel volume calculations combined with normal operating flowrates until trip/shutdown activation. Trip/shutdown times were considered to be 15 minutes for small leaks due to the time required for operator investigation of alarms and manual shutdown, and 3 minutes for larger leaks from which process control/safety equipment is assumed to intervene. Toxic releases were modelled in the horizontal direction at initial release rates, which again demonstrates a conservative risk assessment approach.

## 9. Conclusions

The H&RA study update concludes that the project remains in compliance with the relevant Queensland HIPAP Land-Use Safety Planning (LUSP) criteria for offsite individual risk. The area is currently zoned as rural. The 5 x 10<sup>-7</sup>/yr sensitive land use, 1 x 10<sup>-6</sup>/yr residential, and 1 x 10<sup>-5</sup>/yr public risk contours are not in the vicinity of any of the specific land uses and therefore present minimal risk to the Moranbah community. At present there are no commercial facilities within kilometres of the site, therefore the 5 x 10<sup>-6</sup>/yr risk contour does not impact the population. As such, issues with offsite safety risk should not prevent further development of the project.

The major risk driver for the offsite impact from the project is a release from the Ammonia Storage Tank and from the Ammonia Plant iso-sections. The integrity of the tank is the key issue on the site and in order to ensure the tank does not leak or rupture, the following must be adhered to:

- ▶ An extensive review of the industry best practice with respect to the design and material selection for Ammonia Tank Storage
- ▶ A rigorous inspection and maintenance regime for the tank, including Non-destructive testing (NDT) using best practice; and
- ▶ A HAZOP study should be undertaken to identify the key issues associated with the whole site, including the Ammonia Storage tank at an appropriate state in the project. The study should look at the proposed Control Procedures with respect to critical systems including the Ammonia Storage tank, together with follow up to ensure that operating procedures are adhered to.

The frequency for a rupture of the Ammonia tank is estimated to be approximately once-in-seventeen thousand years. The frequency of a leak in the Ammonia iso-sections is a lot higher (approx once-in-ninety two years) and all means to reduce the potential for a leak from the Ammonia containing components will be undertaken.

The study methodology has taken a high-level and conservative approach to identifying accidents relevant to offsite safety and characterising their consequences and likelihood.

Compliance with the risk criteria is achieved by maintaining a separating distance to the site boundaries, the quick detection and isolation of process releases, quality control during the production and storage operations of Ammonium Nitrate prill, and best-practice security management to control asset threat issues.

## 10. Recommendations

Overall the conservative methodology taken in performing this H&RA identified that further risk reduction may be achieved for both the proposed facilities and surrounding neighbourhood. DN has advised they will consider the following GHD recommendations for incorporation into the design:

1. Dyno Nobel Asia Pacific Limited to introduce a minimisation program to reduce, where possible, (by engineering design) the number of small-bore fittings, valves, and flanged joints on equipment operating with toxic chemicals. These equipment items were assessed to constitute the greatest proportion of leaks affecting offsite areas. This reduces the volume stored and potential leaks. This matter should also be addressed in the development of the piping material specification. Screwed joints should not be used.
2. Update the Quantitative Risk Analysis once the facility design is finalised and modify the Safety Management System (SMS) via the Major Hazard Facility Safety Case. The update will incorporate onsite risks and any potential changes to the population in the area since the H&RA was completed.
3. An integrated communication system encompassing mines/council (emergency services).

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## Appendix A

# Hazard Register

## Detailed Hazard Register for the Plants

The following table presents the results of the hazard identification process and identifies the scenarios advanced to consequence analysis. Consequence assessment for the identified scenarios was conducted using the consequence tool PHAST and the US Military equation for the calculation of TNT explosion impacts as detailed in Section 8.2.

**Table 35 Hazardous Scenario Identification for Ammonium Nitrate Plant.**

Plant Area	Description	Comments	Scenario
Ammonia Plant	Seam Gas Inlet Pipeline leak or rupture	A 150mm (OD) seam gas pipeline provides input to the Ammonia plant.	A rupture of this natural gas pipeline could produce a flash fire with a 3.8m radius at the Lower Flammability Limit (LFL). <i>All credible release sizes were screened out, as the 1% fatality envelope did not reach beyond the site boundary.</i>
	Natural gas Drum and line to compressor leak or rupture	Natural gas from the pipeline is retained in the natural gas feed drum prior to entering the feed compressor. Inventory was calculated to be 6kg of gas at 30 °C and 1900 kPa. Feed drum volume is 1.5 m <sup>3</sup> . Pipe size DN150. Also DN 200 spillback pipe cooler. Allow a total of 2 m <sup>3</sup> . Density of gas is 14 kg/m <sup>3</sup> . Weight of gas prior to compressor is mainly in feed drum and is about 30 kg. The FCV statement should be moved to after the compressor.	25mm, 100mm and ruptures releases were modelled. A rupture of this iso-section would produce a flash fire with a 6.4m radius at the Lower Flammability Limit (LFL). <i>All credible release sizes were screened out, as the 1% fatality envelope did not reach beyond the site boundary.</i>



Plant Area	Description	Comments	Scenario
	Natural Gas mixture through separators and reformers leak or rupture	<p>After the compressor, the seam gas is passed through a purifier, saturator and mixed with steam to form the synthesis gas, with a temperature and pressure of about 250 °C and 4200 kPa. A flow valve is installed after the compressor outlet.</p> <p>The steam/ gas mixture is preheated to 650 °C and passed to the gas heated reformer, secondary reformer with multiple recycle lines, where it is converted to a mixture of H<sub>2</sub> and CO.</p> <p>The gas is then cooled to about 350 °C and passes to the shift reactor where it is converted to a mixture of H<sub>2</sub> and CO<sub>2</sub> and then cooled to 250 °C The pressure gradually reduces to 3500 kPa in this section. The equipment volume is about 270 m<sup>3</sup> or 350 m<sup>3</sup> including pipes and gas weight is about 3,500 kg.</p>	<i>All credible release sizes were screened out, as the 1% fatality envelope did not reach beyond the site boundary.</i>
	H <sub>2</sub> and CO <sub>2</sub> mixture through PSA Unit and Methanator and driers Gas and liquid leaks or ruptures	The mixture of H <sub>2</sub> and CO <sub>2</sub> is purified to H <sub>2</sub> by passing through the PSA Unit, PSA Product Gas Drum, PSA Purge Gas Drum, Methanator and the make-up gas chiller separator and driers.	<i>All credible release sizes were screened out, as the 1% fatality envelope did not reach beyond the site boundary.</i>

Plant Area	Description	Comments	Scenario
		<p>The inventory of this iso-section is calculated to be approximately 5352kg of liquid (water) and 6280kg of gas, with an average temperature of 41 °C and pressure of 3172kPa. It is to note that the liquid in the system is not flammable (water) and is circulated to cool the gas. The last water is removed in the chiller separator and discharged to sewer. The equipment volume is about 175 m<sup>3</sup> or 250 m<sup>3</sup> including pipes and gas weight is about 2,500 kg.</p> <p>The low pressure (50 kPa) purge gas volume is about 400 m3 or 450 m3 including pipes and gas weight is about 75 kg. Manual valves are located at the inlet to the make-up gas driers, which would be used to isolate this section of inventory.</p>	
	Ammonia Compressor and Converter Vapour leaks or ruptures	<p>The Ammonia mixture passes through the Ammonia converter at a temperature of 238 °C and a pressure of 8600kPa. The approximate inventory is 3900kg. Volume of converter and intercoolers is 145 m<sup>3</sup>. Allow for piping with total of 200 m<sup>3</sup> and a weight of 6,000 kg. There is no liquid in this section except for water from the loop boiler.</p>	<p>Rupture of vessel give 1% lethality distances were limited to less than 75 m. It is to note that ruptures will release Syngas or a mixture of gaseous Ammonia, nitrogen and hydrogen.</p> <p><i>All credible release sizes were screened out, as the 1% fatality envelope did not reach beyond the site boundary.</i></p>

Plant Area	Description	Comments	Scenario
	Ammonia converter effluent gas to flash vessels Vapour or liquid leaks or ruptures, Ammonia recycle chiller, and sub-cooler Liquid leaks or ruptures	<p>The Ammonia passes through the low-pressure flash vessel, intermediate pressure flash vessel, Ammonia let-down vessel and the Ammonia catchpot in this iso-section. The liquid inventory is approximately 31212kg, with average temperatures of -8 °C and pressures around 1400 kPa. The intermediate pressure (500 kPa) flash area has a volume of 50 m<sup>3</sup> including up to 5 m<sup>3</sup> of liquid Ammonia, say 70 m<sup>3</sup> including piping. The low pressure (200 kPa) area has a volume of 50 m<sup>3</sup> including up to 7 m<sup>3</sup> of liquid Ammonia, say 50 m<sup>3</sup> including piping. Gas quantity is 350/ 100 kg low/ inter and about 7,500 kg liquid. The iso-section is isolated by several flow control valves.</p> <p>This iso-section consists of several heat exchangers and pipework, the inventory is estimated to be 492kg, at a temperature of -11 °C and a pressure of 207kPa.</p> <p>The iso-section is isolated by flow control valves.</p>	<p>25mm, 100mm and rupture releases were modelled.</p> <p>Most joints are vapour. Liquid joints are small and few. Maximum liquid pipe diameter DN 150 and maximum vapour pipe diameter DN 350.</p>
	Liquid Ammonia Product Accumulator Liquid leaks or ruptures	<p>The section includes the pumping of the liquid Ammonia from the product accumulator through to the Ammonia storage tank. The inventory is estimated to be 19308kg, at 4 °C and 793kPa. Vapour/ liquid vessel volumes estimated at 15/ 30 m<sup>3</sup> and 20/ 40 m<sup>3</sup> including pipework containing 100/ 25,000 kg, respectively. Most of liquid volume (20 m<sup>3</sup>) is contained in accumulator.</p>	<p>25mm, 100mm and rupture releases were modelled. It is to note that maximum liquid piping is DN 100.</p>

Plant Area	Description	Comments	Scenario
	Ammonia Tank Liquid leaks or ruptures	The tank will hold 2000 m <sup>3</sup> of liquid Ammonia. The liquid is contained in the bund.	A double walled tank is expected to be built onsite. Rupture of vessel gives 1% lethality distance limited to less than 3.5km. 300mm release was also modelled.
Nitric Acid Plant.	Liquid leak from the Ammonia Evaporator.	The Ammonia evaporator and superheater supply superheated Ammonia gas via the Ammonia gas filter to the nitric acid reactor. Emergency isolation of the evaporator from the Ammonia supply line is carried out with an emergency shut-down (ESD) valve (XV) at the evaporator inlet.  The liquid inventory contained in the evaporator and associated equipment and pipework was calculated to be less than 750 kg at 13 bar <sub>g</sub> and -11 °C with additional liquid supplied by the inlet line.	<i>All credible release sizes were screened out, as the 1% fatality envelope did not reach beyond the site boundary.</i>

Plant Area	Description	Comments	Scenario
Nitric Acid Plant (continued).	Gas leak from the Ammonia Evaporator.	The gas inventory contained in the equipment and associated pipework was calculated to be less than 10 kg at an average pressure 13 bar <sub>g</sub> and 90 °C however a significant fraction of the resident liquid inventory will flash. Volume of gas which would be flashed was calculated to be less than 250kg	<i>All credible release sizes were screened out, as the 1% fatality envelope did not reach beyond the site boundary.</i>
	Gas leak from the Ammonia/Air Mixer and Burner feed.	The Ammonia/air mixer blends the reactants before they are fed to the reactor. Ammonia fraction in mixture feed is 5% w/w at 1200 kPa <sub>g</sub> and 225 °C. An ESD valve will stop Ammonia feed to the mixer in an emergency and the air feed line is fitted with a non-return valve to prevent reverse flow through the air system.  The reactants are passed over the catalyst basket where they are reacted and converted to NO <sub>x</sub> gases <sup>25</sup> .	All credible release sizes were screened out, as the 1% fatality envelope did not reach beyond the site boundary.  NO <sub>x</sub> gas inventory in downstream sections of reactor calculated at less than 100 kg therefore screened from analysis as 1% fatality envelope did not reach beyond the site boundary.
	Gas leak from downstream of the Burner through to the Acid Absorption Tower.	The Ammonia burner produces NO <sub>x</sub> gas for the nitric acid absorption tower. NO <sub>x</sub> gas is cooled before entering the tower by a series of coolers, economisers, and condensers.  The total inventory of process gas in these equipment items was calculated to be less than 1.5 tonnes at approximately 9 barg between 50 and 200 °C. (90% inventory located in absorber). Tower volume is 505 m <sup>3</sup> and burner m <sup>3</sup> giving a total of 600 m <sup>3</sup> with pipework. Pressure about 11 bar and gas weight is 4.5 T. Estimate that liquid occupies between 5-10% of tower (500 m <sup>3</sup> ) at 5% acid or about 40 m <sup>3</sup> (50T).	A 200mm release from the vessel give 1% lethality distances were limited to less than 620m.

<sup>25</sup> This is a conservative assessment as NO<sub>x</sub> is more toxic than NH<sub>3</sub>

Plant Area	Description	Comments	Scenario
Ammonium Nitrate Plant.	Liquid leak from the connected Evaporator equipment to ammonia tank.	<p>External Ammonia is supplied as a liquid to the Ammonia tank and is converted to a gas in the Ammonia evaporator and water separators from the Ammonia tank. The gas is then heated in the superheated and supplied to the pipe reactor.</p> <p>There will be an ESD valve in the (external) liquid supply line to the Ammonia tank to isolate the liquid supply system and prevent local tank liquid leaks drawing from external volumes (normal flow is controlled on tank level).</p> <p>Most of the liquid is contained in the tank, the evaporator and the water separator is about 12 m<sup>3</sup> (2.6 m<sup>3</sup> tank, 1.5 m<sup>3</sup> separator, 5 m<sup>3</sup> evaporator, 2.1 m<sup>3</sup> pipework) was calculated to be less than 3.5 tonnes at approximately 5 bar<sub>g</sub> and 10 °C with an additional mass supplied by the supply line.</p>	100mm liquid release give 1% lethality distances were limited to less than 75 m.
	Gas leak from the Ammonia Tank and connected Evaporator/ Superheater equipment.	<p>Ammonia gas is supplied to the superheater and pipe-reactor by the gas generation processes conducted in the Ammonia tank, MP/water separator, evaporator, air-cooler separators, and separator, which are all interconnected and contain liquid Ammonia.</p> <p>Isolation of the gas containing items from the Ammonia supply line is possible through an isolation valve (XV) at the Ammonia tank feed.</p> <p>The gas inventory contained in the equipment and associated pipework was calculated to be less than 50 kg at an average pressure 5 bar<sub>g</sub> and 50 °C however a fraction of the resident liquid inventory will flash.</p>	<p>5 mm and 25 mm releases screened out, as the 1% fatality envelope did not reach beyond the site boundary.</p> <p>75 mm and 200 mm releases modelled. A 200mm release gives 1% lethality distances were limited to less than 50 m.</p>

Plant Area	Description	Comments	Scenario
	Explosion in the Ammonium Nitrate Reactor/ Separator.	Ammonium Nitrate (AN) is produced by the reaction between gaseous Ammonia and liquid nitric acid. The Ammonium Nitrate reactor/separator vessel contains approximately 12 tonnes of Ammonium Nitrate at a concentration of approximately 80% in 4 bar <sub>g</sub> and 180 °C conditions. The liquid volume in the QN1 pipe reactor separator is 7.2 m <sup>3</sup> and the liquid volume is likely to be about 1-2 m <sup>3</sup> .  An explosion efficiency of 10% was used based upon information given in Appendix C.	Event screened from offsite impact as explosion modelling calculates that the 21 kPa overpressure contour corresponding to the 10% fatality envelope does not extend beyond 60 m for a TNT NEQ of 32%.  Frequency of event considered in initiating event frequencies for all offsite impact scenarios.
Ammonium Nitrate Plant (continued).	Explosion in (steam) Flash Tank and Ammonium Nitrate Solution Pumps.	The Flash Tank separator steam from the Ammonium Nitrate solution before it is fed by the Solution Pumps to the Primary Evaporator.  The Flash Tank and Solution Pumps were calculated to have an inventory of less than 10 tonnes at a concentration of approximately 85% concentration. The Flash Tank operates at atmospheric pressure and 140 °C however the pump adds up to 4 barg head.  An explosion efficiency of 10% was used based upon information given in Appendix C. There is historical incidence of an Ammonium Nitrate explosion in a deadheading pump. Pipework has steam tracing. Volume of QN1 flash tank is 5.1 m <sup>3</sup> and liquid content of 3 m <sup>3</sup> likely.	Event screened from offsite impact as explosion modelling calculates that the 21 kPa overpressure contour corresponding to the 10% fatality envelope does not extend beyond 60 m for a TNT NEQ of 32%. This equivalency value represents the upper end of the equivalence values for AN prill based on estimated TNT equivalence calculations (refer to Table 23, Appendix C).  Frequency of event considered in initiating event frequencies for all offsite impact scenarios.
	Ammonium Nitrate Storage located near main plant	The Ammonium Nitrate required for feed to the emulsion plant is stored in 1000 m <sup>3</sup> tank as an 84% solution and pumped into the ANSOL tank located in the emulsion plant described below. The tank is steam traced to maintain temperature at about 140 °C.	<i>All credible release sizes were screened out, as the 1% fatality envelope did not reach beyond the site boundary.</i>

Plant Area	Description	Comments	Scenario
	Explosion in the Primary Evaporator.	<p>The Primary Evaporator and Separator dry the Ammonium Nitrate solution from 85% to 95%. Lines from evaporator are steam jacketed to prevent solidification of the solution.</p> <p>The Evaporator and Separator were calculated to have an inventory of less than 20 tonnes at a concentration of approximately 95% concentration. The equipment operates under vacuum at 130 °C. An explosion efficiency of 10% was used based upon information given in Appendix C.</p>	<p>Event screened from offsite impact as explosion modelling calculates that the 21 kPa overpressure contour corresponding to the 10% fatality envelope does not extend beyond 75 m for a TNT NEQ of 32%.</p> <p>Frequency of event considered in initiating event frequencies for all offsite impact scenarios.</p>
	Explosion in the Remelt Tank and Remelt Tank Pumps.	<p>The Remelt Tank collects the concentrated Ammonium Nitrate from the Primary Evaporator before it is sent to the Prilling Tower Head Tank. Remelt tank has internal and external steam coils while the adjoining Pipework is steam jacketed.</p> <p>The Remelt Tank was calculated to have an inventory of less than 13 tonnes at a concentration of approximately 95% concentration. The equipment operates at atmospheric pressure at 150 °C however the pump adds up to 9 bar head. Remelt tank capacity QN is 7 m<sup>3</sup>.</p> <p>An explosion efficiency of 10% was used based upon information given in Appendix C.</p>	<p>Event screened from offsite impact as explosion modelling calculates that the 21 kPa overpressure contour corresponding to the 10% fatality envelope does not extend beyond 65 m for a TNT NEQ of 32%.</p> <p>Frequency of event considered in initiating event frequencies for all offsite impact scenarios.</p>



Plant Area	Description	Comments	Scenario
	Explosion in the Prilling tower head tank.	<p>The Prilling Tower Head Tank feeds the Prilling Tower with Ammonium Nitrate solution. The vessel and pipework is steam jacketed.</p> <p>The Prilling Tower Head Tank was calculated to have an inventory of less than 2 tonnes at a concentration of approximately 95% concentration. The equipment operates at atmospheric pressure at 150 °C.</p> <p>An explosion efficiency of 10% was used based upon information given in Appendix C.</p>	<p>Event screened from offsite impact as explosion modelling calculates that the 21 kPa overpressure contour corresponding to the 10% fatality envelope does not extend beyond 35 m for a TNT NEQ of 32%..</p> <p>Frequency of event considered in initiating event frequencies for all offsite impact scenarios.</p>
Ammonium Nitrate Plant (continued).	Explosion in Prilling Tower (and intermediate conveyors).	<p>At the base of the Prilling Tower Ammonium Nitrate is collected and sent by a conveyer with a chute to the predryer and dryer drum.</p> <p>The Prilling Tower was calculated to have an inventory of less than 10 tonnes of prill. The equipment operates at atmospheric pressure at an inlet prill tower temperature of approximately 150 °C. The dryer drum operates at a temperature of 80 °C.</p> <p>An explosion efficiency of 25% was used based upon information given in Appendix C.</p>	<p>Event screened from offsite impact as explosion modelling calculates that the 21kPa overpressure contour corresponding to the 10% fatality envelope does not extend beyond 70 m for a TNT NEQ of 32%.</p> <p>Frequency of event considered in initiating event frequencies for all offsite impact scenarios.</p>

Plant Area	Description	Comments	Scenario
	Explosion in Predryer/Dryer Drum and Screen Filter (and intermediate conveyors).	<p>The Predryer and Dryer operate at approximately 150°C while the conveyor belts and screen at lower temperatures of 80°C. Both items operate at atmospheric pressure.</p> <p>The Predryer and Dryer calculated to have an inventory of less than 1.5 tonnes of prill. The equipment operates at atmospheric pressure at a temperature of approximately 150 °C. See remarks above.</p> <p>An explosion efficiency of 25% was used based upon information given in Appendix C.</p>	<p>Event screened from offsite impact as explosion modelling calculates that the 21kPa overpressure contour corresponding to the 10% fatality envelope does not extend beyond 40 m for a TNT NEQ of 32%.</p> <p>Frequency of event considered in initiating event frequencies for all offsite impact scenarios.</p>
	Explosion in fluidised bed cooler and precoat drum (and intermediate conveyors).	<p>The Fluidised bed cooler operates at approximately 70 to 30°C and at atmospheric pressure.</p> <p>The cooler and precoat drum calculated to have an inventory of less than 4.5 tonnes of prill.</p> <p>An explosion efficiency of 25% was used based upon information given in Appendix C.</p>	<p>Event screened from offsite impact as explosion modelling calculates that the 21kPa overpressure contour corresponding to the 10% fatality envelope does not extend beyond 55 m for a TNT NEQ of 32%.</p> <p>Frequency of event considered in initiating event frequencies for all offsite impact scenarios.</p>

Plant Area	Description	Comments	Scenario
Ammonium Nitrate Emulsion Plant.	Explosion of Ammonium Nitrate emulsion in a storage tank.	<p>The Emulsion plant will have three 140m<sup>3</sup> emulsion tanks where the emulsion is stored prior to transport off site.</p> <p>Ammonium Nitrate emulsion cannot normally be detonated even with a booster charge and requires to be sensitised at the points of use. It should be noted that uncontaminated ammonium nitrate is extremely difficult to detonate under normal atmospheric conditions and would require a very large amount of energy and the presence of contaminants to exist (such as voids or bubbles or organics matter or fuel) in order for detonation to occur.</p>	<p>The fault tree for the potential emulsion explosions are shown in Appendix D.</p> <p>In the remote case of an explosion, 150 tonnes of AN emulsion at an efficiency of 100% and equivalency of 70% calculates a 21kPa overpressure contour corresponding to the 10% fatality envelope does not extend beyond 300 m.</p>
Ammonium Nitrate Bulk Storage Area	Explosion of Ammonium Nitrate prill in the bulk storage area	<p>The Ammonium Nitrate Plant will store two 3,000 T storage areas, two 2,000 T storage areas, one 1000 m3 AN solution and three 140 T tanks of an emulsion.</p> <p>An explosion efficiency of 100% was used based upon information given in Appendix C.</p>	<p>Due to the expected demand for Ammonium Nitrate Prill, the stockpile will rarely be 100% full. The distance to the edge of the 21kPa overpressure contour, which represents the 10% fatality envelope were calculated for 100% stockpile and the most appropriate 25% full stockpile. The resulting distances were 625m for 100% (3,000 tonnes) and 395m for 25% (750 tonnes).</p> <p>Since the overpressure consequence results do not reach the site boundary, all AN Prill explosions were removed from the Risk model.</p> <p>Missiles generated as a result of the explosion were conservatively assessed to have the potential to travel up to 600 metres from the epicentre of the explosion.</p>

Plant Area	Description	Comments	Scenario
Ammonium Nitrate prill transport to the site boundary	Explosion of AN in transfer truck	A 20 tonne load of prill was modelled as detonating to simulate the detonation of a transport truck, however frequency analysis of explosion in truck while transporting prill to site boundary demonstrates likelihood negligibility and was screened from analysis. Supporting details provided in Appendix B. It is noted that prill is transported in 65 T B-triples having three separate storage containers.	Screened from analysis because of negligible event frequency while onsite, (i.e. $5.8E-05$ pa) refer to Table 36 in Appendix D.
AN Emulsion trucks	Explosion of Emulsion Truck	For the Emulsion truck to explode one of three possible mechanisms needs to occur: heating in confinement or runaway reaction or detonation of AN emulsion. If the material becomes contaminated the material will become more sensitised to detonation, e.g. compromised pH of product or gas entrapment, and the presence of a extreme ignition source, which could only be provided by a vehicle in this situation could result in the detonation of the AN material. Supporting details provided in Appendix B.	Screened from analysis because of negligible event frequency while onsite, refer to Appendix D.

No Ammonium Nitrate solution explosion event was found to generate 21 kPa overpressures (conservatively taken as a 10% fatality envelope) beyond the site boundary, instead the range of their effects was determined to be somewhat local to the nitric acid and Ammonium Nitrate plant.



## Appendix B

# Assumptions Register

## AN Plant and Emulsion Plant Modelling Assumptions

## Parts Count

Parts Count Assumptions	Rationale
1. Line distances estimated from engineering judgement and knowledge of equipment height.	Equipment plot plans were not available and the H&RA is being conducted as a high level review.
2. Shutdown valves counted as actuated valves	Shutdown valves rely on electrical and mechanical / pneumatic component interaction.
3. 18.75 mm lines included in parts count	<p>Liquid Ammonia leaks from 18.75 mm lines have the potential to impact offsite – a distance of 150 metres from the plant.</p> <p>Lines less than 18.75 mm were excluded from the parts count as high pressure releases were not found to cause fatal impacts offsite.</p>
4. Filters counted as vessels	Lack of information available on filter vessels types. Vessels similar to process vessels in that leaks likely to occur around flanged joints and weld seams.
5. Transmitters etc counted as small bore fittings	These items likely to fail due to impact etc. Small-bore fittings historically leak in sizes of 10 mm to 25 mm leak frequency.
6. Manholes counted as 600 mm flange	Vessel failure rates do not explicitly state that manholes are included in their failure modes. These items were modelled as 600 mm flanged joints.

## Hazardous Materials

Hazardous Materials Assumptions	Rationale
Nitric acid and steam will cause severe burns with bodily contact however will not travel sufficient distances upon release to affect an offsite populations.	Closes site boundary located 500-600 metres from plant.
The coating agent (alkyl amine) and emulsion agents (process oils, diesel) will cause localised pool fires that likewise were considered unable to affect an offsite population. Toxic smoke plumes will not affect offsite populations	Closes site boundary located 500-600 metres from plant.
Nitrogen poses both asphyxiation and frostbite hazards however will rapidly disperse before reaching the site boundary.	Closest site boundary located 500-600 metres from plant.
Ignition of Ammonia not considered credible for process release events	<p>Ammonia has an autoignition temperature of 651°C – LFL 15 % v/v and UFL 28 % v/v. Minimum ignition energy &gt; 100 mJ which is 400 times greater than that for propane and butane (0.25 mJ) and 1000 times greater than for other hydrocarbons [26].</p> <p>This assumption is consistent with the findings of a study conducted by the UK HSE, in which of a total of 139 Ammonia-related incidents were assessed. The study found that while all involved toxic exposure, none involved flammable effects.</p> <p>With respect to the assessment of offsite risk levels, the toxic effects of Ammonia have greater consequence distances and therefore the focus on their analysis is considered to give more conservative results (as ignited releases will not impact as far offsite).</p>
NO <sub>x</sub> gas considered to be dominated by Nitrogen Dioxide.	Nitrous Oxide not present in sufficient concentrations to cause asphyxiation offsite.

<sup>26</sup> Lees [16/22], [17/237], [15/56]



Hazardous Materials Assumptions	Rationale
<p>The plume of combustion products resulting from an Ammonium Nitrate fire is considered buoyant due to the high temperatures involved, and is thus not considered to return to grade beyond the site boundary at sufficient concentrations to cause harm.</p>	<p>Closest site boundary located 500-600 metres from plant. This assumption is based on a 1996 DNV report conducted on the importation of AN through Bunbury Port, W.A.</p>

## Consequence Assessment

Consequence Assessment Assumption	Rationale
Explosion efficiency of Ammonium Nitrate equal to 100%.	In order to ensure compliance with Ammonium Nitrate Guidance Note No.4: Siting of New Facilities, 100% efficiency has been used for modelling purposes.
TNT equivalency of Ammonium Nitrate equal to 32%.	<p>Pure AN has a TNT equivalency of 0.32 but in the presence of contaminants, this value may increase up to an equivalence of 55% for contaminated AN. This value was used in line with the UK HSE requirements. This value is also widely recognised and has been used as a basis for this study to represent a best estimated TNT equivalency level for AN prill.</p> <p>As per Ammonium Nitrate Guidance Note No.4: Siting of New Facilities, a TNT equivalency of 32% was used.</p>
Overpressure levels of 21 kPa – 10% fatalities, 35 kPa – 30% fatalities, and 70 kPa – 100% fatalities.	<p>21 kPa – range of fatalities listed is between 1% - 10%. The 10% criterion was selected as conservative and accommodates for the likelihood of some populations being located indoors.</p> <p>35 kPa – range of fatalities listed is between 20% - 50%. NSW Hazardous Industry Planning Advisory Paper (HIPAP) No. 4 [Ref 13] provides a 15% probability. 30% taken as conservative.</p> <p>70 kPa – range of fatalities listed is between 100% whether inside a building or outdoors. Taken from HIPAP 4.</p>
3 missiles generated from an AN prill explosion which are large enough to cause tank rupture	<p>Findings of an investigation into the Toulouse accident identified a number of 5 metre sections of metal I-beams located up to 280 metres from the AZF site. It is noted that the mass of these I-beams was approximately 50 kilograms.</p> <p>It is therefore conservatively assumed that 3 projectiles will be created in the event of an explosion, each with the capacity to penetrate assets on impact.</p>

<b>Consequence Assessment Assumption</b>	<b>Rationale</b>
Projectiles may impact anywhere within a 600 metre radius from the AN explosion epicentre.	Findings of an investigation into the Toulouse accident identified 5 metre sections of metal I-beams located up to 280 metres from the AZF site.  Given the potential for more ANP to be involved in one of the prill explosions, projectiles were conservatively assumed to have the potential to impact up to 600 metres from the explosion epicentre using a proportionate correlation.
Shutdown Valve and blowdown valves assumed to operate 95%.	Conservative assumption given the typical SIL3 rating required by these protective functions. Failure assumed to result from a failure for the valve solenoid to de-energise.
Excess Flow Valve (XfV) on Ammonia sphere assumed present and will operate 95% of time.	High depressurisation flow rate will supply sufficient forces to close valve.
Ammonia-air stream and NO <sub>x</sub> gases mixture probit calculated by scaling of Ammonia probit in line with molar concentration.	Toxic components only constitute a fraction streams. Given in PFD balance sheets.
Ammonia-air moisture interaction assumed to have negligible effect on dispersion rates. The main action is to cool the air and condense the moisture in the air into fine droplets (fog). The dispersion would be affected by temperature.	Beyond modelling capabilities of PHAST package used to model dispersion.
Small size releases assumed to last 15 minutes. Large size releases assumed to last 3 minutes.	Manual intervention requires alarm sounding, manual investigation and then DCS shutdown. Large leaks will trip DCS or hardwire systems and isolate leak almost immediately.

**Table 37 Failure Case Inventory Calculations for the AN Plant (330,000 tonnes/yr)**

	Vessel	Capacity		% Capacity Phase			Density (kg/m <sup>3</sup> )	Approximate Mass (kg)	
				Liquid	Vapour	AN		Liquid	Vapour
NH3 Pipe	Pipe	4	m3	1	-	-	640	2291	-
	NH3 HNO3 liquid filter	1	m3	1	-	-	640	852	-
Nitric NH3 Releases	NH3 Evaporator	6	m3	0.2	0.8	-	-	722	18
	NH3 stripper	1	m3	0.2	0.8	-	-	92	2
	NH3 Preheater	0	m3	-	0.8	-	4	-	0
	NH3 gas filter	0	m3	-	1	-	-	-	0
Nitric NOX Releases	NOX Process Gas Cooler	30	m3	-	0.5	-	8	-	120
	Tail Gas Heater 3	5	m3	-	0.5	-	-	-	18
	Economiser	3	m3	-	0.5	-	-	-	13
	Cooler-Condenser	21	m3	-	0.5	-	-	-	82
	Absorption tower	1121	m3	-	0.2	-	-	-	1794
AN NH3 Releases	NH3 Tank	6	m3	0.5	0.5	-	640	1847	12
	Water MP NH3 Separator	0	m3	0.2	0.8	-	-	0	0
	NH3 Evaporator	14	m3	0.2	0.8	-	-	1849	46
	Air Cooler NH3 Separator	1	m3	0.5	0.5	-	-	254	2
	Air Cooler Secondary NH3 Separator	0	m3	0.5	0.5	-	-	14	0
	NH3 Separator	1	m3	0.5	0.5	-	-	426	3
	NH3 Superheater Separator	0	m3	-	1	-	4	-	1
AN Releases	Pipe Reactor Separator	16	m3	-	-	0.8	1290	16495	-
	Flash tank	11	m3	-	-	0.8	1341	12146	-
	An Primary Evaporator	16	m3	-	-	0.3	1417	6606	-
	AN Primary Evaporator Separator	18	m3	-	-	0.8	1417	20133	-
	Remelt tank	16	m3	-	-	0.8	1414	17579	-
	Prilling tower head tank	2	m3	-	-	0.8	1412	2508	-
	Prilling tower	3141	m3	-	-	0.005	900	14136	-
	Predryer/Dryer Drum	260	m3	-	-	0.01	750	1949	-
	Fluidised Bed Cooler	78	m3	-	-	0.1	750	5877	-
	Coating Drum	0	m3	-	-	0.1	750	17	-

**Table 39 Failure Case Inventory Calculations for Ammonia Plant.**

Iso-Section Name	Vessel	Capacity		% Capacity Phase		Approximate Mass (kg)	
				Liquid	Vapour	Liquid	Vapour
Saturator, Shift Converter, Desaturator (3)	Nat Gas Purifier, Saturator, Shift Converter, Gas Heated Reformer, Secondary Reformer, Desaturator.	350	m3	0	1	0	3500
PSA Unit, Methanator (4)	PSA Unit, PSA Product Gas Drum, PSA Purge Gas Drum, Methanator, Make-up Gas Chiller Separator, Make-up Gas dryers.	450	m3	0.5	0.5	water	2575
Ammonia Compressor and Ammonia Converter (6)	Ammonia Compressor, Ammonia Converter.	200	m3	0.8	0.2	water	6000
Converter Effluent Gas to Flash vessels (7)	Low Pressure Flash Vessel, Intermediate Pressure Flash Vessel, Ammonia Let-down Vessel, Ammonia Catchpot.	0.6	m3	1	0	7500	450
Liquid Ammonia Product Accumulator (9)	Product Accumulator	40	m3	1	0	25000	100
Ammonia Storage Tank (10)	Ammonia Storage Tank	7325	m3	1	0	1263400	0

## Appendix C

# Consequence Analysis

Consequence Modelling and Explosion  
Impact for the Ammonia, AN and  
Emulsion Plants

## **Consequence Modelling**

The following sections describe the basic theory behind the consequence modelling conducted during this assessment in SAFETI.

A 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 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.

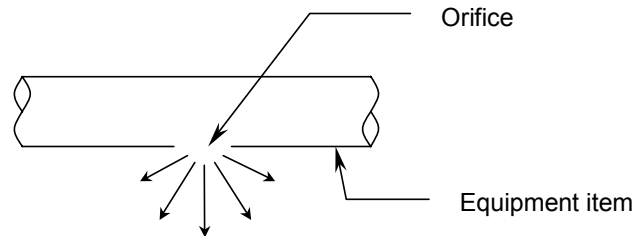
This Appendix discusses basic concepts and theory behind the various consequence models used in the analysis. The models discussed are:

- ▶ Discharge modelling
- ▶ Dispersion
- ▶ Toxic Effects
- ▶ Explosions
- ▶ Overpressure Effects

### **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 18 illustrates an example scenario.

**Figure 17 Typical Discharge**



The discharge can be considered to have 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, ie, entropy before release = 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:

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

$$\text{And } u_0 = C_d \sqrt{-2(H_o - H_i)}$$

Where  $C_d$  = Discharge coefficients

$A_o$  = Area of the orifice

$\rho_o$  = 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; ( $\dot{m}$ )
- ▶ thermodynamic data: release temperature (single phase) or liquid mass fraction (two-phase), initial drop size;
- ▶ for instantaneous release: mass of released material (kg), expansion energy (J)
- ▶ for continuous release: release angle (degrees), rate of release (kg/s), release velocity (m/s), release duration (s).



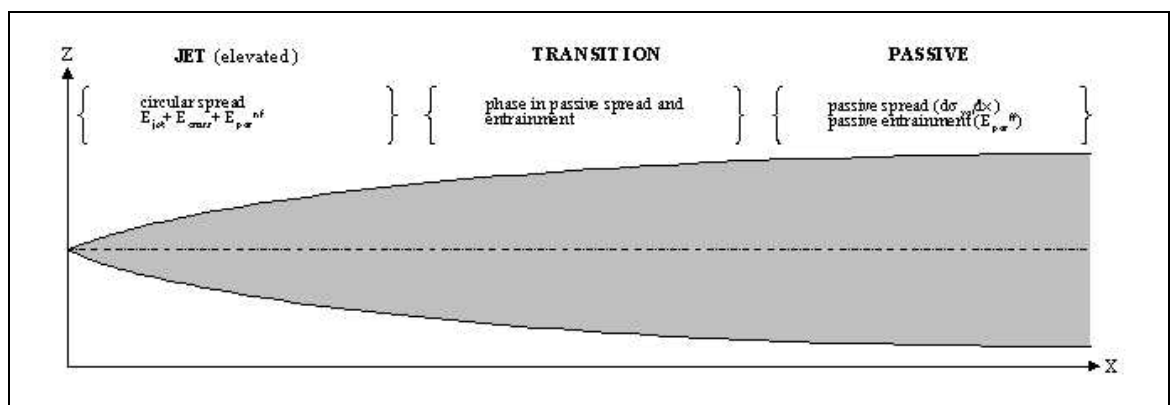
## Dispersion

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.

The dispersion-modelling package PHAST 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.

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 19 below shows a typical release and the various phases involved.

**Figure 18 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).

## **Toxic Impact**

If the release is a toxic material, then 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 relate 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 report.

GHD has found that commonly used secondary sources of information may be unreliable, in that the toxicological values given may be inaccurate representations of the original results, or that the primary sources of such values are either difficult to verify or of doubtful quality. Therefore, all the data used in the assessment of individual substances should be obtained from the original reports.

However, 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, phosgene). Nevertheless, for most substances the data are 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 has 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 a comfortable 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.

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 single criteria 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.

### Probit Functions

A method of measuring toxic effects is to use the probit function. It 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:

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

Where Pr = Probit value

C = Concentration of interest

t = time exposed to concentration, C

$k_1, k_2, n$  = coefficients specific to each material

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

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

From a review of the most suitable probit functions the following probits and subsequent figures have been used.

**Table 41 Probits used**

Material	Ammonia	Nitrogen Dioxide
Probit Co-efficient: a	-16.33	-13.79
Probit Co-efficient: b	1	1.4
Probit Co-efficient: n	2	2
Source	TNO Green Book, CPR16: "Methods for Determining possible Damage", 2002.	DSM Memo 1156 CVM/78 "Inloed van Toxische Stoffen", ten Berge W.F., 1978
ERPG-3 Value	750 ppm for 1 hour	25 ppm for 1 hour
Equivalent Toxic Dose to ERPG-3	$d = c^N t = 750^2 \times 60$ $= 3.4E7 \text{ ppm}^2 \cdot \text{min}$	$d = c^N t = 30^2 \times 60$ $= 5.4E4 \text{ ppm}^2 \cdot \text{min}$

Consequently, the probit values listed in Table 41 are used by PHAST to calculate the portion of people fatally exposed to the toxic releases.

It is also important to report information useful for planning emergency response to potential release scenarios. For this purpose reporting distances to the Equivalent Toxic Dose to ERPG-3 has been quoted. The use of the Equivalent Toxic Dose to ERPG-3 is conservative with respect to fatalities as

it is a dose, which “nearly all individuals can be exposed to for an hour without experiencing or developing life threatening health effects”.

In addition, though many of the releases are of short duration, the cumulative dose at some points may reach the ERPG-3 Equivalent Toxic Dose and so this calculation incorporates the range of concentrations which wash over a point during the course of the release.

### Emergency Planning Response Group Criteria

The following is provided for background on the emergency planning criteria used. In the case of the Emergency Planning Response Group (a committee of the American Industrial Hygiene Association), the three criteria they publish are provided to assist emergency response workers to know what level of population will require evacuation given a toxic release. Hence the exposure time is for a full hour, to try and account for the time to effect an evacuation. The three ERPG concentrations are quoted below in Table 43:

**Table 43 ERPG Concentrations for Chemicals of Interest.**

Category	Definition	Ammonia	Nitrogen Dioxide
ERPG-1	The maximum airborne concentration to which nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient health effects or perceiving a clearly defined objectionable odour.	25 ppm	1 ppm
ERPG-2	The maximum airborne concentration below which, it is believed, nearly all individuals can be exposed for up to 1 hour without experiencing or developing irreversible adverse health effects or symptoms, which could impair an individual's ability to take protective action.	150 ppm	15 ppm
ERPG-3	The maximum airborne concentration below which, it is believed, nearly all individuals can be exposed for up to 1 hour without experiencing or developing life threatening health effects.	750 ppm	30 ppm

## Explosion Impact

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.

### *Detonability of Ammonium Nitrate*

Ammonium Nitrate as prepared by DN to UN 1942 specification is classed as an oxidiser and has the following characteristics:

- ▶ It cannot burn without a combustible material present
- ▶ It melts at 169 °C
- ▶ It begins to decompose after melting, releasing fumes of NO<sub>x</sub>, HNO<sub>3</sub>, NH<sub>3</sub> and H<sub>2</sub>O
- ▶ At roughly 290 °C 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; high 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 making it more sensitive 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. In other words, it is also affected by high temperatures.
- ▶ For UN 1942 grade Ammonium Nitrate, whilst it is normally extremely difficult to detonate under normal atmospheric conditions in its uncontaminated form, detonation could occur if a very large amount of energy is applied (i.e. in excess of 80 atmospheres pressure (gauge)) and/or if the presence of contaminants exists within the AN (such as voids or bubbles or organics matter or fuel).

However, it is noted that *Contamination* makes Ammonium Nitrate more sensitive to detonation as detailed below:

- ▶ Combustible material is limited to no more than 0.2% in the UN 1942 specification, if more is added, this increases the sensitivity to detonation, up to 1% hydrocarbon which is the 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 combining in a manner greater than their individual effects.

#### *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, although these would act locally considering the mostly enclosed storage shed.

If a vehicle fire in the Ammonium Nitrate prill store occurs the material could exhibit decomposition behaviour due to the catalytic effect of certain types of compound fertilizers. Under certain exceptional conditions, such as if the spontaneous heating of the AN material occurs in a highly confined area with insufficient ventilation, this would increase the sensitivity of the ammonium nitrate. This would lead to a considerable pressure build-up in material and would result in the detonation of the AN prill. However, if burning fuel from the vehicle were to mix with molten Ammonium Nitrate and an explosion from the vehicle cause 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 lead to increased pressure and greater sensitivity to detonation. For UN 1942 grade Ammonium Nitrate, it has been reported that that in its uncontaminated form very high pressures, in excess of 80 atmospheres, are required for detonation [Babcock, 1960]; a pressure far beyond that which is found in a bulk pile of prill or in a ship's hold. However, sensitisation of the AN prill can occur with the addition of contaminants, which could result in a lowered activation energy state in the AN material, e.g. it may become conceivable to detonate the contaminated for of 1942 grade Ammonium

nitrate in excess of the pressure for detonation can drop to 20 atmospheres compared to the uncontaminated pure AN grade.

Hence 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 4326-1995: 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 which with heating may result in detonation [Shah, 1996 - Table 4, No. 48, 60, 69].

#### **Credible Detonation Scenarios**

Table 7 (first table in section 3) in the main report details the significant Ammonium Nitrate inventories throughout the project. Each one is then assessed for credible scenarios leading to detonation. Note that potential fire or fumes as an outcome is not detailed here, only detonation. From the inventories that are identified in Table 7, the explosion results are presented in Table 15 of the main report. The table includes sensitivities conducted on the explosion equivalency. Consequences were determined via the following steps.

The potential decomposition fires that produce NO<sub>x</sub> are expected to present a more localised risk issue and not impact off-site populations. The hot plume from a fire would carry the NO<sub>x</sub> away from the ground (and thus people) making harmful exposure to the NO<sub>x</sub> unlikely to off-site populations.

#### *Proportion Sensitised to Detonation*

The proportion of material sensitised to detonation help define the consequences of an explosion. The action of higher temperature, confinement and contaminants sensitise Ammonium Nitrate to explosion. However, the effects of heat, confinement or contamination are not expected to extend to the entire inventory. Reviewing the inventories of Ammonium Nitrate onsite, the following cases are identified:

*Tanks* under the influence of heat, confinement and contaminants are conservatively assumed to contain Ammonium Nitrate homogeneous in its sensitivity to detonation. For this reason, the entire tank's inventory is

assumed to be sensitised to the same degree and hence if an explosion were instigated, the entire contents of the tank are assumed to be involved.

*Bulk Ammonium Nitrate* prill stored in a warehouse in freestanding piles, hence it is considered difficult for the influence of heat, confinement and contaminants to carry throughout the entire inventory. A review of significant Ammonium Nitrate accidents since 1961 [Shah 1996, GHD Review] identifies two instances where bulk prill has exploded. In both cases only a small proportion of the Ammonium Nitrate present was detonated:

- ▶ Toulouse [Dechy, 2004, event occurred in 2001]. The Toulouse incident involved an explosion of contaminated and offspec prill. In the Toulouse incident, the overall equivalence of Ammonium Nitrate to TNT was considered to be 5-10% [Dechy, 2004].
- ▶ Cherokee [Shah 1996, Table 4, Entry 24, event occurred in 1973]. The Cherokee incident involved a fire from a front-end loader. This is significant as despite the fact that the warehouse was at capacity (14,000 tonnes), only the contaminated AN exploded not the entire contents of the pile.

A worst-case scenario for the AN facilities has been identified as the detonation of 100% of an entire 3,000 tonne stockpile, which is compliance with Ammonium Nitrate Guidance Note No.4: Siting of New Facilities. This is obviously overly conservative, in relation to historical incidents.

#### Efficiency

The proportion of the sensitised material that detonates in an explosion is called the efficiency. If the explosion is slow (in detonation speed terms, which Ammonium Nitrate is) then a large proportion of the material present will be blown away before becoming part of the chemical reaction, which is the detonation.

The following efficiencies were used in this study:

- ▶ 10% for Ammonium Nitrate solution (for concentrations greater than 80 %), this efficiency value is supported by the events that occurred at Port Neal, USA 1994 when two vessels containing a total of 81 tonnes of Ammonium Nitrate exploded consecutively. However, only a total of 7 tonnes of Ammonium Nitrate detonated, therefore implying 9% efficiency. 10% was taken as a conservative efficiency.
- ▶ 100% for Ammonium Nitrate prill. This value is conservatively used to model the efficiency with accordance with Ammonium Nitrate Guidance Note Number 4 : Citing of New Facilities.
- ▶ 70% efficiency for AN Emulsion. This value is a conservative estimate based on industry knowledge and the explosive characteristics of emulsion.



### *Equivalency*

When calculating the consequences from accidental explosions, one of the most common techniques used is to characterise a material as if it was an equivalent quantity of TNT. This technique is used because of the significant quantity of information on the consequences of explosions involving TNT and the scarcity of reliable information on the explosive nature of many other materials.

There are many ways to calculate "TNT equivalence". The key parameter is blast energy produced. Where this information is not available, other information is used as a surrogate such as the heat of combustion.

### *Heat of Explosion*

For TNT, the heat of explosion is 1080 kcal/kg (4522 kJ/kg) [Fedoroff 1969] obtained from field experiments on large charges. For Ammonium Nitrate, which does not consume any appreciable quantity of external oxygen during an explosion, the chemical reactions that occur during combustion are the same as those that occur during an explosion. Thus the heat of combustion is often used as a surrogate for the heat of explosion.

However, there are conflicting literature values for the heat of combustion and heat of explosion of Ammonium Nitrate. Some sources list the heat of combustion and the heat of explosion of Ammonium Nitrate to be 346 kcal/kg, the heat of combustion at constant volume to be 627.8 kcal/kg (2628 kJ/kg) and at constant pressure to be 616.9 kcal/kg (2583 kJ/kg).

A Livermore software program called CHEETAH (v2.0), derived from more than 40 years of experiments on high explosives at Lawrence Livermore and Los Alamos national laboratories, predicts detonating Ammonium Nitrate (with density 780 kg/m<sup>3</sup>) to have detonation energy of 378 kcal/kg (1583 kJ/kg).

The range of TNT equivalents calculated using the previous data is given below in Table 45.

**Table 45 Ammonium Nitrate to TNT equivalencies**

Source	Heat of explosion		Equivalence Value
	Ammonium Nitrate	TNT	
Encyclopedia of Explosives and Related Items Vol. 4, 1969 (Fedoroff and Sheffield)	1449 kJ/kg	4522 kJ/kg	0.32
Encyclopedia of Explosives and Related Items, Vol. I, 1960) quoting Medard and Thomas (1953)	2583 kJ/kg	4522 kJ/kg	0.57

Source	Heat of explosion		Equivalence Value
	Ammonium Nitrate	TNT	
CHEETAH model	1583 kJ/kg	4580 kJ/kg	0.35

These estimates of TNT equivalence can be compared with the value given in the Ammonium Nitrate Guide quoted in Lees (1996, p9/104). "The Guide (FMA Ammonium Nitrate guide, 1989) discusses the hazard of explosion of Ammonium Nitrate and considers the consequences of deflagration of a stack of 300 tonne of Ammonium Nitrate.

It obtains for such an explosion a TNT equivalent of 41 tonne based on an Ammonium Nitrate TNT equivalent of 55% ...". This value is contradicted by Marie-Astrid Kordek of the Certification Division, France National Institute for Industrial Environment and Risks (INERIS) who recently presented a paper on an Analysis of the explosion effects of the accident on 21 September 2001 in Toulouse. In this paper the quoted TNT equivalence estimates used were ~0.3 for AN fertiliser grade. These two estimates are consistent with the dichotomy noted above. There are thus two different estimates of the TNT equivalence for Ammonium Nitrate (~55% and ~32%). Both of these estimates have been previously used in consequence calculations for explosions of Ammonium Nitrate.

The main reason for the difference in TNT equivalence estimates is the difference in heat of combustion estimates, which were used as surrogates for heat of explosion estimates.

#### *Heat of Combustion*

The physical property "heat of combustion" is a standard chemical property. This is defined to be the heat evolved when a material is combusted with air, starting with the reactants at 25 °C and one atmosphere pressure and ending with the products at 25 °C and one atmosphere pressure. Thus any H<sub>2</sub>O produced in the combustion reaction is considered to be in the liquid phase.

However, during an isentropic expansion, such as occurs in an explosion, the pressure will reduce rapidly and the temperature will follow more slowly. Clearly, if water condensation is included in the calculations, the latent heat of condensation is considered to be part of the blast energy. Yet, such condensation does not contribute to the blast effects.

Thus, for consideration of the TNT equivalence, the H<sub>2</sub>O produced should be considered to be in the vapour phase as any condensation of water vapour occurs long after the explosion has finished. This is considered to be the most likely reason for the dichotomy of heat of combustion and heat of explosion estimates for Ammonium Nitrate. The estimates from physical

property databases, not concerned with potential explosive effects, quote heats of combustion around 620-630 kcal/kg (2596-2638 kJ/kg), which include the heat of condensation of water vapour. The estimates from experiments associated with explosive properties of materials quote heats of explosion around 340-380 kcal/kg (1424-1591 kJ/kg), which do not include any effects from condensing water.

This reasoning is supported by the Encyclopaedia of Explosives and Related Items, Vol. I (1960) which quotes the US Army (1955) for the heat of combustion at constant volume (H<sub>2</sub>O liquid) to be 630 kcal/kg (2638 kJ/kg) and the heat of combustion at constant volume (H<sub>2</sub>O vapour) to be 346.3 kcal/kg (1450 kJ/kg). These values, being obtained at constant volume, cannot be used directly in the TNT equivalence calculations but are similar to the previously quoted estimates at constant pressure (617 kcal/kg, 346 kcal/kg and 378 kcal/kg).

#### *Overpressure vs. Distance Model*

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. This method was first discovered by Hopkinson in 1915 [Bulson 1997] and has proven since then to be a robust method of explosive consequence prediction [Ref 32].

An 'Overpressure vs. Scaled Distance' relationship can take the form of an equation or graph. In this case an equation is used which is sourced from the US Army [Bulson 1997] and has the form:

$$p_o = \frac{4120}{Z^3} - \frac{105}{Z^2} + \frac{39.5}{Z}$$

where:  $2 < p_o < 160$  psi gauge

$$Z = \frac{R}{W^{1/3}} \quad \text{and} \quad 3 < Z < 20 \text{ ft/lbs}^{1/3}$$

The process of using this equation is:

1. Convert the explosive of interest into an equivalent mass of TNT in pounds (W).
2. Choose the overpressure of interest in psi ( $p_o$ ).
3. Solve the equation for R, the distance in feet the overpressure is felt at.

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## Appendix D

# Frequency Analysis

Frequency Calculations for the Ammonia,  
AN and Emulsion Plants

## Leak Frequency Data and Analysis

This Appendix describes the leak and explosion frequencies employed by GHD as the basis for determining the relative likelihood of releases from onshore process equipment.

### *Leak Data Overview*

During the 1990s, the offshore process industry in the North Sea made the most comprehensive collection of leak frequency data that is currently available in any industry, which has now become the standard data source for offshore risk analyses (HSE 2001). After careful consideration of the strengths and limitations of different data sources available, and the expected differences in leak frequencies between offshore and onshore industries, GHD has concluded that it is appropriate to use the high-quality *offshore* data for *onshore* QRAs with very few exceptions (until verifiable onshore experience becomes available). The relevant arguments are summarised below.

The UK Health & Safety Executive data cover a large population of equipment over a considerable period of time, providing a valid statistical basis for estimating the frequency with which different sizes of leaks shall occur. Data previously collected was frequently from indirectly related sources, inconsistently collected and representative of a poorly defined equipment population – factors that combine to introduce considerable uncertainty. The UK HSE data set was initially collected over 10 years from 1990 – 2000. It is updated regularly and thus takes some account of the recent technological developments and current industry best practice that reduce the likelihood of a release.

The HSE 2001 data provides a detailed breakdown of hole sizes for individual equipment items. The hole size of a leak and frequency for a release of that size are found to be inversely proportionate. For example, full bore rupture is expected to occur much less frequently than a pinhole size leak. Given the data is categorised into different leak sizes, an accurate calculation can be made of leak frequencies for various hole sizes.

The HSE 2001 data has been collected from offshore operations, which experience a harsher environment than that of onshore plant equipment (being assessed in this QRA). The offshore environment frequently has more sand or other impurities in the process streams than onshore plants, which can lead to corrosion / erosion leaks. Moreover, the salt-water environment means the atmosphere is also more corrosive. In addition to this, the closely spaced nature of an offshore plant can lead to increased leaks from eg collisions / impact. However, the HSE data set shows that corrosion / erosion is a minor contributor as a cause to potential leaks, with operational / procedural faults and mechanical defects being the primary causes.

In the case of infrequent events such as Ammonium Nitrate explosions, historical events are reviewed and those applicable to the situation under assessment are applied using conservative best estimates.

#### *Leak Data Source*

In order to improve the quality of the data used in risk assessments GHD has modified the leak frequencies in HSE 2001 in the manner described below:

Frequencies for small populations of similar equipment have been combined where appropriate, in order to obtain frequencies for all types of equipment and to minimise differences that are not statistically reliable.

For each equipment item, several leaks are not associated with a hole size but are labelled 'n/a'. It is unclear what the cause or size of these leaks was and therefore the UK HSE data set does not attribute them to one particular size. These leak events were therefore excluded from leak frequency derivation.

As a result of the above modifications, the leak frequencies used in this report may differ from the base HSE 2001 data. However, they are considered to be a more suitable basis for risk analysis.

#### *Leak Size Groups*

In this appendix, the leak frequencies are given for representative hole sizes, as shown in Table 47. The nominal size for each leak size range is the suggested size of a hole to be used in discharge and consequence modelling.

**Table 47** Leak size groups

Range	Nominal
< 10 mm	5 mm
10–50 mm	25 mm
50 -100 mm	100 mm
> 100 mm	Full-bore



### Equipment Type

This section of the Appendix reports the leak frequency data for the following equipment types:

- ▶ Process pipes
- ▶ Flanged joints
- ▶ Small bore fittings
- ▶ Valves
- ▶ Flexible hose
- ▶ Centrifugal pumps
- ▶ Centrifugal compressors
- ▶ Atmospheric storage tanks
- ▶ Heat exchangers
- ▶ Filters
- ▶ Pressure vessels

Table 49 gives leak frequencies for typical pipe diameters (Ø) and hole size categories. Leak frequency for pipes represents the number of leaks per meter per year.

**Table 49 Summary of Process Pipe Leak Frequencies**

Hole Diameter		Leak Frequency (per metre year)					
Range	Nominal	< DN 25	DN 25	DN 50	DN 80 < <DN 150	DN 200, 250	> DN 250
< 10 mm	5 mm	$1.6 \times 10^{-4}$	$1.6 \times 10^{-4}$	$1.6 \times 10^{-4}$	$4.4 \times 10^{-5}$	$4.4 \times 10^{-5}$	$3.5 \times 10^{-5}$
10–50 mm	25 mm	-	$*2.5 \times 10^{-5}$	$*2.5 \times 10^{-5}$	$3.1 \times 10^{-6}$	$3.1 \times 10^{-6}$	$4.6 \times 10^{-6}$
50 -100 mm	50 mm	-	-	$1.2 \times 10^{-5}$	$*2.2 \times 10^{-6}$	$2.2 \times 10^{-6}$	-
> 100 mm	100mm	-	-	-	-	-	-
	Full-bore	-	-	-	-	$5.8 \times 10^{-6}$	$9.2 \times 10^{-6}$
	TOTAL	$1.6 \times 10^{-4}$	$1.9 \times 10^{-4}$	$2.0 \times 10^{-4}$	$4.9 \times 10^{-5}$	$5.5 \times 10^{-5}$	$4.9 \times 10^{-5}$

\* Constitutes a full-bore rupture

These values are appropriate for liquid, gas and liquefied gas service.

The principal failure modes for pipes are:

1. External leak through the pipe wall or welds
2. Blockage, due to deformation or objects inside
3. Unacceptable deformation or corrosion (without leakage or blockage)

Causes of failure in pressure systems in general are discussed by Lees (1996 p12/80). The main causes of failures of pipes are mechanical failures (typically due to combinations of overloading and inadequate design) and corrosion.

### Flanged Joints

The estimate of leak frequencies from flanged joints is provided by HSE 2001 data. Table 51 reports leak frequencies for typical flange sizes and hole size categories.

Leak frequencies are quoted as leak per joint year (ie flange – gasket – flange = 1 joint).

**Table 51 Summary of Flange Leak Frequencies**

Hole Diameter		Leak Frequency (per joint year)				
Range	Nominal	DN25, DN50	DN 80	DN 150	DN 200, DN 250	> DN 250
< 10 mm	5 mm	$3.1 \times 10^{-5}$	$3.1 \times 10^{-4}$	$4.7 \times 10^{-5}$	$4.7 \times 10^{-5}$	$8.4 \times 10^{-6}$
10–50 mm	25 mm	$8.6 \times 10^{-5}$ *	$7.2 \times 10^{-6}$	$5.1 \times 10^{-6}$	$5.1 \times 10^{-6}$	$3.7 \times 10^{-6}$
50 -100 mm	100 mm	n/a	$1.4 \times 10^{-6}$ *	$3.8 \times 10^{-6}$ *	$5.7 \times 10^{-7}$	$3.7 \times 10^{-6}$
> 100 mm	Full-bore	n/a			$3.4 \times 10^{-6}$	$7.3 \times 10^{-6}$
	TOTAL	$1.2 \times 10^{-4}$	$3.2 \times 10^{-4}$	$5.6 \times 10^{-5}$	$5.6 \times 10^{-5}$	$2.3 \times 10^{-5}$

\* constitutes a full-bore rupture

These values are appropriate for liquid, gas and liquefied gas service. In the absence of better data they are considered suitable for all types of gaskets in flanges and for other types of mechanical pipe connections (e.g. Grayloc clamps).

Leaks from a flanged joint are most commonly due to failure of the gasket, and many data sources do not distinguish flange leaks from gasket leaks. However, leaks can occur through the flange itself with the gasket intact (see Lees 1996 p16/160). Major leaks tend to result from bolt failures or incorrect assembly of the flanged joint. Complete parting of the flanged joint may in effect cause a full-bore rupture of the pipe.

#### *Small Bore Fittings*

The best estimate of leak frequencies from small-bore fittings is taken to be the leak frequency for instruments in provided in the Offshore Hydrocarbon Release Statistics (HSE, 2001). Table 53 gives leak frequencies for typical instrument sizes and hole size categories. Leak frequency is quoted as leak per fitting year.

**Table 53 Summary of small bore fitting leak frequencies**

Hole Diameter		Leak Frequency (per fitting year)
Range	Nominal	
< 10 mm	5 mm	$4.7 \times 10^{-4}$
10–50 mm	25 mm	$1.2 \times 10^{-4}$
	TOTAL	$5.9 \times 10^{-4}$

\* Maximum hole size for small bore fittings is 25 mm.

Small-bore fittings are instrument connections and other branches less than 50 mm in diameter from larger pipes. Pressure, temperature or flow measuring instruments are typically attached to pipes or vessels by small-diameter pipes, with isolation valves and flanged connections. This concept is convenient in a QRA, because each small-bore fitting can be represented in a generic manner, instead of analysing their actual pipe lengths, numbers of flanges etc.

The only failure mode considered is 'external leak of process fluid'. External leaks of instrument air, steam, nitrogen etc are analysed by Sterling (1999). Based on a survey of 12 US industrial plants in 1998, an average of 12% of fittings were leaking. The median leak rate was 1 ml/min and the mean was 500 ml/min. The leak rate distribution was not correlated with internal pressure.

#### Valves

The estimate of external leak frequencies from valves is taken from HSE 2001 data. A statistically significant difference is reported between manual and actuated valves and these are treated separately. Table 55 and Table 57 give leak frequencies for manual and actuated valves. Leak frequencies are quoted as per valve year of operation.

**Table 55 Summary of valve external leak frequencies for manual valves**

Hole Diameter		Leak Frequency (per valve year)			
Range	Nominal	<DN 80	DN 80	DN 80 < DN 150	> DN 150
< 10 mm	5 mm	$6.3 \times 10^{-5}$	$6.3 \times 10^{-5}$	$6.3 \times 10^{-5}$	$6.3 \times 10^{-5}$
10–50 mm	25 mm	$2.4 \times 10^{-5*}$	$2.4 \times 10^{-5}$	$2.4 \times 10^{-5}$	$2.4 \times 10^{-5}$
50 -100 mm	100 mm	n/a	$3.8 \times 10^{-6*}$	$6.9 \times 10^{-6*}$	$3.8 \times 10^{-6}$
> 100 mm	Full-bore	n/a			$3.1 \times 10^{-6}$
TOTAL		$8.7 \times 10^{-5}$	$9.1 \times 10^{-5}$	$9.2 \times 10^{-5}$	$9.2 \times 10^{-5}$

\* constitutes a full-bore rupture

**Table 57 Summary of valve external leak frequencies for actuated valves**

Hole Diameter		Leak Frequency (per valve year)			
Range	Nominal	<DN 80	DN 80	DN 80 < DN 150	> DN 150
< 10 mm	5 mm	$5.5 \times 10^{-4}$	$5.5 \times 10^{-4}$	$5.5 \times 10^{-4}$	$5.5 \times 10^{-4}$
10–50 mm	25 mm	$1.3 \times 10^{-4*}$	$1.7 \times 10^{-4}$	$1.3 \times 10^{-4}$	$1.3 \times 10^{-4}$
50 -100 mm	100 mm	n/a	$1.8 \times 10^{-5*}$	$3.1 \times 10^{-5*}$	$1.8 \times 10^{-5}$
> 100 mm	Full-bore	n/a			$1.3 \times 10^{-5}$
TOTAL		$6.7 \times 10^{-4}$	$6.9 \times 10^{-4}$	$7.0 \times 10^{-4}$	$7.0 \times 10^{-4}$

\* constitutes a full-bore rupture

The valve leak (Table 25 covers external leaks – most of the failure modes below are internal) frequency includes the valve body and control system but not the flanged connections to the piping.

The principal failure modes for valves are:

1. External leak
2. Internal leak (when closed)
3. Blockage
4. Failure to open
5. Failure to close
6. Spurious operation (i.e. without command)

In a QRA, any of these failure modes may be important, depending on the valve's function. The most important ones are typically:

- ▶ External leak for all valve types
- ▶ Failure to close for ESDV (internal)
- ▶ Failure to close for NRV (internal)
- ▶ Failure to close for EFV (internal - excess flow valve)
- ▶ Failure to open for PRV (external)
- ▶ Failure to open for BDV (external)

#### *Flexible Hose*

The operations involving flexible hosing onshore and offshore are considerably different, in terms of duration of operation and flows. For the purpose of onshore flexible hose release statistics the data employed is derived from leak frequencies from motor spirit road tankers during unloading, determined by ACDS (1991) based upon experience in Cheshire and Cleveland, UK, during 1987-88. Hole size distribution for flexible hoses is also provided in this data set. The risk for this operation is at least 10 times greater than for fixed hoses – these are constantly being connected and disconnected Table 59 shows the leak frequency for flexible hoses. Leak frequency is reported per operation.

**Table 59 Summary of flexible hose leak frequencies**

Hole Diameter		Leak Frequency (per operation)
Range	Nominal	
< 10 mm	5 mm	$9.0 \times 10^{-6}$
10–50 mm	25 mm	$9.0 \times 10^{-6}$
50 -100 mm	100 mm	n/a
> 100 mm	Full-bore	$1.8 \times 10^{-6}$ *
	TOTAL	$2.0 \times 10^{-5}$

\* Maximum hole size is 50 mm.

The leak frequencies considered here consider only the loading equipment itself, including quick release couplings, but not flanges or valves connecting it to other

equipment, e.g. transfer pumps – these are covered separately. Causes of the hose failures include mechanical damage during handling or storage of the hose, corrosion, surge pressure and incorrect material.

### *Centrifugal Pumps*

Pumps are devices to transfer liquids through pipes. Centrifugal pumps are the most common type of process pump. It uses an impeller, consisting of blades mounted on a shaft, rotating within a casing. The pump failure frequency does not include the flanges, which connect a pump to process piping, nor any valves (eg isolation, check) in the suction or discharge piping. These are considered separately.

The estimate of external leak frequencies from pumps is taken from HSE 2001 data. Table 61 below shows the leak frequency for centrifugal pumps. Frequency is reported per pump year; if pumps are not running continuously a correction to the tabulated frequency is made.

These are appropriate for both single-seal and double-seal pumps, in both liquid and liquefied gas service. The main causes of failures on centrifugal pumps are (Lees 1996 p 12/40):

- ▶ Bearing failure - typically due to misalignment, possibly resulting in seal failure.
- ▶ Gland/seal failure - a common cause of minor leaks.
- ▶ Maloperation damage, which may be due to:
- ▶ Cavitation - vaporisation of a liquid close to its boiling point within the pump, causing pitting and eventually serious damage to the impeller.
- ▶ Deadheading - pumping against a closed outlet, causing overpressure of the pump.
- ▶ Dry running - loss of supply to the pump, causing internal damage.
- ▶ Mechanical damage due to major internal failures may cause large leaks.

In most cases the leak occurs while the pump is in normal operation.

**Table 61 Summary of centrifugal pump leak frequencies**

Hole Diameter		Leak Frequency (per pump year)
Range	Nominal	
< 10 mm	5 mm	$4.8 \times 10^{-3}$
10–50 mm	25 mm	$7.2 \times 10^{-4}$
50 -100 mm	100 mm	n/a
> 100 mm	Full-bore	n/a
TOTAL		$2.0 \times 10^{-5}$

### *Centrifugal Compressors*

Compressors are devices to increase the pressure of gases. A centrifugal compressor is the most common type of compressor. It uses an impeller (or rotor), consisting of blades mounted on a shaft, rotating within a casing. It is suitable for general compression and refrigeration.

The leak frequencies tabulated cover failures in the compressor itself. A compressor is normally connected to pipes by flanges and valves (eg check, isolation); failure of these is not included. The principal failure modes for compressors are:

External leak through compressor casing or seals

*Internal explosion*

The estimate of external leak frequencies from centrifugal compressors is taken from HSE 2001 data. Table 63 below shows the leak frequency for centrifugal compressors. Frequency is reported per compressor year; if it is not running continuously a correction to the tabulated frequency is made.

**Table 63 Summary of centrifugal compressors leak frequencies**

Hole Diameter		Leak Frequency
Range	Nominal	(per compressor year)
< 10 mm	5 mm	$6.7 \times 10^{-3}$
10–50 mm	25 mm	$1.7 \times 10^{-3}$
50 -100 mm	100 mm	
> 100 mm	Full-bore	
	TOTAL	$8.4 \times 10^{-3}$

#### *Heat Exchange Equipment*

Heat exchangers are devices to transfer heat from one fluid to another. Shell and tube heat exchangers and fin fan coolers are only two of the many types of heat exchangers available.

- ▶ Shell and tube type - the most common type of heat exchanger. It contains one fluid in a bundle of small tubes, positioned inside an outer shell containing the second fluid.
- ▶ Fin-fan (or air-cooled) type- the fluid is held in a bank of tubes, cooled by air from an electric fan.

The boundary for failures of heat exchange equipment includes only failures in the heat exchanger itself, including failures of the shell, tubes and gaskets. A heat exchanger is normally connected to pipes by flanges, which are not included. The main failure mode of interest in a QRA is external leak of the process fluid. This can be the indirect result of other failure modes, such as blockage, coolant supply failure etc. The principal causes of external leaks from heat exchangers depend on the design, as follows:

1. Shell and tube type:
  - ▶ Leaks through the shell.
  - ▶ Rupture of tubes, causing failure of the shell due to overpressure. This may occur when there is high pressure gas in the tubes and low pressure liquid in the shell. Such heat exchangers have overpressure protection (PRV's), and this failure mode requires this to fail.
2. Fin-fan (or air-cooled) type. Leaks may occur in the headers or individual tubes. Being open, they are vulnerable to impacts.

The estimate of leak frequencies from heat exchangers is taken from HSE 2001 data. Table 65 gives leak frequencies for heat exchange equipment. The leak frequencies are quoted in units of per heat exchanger per year of operations. These values are appropriate for liquid and gas service.

**Table 65 Summary of heat exchange leak frequencies**

Hole Diameter		Leak Frequency (per heat exchanger per year)		
Range	Nominal	Shell & Tube, (h/c in shell)	Shell & Tube, (h/c in tube)	Fin Fan Cooler
< 10 mm	5 mm	$3.7 \times 10^{-3}$	$2.5 \times 10^{-3}$	$2.3 \times 10^{-3}$
10–50 mm	25 mm	$8.2 \times 10^{-4}$	$2.3 \times 10^{-4}$	n/a
50 -100 mm	100 mm	n/a	n/a	n/a
> 100 mm	Full-bore	n/a	n/a	n/a
	TOTAL	$4.5 \times 10^{-3}$	$2.7 \times 10^{-3}$	$2.3 \times 10^{-3}$

#### *Pressure Vessel*

The chosen source of leak frequencies for hydrocarbon process pressure vessels is the Smith and Warwick (1981) data. The event frequency for this type of release is considered sufficiently low to render the HSE 2001 data less suitable. The Smith & Warwick data is widely used because it includes a description of every event, allowing the data to be screened according to the requirements of the study. Screening has eliminated leaks from associated pipes, and allocated the data to size categories. Table 65 shows the leak frequency for vessels in units of per vessel per year.

**Table 67 Summary of pressure vessel leak frequencies**

Hole Diameter		Leak frequency
Range	Nominal	(per vessel per year)
< 10 mm	5 mm	$3.7 \times 10^{-5}$
10–50 mm	25 mm	$9.6 \times 10^{-5}$
50 -100 mm	100 mm	$9.7 \times 10^{-6}$
> 100 mm	Catastrophic	$6.5 \times 10^{-6}$
	TOTAL	$1.5 \times 10^{-4}$

20,000 pressure vessels were covered by the study giving a total of 310,000 vessel-years. Thus the overall screened leak frequency is  $1.5 \times 10^{-4}$  per vessel year. The table gives the size breakdown. The catastrophic failure frequency of  $6.5 \times 10^{-6}$  is based on only 2 events, and its 90% statistical confidence range extends from a factor of 3 higher to a factor of 5.5 lower.

Pressure vessels are process or storage vessels operating under pressure of at least 0.5 bar (according to the code it is lower than this and also depends on the volume). They include a wide variety of vessels, and the frequencies quoted in Table 67 have been used for pressure vessels, columns and process reactors. The definition of these equipment items is:

- ▶ Process reactors - vessels in which batch or continuous chemical reaction processes take place involving high temperature or pressure.
- ▶ Process vessels - vessels used for temporary storage of process fluids. These include:
  - ▶ Gas-liquid separators used in preliminary processing of fluid from hydrocarbon wells.
  - ▶ Knock-out drums used to remove liquids from compressor and flare systems.
  - ▶ Feed/surge drums used to even out fluctuations in the flow of process fluids.
  - ▶ Hydrocyclones used to remove hydrocarbons from water.
- ▶ Columns - tall vertical cylindrical process vessels used for distillation, absorption, stripping and extraction. These include fractionating columns used in crude oil refining, catalytic cracking and delayed coking processes (Perry & Green 1997 p13-90).

The leak frequencies include the pressure vessel itself and any equipment directly associated with it, i.e. nozzles and instrumentation (with associated flanges), and the inspection cover (man-way). Connection points are included up to the first flange, although the flange itself is not included. Any lines into and out of the vessel and the associated flanges and valves are not included in the leak frequency are included separately.

The principal failure modes for pressure vessels are:



- ▶ External leak (including rupture) through the vessel wall, welds or fittings
- ▶ Hot rupture due to fire impingement (e.g. boiling liquid and vapour cloud explosion (BLEVE))
- ▶ Rupture due to overpressure (in shell-type steam boilers)(PRV malfunction)

Causes of failure in pressure systems in general are discussed by Lees (1996 p12/80). The main causes of failures of pressure vessels are mechanical failures (typically due to operational overloads and fatigue), and corrosion, although many failures have elements of both. Many failures of process vessels and reactors are due to reactions specific to the fluid contents.

Smith (1986) reports that 93% of pressure vessel failures result from crack formation, and of these 71% occurred in the weld or heat-affected zone. Almost all cracked welds were at discontinuities or attachment welds. These are usually fillet welds, which before BS5500:1982 were exempt from code inspection requirements, which only specified examination of the main seam butt welds. Over 40% of cracks were traced to defects existing before the component went into service, and a further 32% were due to fatigue, which could also imply a pre-existing defect.

### Facility Parts Count

The parts count conducted on the project indicated that leaks could occur from the following equipment items, as shown in Table 71 and Table 73. The count was completed based on P&IDs from the Moura site and preliminary PFDs available at the time of the study.

**Table 71 Dyno Nobel Proposed Ammonium Nitrate Plant Parts Count**

Equipment / mm	HNO <sub>3</sub> - Feed	HNO <sub>3</sub> - EvapL	HNO <sub>3</sub> - EvapV	HNO <sub>3</sub> - React	HNO <sub>3</sub> - NOX	AN- Liquid	AN Vapour
Automatic Valve - 50 mm		1	1				
Automatic Valve - 75 mm	1					1	
Automatic Valve - 100 mm							1
Automatic Valve - 200 mm			2				2
Flange - 50 mm						1	
Flange - 200 mm							2
Flange - 600 mm				1	2	2	
Manual Valve - 50 mm	12	6	12	1	3	7	14.5
Manual Valve - 75 mm						2	
Manual Valve - 100 mm							0.5
Manual Valve - 200 mm			1				3
Pipe - 50 mm	1	8	2			100	30
Pipe - 75 mm	10		10			30	
Pipe - 100 mm	350					50	15
Pipe - 150 mm							20
Pipe - 200 mm			20				150
Pipe - 350 mm					4		
Pipe - 450 mm					12		
Pipe - 600 mm				10	5		
Pipe - 700 mm					10		
Heat Exchanger - Shell		2	1		1	2	
Heat Exchanger - Tube							2
Small Bore Fitting			10	2	4	6	6
Vessel - Smith/Weston	1		1	1	1.5	2	2

**Table 73 Dyno Nobel Proposed Ammonia Nitrate Plant Parts Count**

Equipment / mm	Natural Gas Inlet pipeline	Nat gas Drum thru Compressor	Saturator, Shift Converter, desaturator	PSA Unit, Methanator	Ammonia Compressor and Top half of Ammonia Converter	Converter Effluent Gas to Flash vessels	Recycle chiller, and sub-cooler	Liquid Ammonia Product Accumulator	Ammonia Storage Tank
AV-200		2	6	22	5	9	5	1	
COMP-C		1			3	3			
FLANGE025				44					
FLANGE040				12					
FLANGE075		2							
FLANGE100					12				
FLANGE200		2	14	56	10	22	12	2	
FLANGE250					2				
MV-025				22					
MV-040				6					
MV-075		1							

Equipment / mm	Natural Gas Inlet pipeline	Nat gas Drum thru Compressor	Saturator, Shift Converter, desaturator	PSA Unit, Methanator	Ammonia Compressor and Top half of Ammonia Converter	Converter Effluent Gas to Flash vessels	Recycle chiller, and sub-cooler	Liquid Ammonia Product Accumulator	Ammonia Storage Tank
MV-100					6				
MV-200			1	2		2	1		
MV-250					1				
PIPE025				20					
PIPE040				5					
PIPE075		5							
PIPE100	500				5				
PIPE200		20	40	60	25	10	20	15	20
PIPE250			40		10	20			
PIPE300			10			20			
PUMP-C			2					2	
S/T HX -T		1	9	5	2	7	3		
SMALLB		5	7	13	6	8	4	2	
VESSEL-SW		1	6	7	0.5	4.5		1	1

Release events modelled in the consequence analysis were first screened to eliminate those events not found to affect offsite populations. Releases from each of the major plant areas were then grouped into several simple categories for which frequency estimates were obtained.

Pinhole leaks (less than 10 mm in diameter), were estimated to occupy approximately 85% of the total failure probability distribution however were screened from the analysis at an earlier stage. Table 75, Table 77 and Table 79 presents the frequency groupings for the medium/large and rupture leaks for the Nitric Acid and Ammonium Nitrate Plants; Ammonia Plant; and the Ammonia Tank, respectively.

**Table 75 Grouped Release Frequencies for Nitric Acid and AN Plants**

Case ID	Base frequencies (per year)					Totals
	5 mm	25 mm	50 mm	100mm	Rupture	QRA
HNO3-Feed	0.00E+00	2.02E-03	0.00E+00	5.36E-04	0.00E+00	2.56E-03
HNO3-EvapL	0.00E+00	1.73E-03	0.00E+00	5.38E-04	0.00E+00	2.27E-03
HNO3-EvapV	0.00E+00	0.00E+00	8.77E-04	0.00E+00	1.51E-04	1.03E-03
HNO3-React	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
HNO3-NOX	0.00E+00	1.43E-03	0.00E+00	2.31E-04	3.25E-06	1.67E-03
AN- Liquid	0.00E+00	6.03E-03	0.00E+00	1.43E-03	0.00E+00	7.46E-03
AN Vapour	0.00E+00	0.00E+00	9.98E-04	0.00E+00	1.55E-03	2.55E-03
Total	0.00E+00	1.12E-02	1.88E-03	2.74E-03	1.71E-03	1.75E-02
	0%	64%	11%	16%	10%	100%

**Table 77 Grouped Release Frequencies for Ammonia Plant**

Case ID	Base frequencies (per year)			Totals
	25 mm	100mm	Rupture	QRA
Saturator, Shift Converter, desaturator	6.87E-03	1.23E-03	6.70E-04	8.77E-03
PSA Unit, Methanator	7.40E-03	2.14E-03	1.58E-04	9.70E-03
Ammonia Compressor and Converter	6.49E-03	1.34E-03	3.15E-04	8.15E-03
Converter Effluent Gas to Flash vessels	8.55E-03	1.72E-03	5.85E-04	1.09E-02
Liquid Ammonia Product Accumulator	1.85E-03	2.76E-04	1.13E-04	2.24E-03
TOTAL	3.12E-02	6.71E-03	1.84E-03	3.98E-02
	78%	17%	5%	100%

**Table 79 Ammonia Tank Release Frequencies for Ammonia Storage**

Case ID	Base frequencies (per tank year)		Totals
	300 mm	Rupture	QRA
Ammonia Tank	6.0E-05	5.0E-07	6.5E-05

#### *Leak Frequencies for Ammonia Tank Storage*

Frequencies for leak rates of a double walled refrigerated tanks were taken from “New Failure Rates for Land-use Planning QRA: Update” by Gould, J.H. and Glossop, M. (2000). The failure rates have been derived for large flat-bottomed refrigerated storage vessels that are cylindrical, constructed on site, and operated upright (vertically) and at atmospheric pressure. They have been derived from a number of studies. In these studies, no LNG vessel failures were recorded. This suggests that the failure values for vessels on LNG duty may well be lower than those given above. The failure rates were not intended to be applied to refrigerated liquefied oxygen vessels.

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## Appendix E

# Material Safety Data Sheets

MSDSs taken from various sources



# Material Safety Data Sheet

Date of Issue: July 2002



Not Classified as Hazardous according to criteria of Worksafe Australia

Note: This substance is classified Class 5.1 Dangerous Good  
® Registered Trade Mark of Dyno Nobel Asia Pacific Limited.

## COMPANY DETAILS

**Company Name** Dyno Nobel Asia Pacific Limited (ACN 003 269 010)  
**Address** Level 20, AGL Building,  
111 Pacific Highway,  
North Sydney NSW 2060  
**Emergency Telephone** 1800 098 836  
**Telephone/Fax** Ph: +61 2 9968 9000 Fax: +61 2 9964 0170

## IDENTIFICATION

**Product Name** Ammonium Nitrate  
**Ship. Name (CSN)** Ammonium Nitrate  
**Other Names** Nitropril  
Detaprill®  
**UN Number** 1942  
**DG Class** 5.1  
**Packaging Group** III  
**Hazchem Code** 1 [Y]  
**Product Use** Component of blasting explosives

## Physical Data

**Appearance** White prills, hygroscopic, odourless.  
**Melting Point** 155°C  
**Boiling Point** Decomposes @ 210°C  
**Vapour Pressure** Not applicable  
**Bulk Density** 0.70 – 0.85 g/cc  
**Flash Point** Not applicable  
**Flamm. Limit LEL** Not applicable  
**Flamm. Limit UEL** Not applicable  
**Solubility in Water** 366g/100g @ 35°C

## Other Properties

**pH Value** 5.4 (0.1M aq soln)  
**Solubility in Organic Solvent** Soluble in ethanol.  
**Form** Solid

### Other Information

Reactivity: Powerful oxidising agent. Will react with organic materials, reducing agents and metal powders. May explode under confinement and temperatures, but not readily detonated. When heated to decomposition (unconfined) produces nitrous oxide, white ammonium nitrate fumes and water. When mixed

with strong acids, and occasionally during blasting, produces irritating and toxic brown gas, mostly of nitrogen dioxide. When molten may decompose violently due to shock or pressure. Under certain conditions may react violently with nitrites, chlorates, chlorides or permanganates.

## Ingredients

Ingredient Name	CAS	Proportion
Ammonium nitrate	6484-52-2	100%

## HEALTH HAZARD INFORMATION

### Health Effects

Acute - Ingestion	Swallowing can result in nausea, vomiting, gastric irritation, headaches, dizziness and hypertension.
Acute - Eye	An eye irritant.
Acute - Skin	Contact with skin will result in mild irritation.
Acute - Inhalation	Inhalation of dust may result in respiratory irritation.
Chronic	No information available for product.
Other Information	No adverse health effects expected if the product is handled in accordance with this Safety Data Sheet and the product label.

## First Aid

Ingestion	Rinse mouth with water. Give water to drink. DO NOT induce vomiting. Seek immediate medical assistance.
Eye	Irrigate with copious quantities of water for 15 minutes. In all cases of eye contamination it is a sensible precaution to seek medical advice.
Skin	Wash contaminated skin with plenty of water. Remove contaminated clothing and wash before re-use. If irritation occurs seek medical advice.
Inhalation	Remove victim from exposure - avoid becoming a casualty. Seek medical advice if effects persist.

## Advice To Doctor

Advice to Doctor	<p><u>Clinical Findings:</u> The smooth muscle relaxant effect of ammonium nitrate may lead to headache, dizziness and marked hypotension.</p> <p>Cyanosis is clinically detectable when approximately 15% of the haemoglobin has been converted to methaemoglobin (ie. ferric iron). Symptoms such as headache, dizziness, weakness and dyspnoea occur when methaemoglobin concentrations are 30% to 40%; at levels of about 60% stupor, convulsions, coma, and respiratory paralysis occur and the blood is a chocolate brown colour. At higher levels death may result.</p> <p>Spectrophotometric analysis can determine the presence and concentration of methaemoglobin in blood.</p>
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## Other Health Hazard Information

## PRECAUTIONS FOR USE

<b>Other Exposure Info.</b>	No value assigned for this specific material by the National Occupational Health and Safety Commission (Worksafe Australia).
<b>Engineering Controls</b>	Avoid generating and inhaling dusts. Use in a well ventilated area. Keep containers closed when not in use.

## Personal Protection

<b>Respirator Type (AS 1716)</b>	If dust exists, wear respirator meeting the requirements of AS/NZS 1715 and AS/NZS 1716.
<b>Eye Protection</b>	Wear safety glasses.
<b>Glove Type</b>	Wear impervious gloves.
<b>Clothing</b>	Wear overalls.
<b>Protective Equip.</b>	Wear overalls, safety glasses and impervious gloves.
<b>Work/Hygienic Practices</b>	Always wash hands before smoking, eating, drinking or using the toilet. Wash contaminated clothing and other protective equipment before storing or re-using.
<b>Other Information</b>	Avoid eye contact and repeated or prolonged skin contact. Avoid generating and inhaling dusts.

## Flammability

<b>Fire Hazards</b>	Not combustible but is strong oxidising agent. Supports combustion. Increase intensity of a fire.
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## SAFE HANDLING INFORMATION

### Storage and Transport

<b>Storage Precautions</b>	Store in a cool, well ventilated area, away from sources of heat or ignition. Store away from combustible materials, reducing agents, metal powders, herbicides and fungicides. If using wooden pallets, these must be hardwood and periodically washed down with copious quantities of water to remove all traces of ammonium nitrate. Keep containers closed to prevent absorption of moisture from the atmosphere. Check regularly for spills.
<b>Transport</b>	Classified as a 5.1 (Oxidising Agent) Dangerous Substances for the purpose of transport. Refer to relevant regulations for storage and transport requirements.  Not to be loaded with explosives (Class 1), flammable gases (Class 2.1), poisonous gases (Class 2.3), flammable liquids (Class 3), flammable solids (Class 4.1), spontaneously combustible substances (Class 4.2), dangerous when wet substances (Class 4.3), organic peroxides (Class 5.2), poisonous substances (where the poisonous substances are fire risk substances) (Class 6), radioactive substances (Class 7), corrosives (Class 8), miscellaneous dangerous goods (Class 9), (where the miscellaneous dangerous goods are fire risk substances), fire risk substances other than dangerous goods, however exemptions may apply.
<b>Proper Shipping Name</b>	Ammonium Nitrate
<b>Package Group</b>	III

EPG Number 5.1.002  
IERG Number 31

### Spills and Disposal

**Spills and Leaks** Shut off all possible ignition sources. Clear area of all unprotected personnel. Wear protective equipment to prevent skin and eye contamination and inhalation of dust. Cover with damp absorbent inert materials, sand or soil. Sweep up, but avoid generating dust. Collect and seal in properly labelled drums or containers for disposal or re-use. Wash down area with excess water. Do not contaminate streams, rivers or water courses. The Australian Code for the Transport of Dangerous Goods by Road and Rail identifies this material as a pollutant to the environment. In the event of a spillage, notify the local environmental protection authority or emergency services.

**Disposal** Refer to State Land Waste Management Authority.

### Fire/Explosion Hazard

**Fire/Explos. Hazards** Strong oxidising agent. On its own is not combustible, however will support combustion. Decomposes on heating emitting irritating white fumes of nitrous oxide and ammonium nitrate mist. Brown fumes indicate the presence of toxic oxides of nitrogen.

On detection of fire the compartment(s) should be opened up to provide maximum ventilation. Fire fighters to wear self-contained breathing apparatus if risk of exposure to products to combustion/decomposition. Fires should be fought from a protected location.

Keep containers and adjacent areas cool with water spray. If safe to do so, remove containers from path of fire. A major fire may involve a risk of explosion in the event of contamination or strong confinement. An adjacent detonation may also involve the risk of explosion.

**Hazardous** Emits irritating white fumes of nitrous oxide and ammonium nitrate mist.

**Decomposition or By-products** Brown fumes indicate the presence of toxic oxides of nitrogen.

**Extinguishing Media** Water spray (large quantities).

**Hazchem Code** 1 [Y]

### OTHER INFORMATION

**Information on Ecological Effects** Ammonium Nitrate was evaluated at 5, 10, 25 and 50 mg (NH<sub>4</sub>)/L. The fertility of *Daphnia magna* was decreased at 50 mg/L. Post embryonic growth of crustacea was impaired at 10, 25 and 50 mg/L.

**Pkg. & Labelling** 40 hr LC<sub>50</sub> (*Aspergillus niger*) : 15 mg/L (36°C).  
Packaging group III.

### CONTACT POINT

**Contact** Dyno Nobel Asia Pacific Limited

Mt Thorley Technical Centre  
Telephone: +61 2 65 74 2500  
Fax: +61 2 65 74 6849

**DISCLAIMER:**

The information and suggestions above concern explosive products which should only be dealt with by persons having appropriate technical skills, training and licences. The results depend to a large degree on the conditions under which the products are stored, transported and used.

While Dyno Nobel Asia Pacific makes every effort to ensure the details contained in the data sheet are as current and accurate as possible the conditions under which its products are used are not within Dyno Nobel Asia Pacific Limited's control. Each user is responsible for being aware of the details in the data sheet and the product applications in the specific context of the intended use.

Buyers and users assume all risk, responsibility and liability arising from the use of this product and the information in this data sheet. Dyno Nobel Asia Pacific Limited is not responsible for damages of any nature resulting from the use of its products or reliance upon the information. Dyno Nobel Asia Pacific Limited makes no express or implied warranties other than those implied mandatory by Commonwealth, State or Territory legislation.

**...END OF REPORT...**

# Material Safety Data Sheet

Page: 1 of 8

Infosafe No. LPSA2 Issue Date : April 2004 ISSUED by DYNONOB

Product Name : **TITAN 2000 EMULSION**

Not classified as hazardous according to criteria of NOHSC

## 1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND COMPANY/UNDERTAKING

**Product Name** TITAN 2000 EMULSION  
**Company Name** Dyno Nobel Asia Pacific Limited  
**Address** Level 20, AGL Building 111 Pacific Highway North Sydney  
NSW 2060  
**Emergency Tel.** 1800 098 836  
**Telephone Number/Fax** Tel: +61 2 9968 9000 Fax: +61 2 9964 0170

## 2. HAZARDS IDENTIFICATION

Ingredients	Name	CAS	Proportion
	Ammonium Nitrate	6484-52-2	60-100 %
	Water	7732-18-5	10-30 %
	Oils and other oxygen negative materials		0-10 %
	EMULSIFIER		0-10 %
	Inorganic oxidisers		0-10 %
	Ingredients determined not to be hazardous.		0-10 %

## 3. COMPOSITION/INFORMATION ON INGREDIENTS

### Hazards Identification

**Other Information** This material is classified as a Class 5.1 Dangerous Good according to the Australian Code for the Transport of Dangerous Goods.  
Severe overexposure may interfere with the ability of the blood to carry oxygen (methemoglobinemia). This can cause headache, weakness, to have dizziness and a blue color to the skin and lips. Higher levels may cause trouble in breathing, collapse and even death.

## 4. FIRST AID MEASURES

**Inhalation** Remove victim from exposure - avoid becoming a casualty. Remove contaminated clothing and loosen remaining clothing. Allow patient to assume most comfortable position and keep warm. Keep at rest until fully recovered. If patient finds breathing difficult and develops a bluish discolouration of the skin (which suggests a lack of oxygen in the blood - cyanosis), ensure airways are clear of any obstruction and have qualified person give oxygen through a face mask. Apply artificial respiration if patient is not breathing. In event of cardiac arrest, apply external cardiac massage. Seek immediate medical advice.

**Ingestion** Do NOT induce vomiting. Wash out mouth with water. Do not give anything by mouth to an unconscious person. Where vomiting occurs naturally have victim place head below hip level in order to reduce risk of aspiration. Seek immediate medical attention. For advice, contact a Poisons Information Centre 131 126 or a doctor (at once).

**Skin** If skin or hair contact occurs, remove contaminated clothing and flush skin and hair with soap and running water until all oils and oxidiser (ammonium nitrate) are removed. Remove contaminated clothing immediately. Wash contaminated clothing before re-use. If irritation occurs seek medical advice.

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# Material Safety Data Sheet

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Infosafe No. LPSA2 Issue Date : April 2004 ISSUED by DYNONOB

Product Name : **TITAN 2000 EMULSION**

Not classified as hazardous according to criteria of NOHSC

<b>Eye</b>	If in eyes, hold eyelids apart and flush the eye continuously with running water. Take care not to rinse contaminated water into the non-affected eye. Continue flushing until advised to stop by the Poisons Information Centre or a doctor, or for at least 15 minutes. Remove clothing if contaminated and wash skin. Seek immediate medical assistance.
<b>First Aid Facilities</b>	Eye wash and normal washroom facilities.
<b>Advice to Doctor</b>	<p>Treat symptomatically. May cause methaemoglobinemia. Clinical effects: The smooth muscle relaxant effects of nitrate salts may lead to headache, dizziness and marked hypotension. Cyanosis is clinically detectable when approximately 15% of the haemoglobin has been converted to methaemoglobin (ie. ferric iron). Symptoms such as headache, dizziness, weakness and dyspnoea occur when methaemoglobin concentrations are 30% to 40%; at levels of about 60%, stupor, convulsions, coma and respiratory paralysis occur and the blood is chocolate brown in colour. At higher levels death may result. Spectrophotometric analysis can determine the presence and concentration of methaemoglobin in blood.</p> <p>Treatment:</p> <ol style="list-style-type: none"><li>1. Give 100% oxygen.</li><li>2. In cases of (a) ingestion: use gastric lavage, (b) contamination of skin (unburnt or burnt): continue washing to remove salts.</li><li>3. Observe blood pressure and treat hypotension if necessary.</li><li>4. When methaemoglobin concentrations exceed 40% or when symptoms are present, give methylene blue 1 to 2 mg/kg body weight in a 1% solution by slow intravenous injection. If cyanosis has not resolved within one hour a second dose of 2 mg/kg body weight may be given. The total dose should not exceed 7 mg/kg body weight as unwanted effects such as dyspnoea, chest pain, vomiting, diarrhoea, mental confusion and cyanosis may occur. Without treatment methaemoglobin levels of 20-30% revert to normal within 3 days.</li><li>5. Bed rest is required for methaemoglobin levels in excess of 40%.</li><li>6. Continue to monitor and give oxygen for at least two hours after treatment with methylene blue.</li><li>7. Consider transfer to centre where haemoperfusion can be performed to remove the nitrates from the blood if the condition of the patient is unstable.</li><li>8. Following inhalation of oxides of nitrogen the patient should be observed in hospital for 24 hours for delayed onset of pulmonary oedema.</li></ol> <p>Further observation for 2-3 weeks may be required to detect the onset of inflammatory changes of bronchiolitis fibrosa obliterans.</p>

## 5. FIRE FIGHTING MEASURES

<b>Specific Hazards</b>	<p>Not known to be a fire or explosion hazard under normal conditions of use. Will explode if suitably primed. Avoid extreme conditions of heat or shock. If the product ignites then mass cooling by heavy dousing with water should effectively extinguish small fires.</p> <p>DO NOT FIGHT LARGE FIRES. If a fire becomes established immediately isolate area and evacuate personnel to a safe distance. Toxic fumes may be generated as the product decomposes.</p>
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## 6. ACCIDENTAL RELEASE MEASURES

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# Material Safety Data Sheet

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Product Name : **TITAN 2000 EMULSION**

Not classified as hazardous according to criteria of NOHSC

**Other Information** Shut off all possible ignition sources. Contain the source and spread of the spill and ensure that the material does not enter any waterways or drains. Small spills should be scooped up and placed in clean, approved containers which are then labelled and sealed. Where possible, all residues should be scraped up for disposal and an inert absorbent material such as sand or vermiculite spread over the area. For large spills, collect as much of the material as possible and place in clean, approved containers which are then labelled and sealed. Contaminated bulk product recovered from a spill should be passed through a 10mm screen before pumping. The screened material should only then be pumped using a double diaphragm positive displacement pump. Surplus or defective explosives must not be placed in any waterway, buried, thrown away, discarded or placed with rubbish.

## 7. HANDLING AND STORAGE

**Storage** Store material in a cool, well ventilated store suitably licensed for Class 5.1 Oxidising liquids. Store in accordance with Local, State and Federal Regulations and the National Fire Protection Association regulations. Store away from heat, naked flames or sparks. Do not store or consume food, drink or tobacco in areas where they may become contaminated with this material. Ammonium Nitrate is incompatible with, and must be stored away from, tetranitromethane, dichloroisocyanuric acid, trichloroisocyanuric acid, any bromate, chlorate, chlorite, hypochlorite or chloroisocyanurate or any inorganic nitrite.

## 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

**Other Exposure Information** None established for product. During preparation of this material, ammonium nitrate dust - nuisance dust  
TLV (TWA) 10 mg/m<sup>3</sup> total (NOHSC)  
mineral oil mist -  
TLV (TWA) 5 mg/m<sup>3</sup> (NOHSC)  
As a result of detonation of this product, oxides of nitrogen or carbon fumes may be liberated. Nitrogen oxides are skin, eye and respiratory system irritants. Systematic toxicity resulting from oxidation of lung tissue and bronchopneumonia. Acute exposure can lead to death from asphyxia or pulmonary oedema. In animals, nitrogen oxide caused methemoglobinemia, was not carcinogenic, but caused embryotoxicity and reproductive effects. Carbon dioxide is a colourless, odourless gas. It is a simple asphyxiant, attacking the lungs, skin and cardiovascular system. Concentrations of 5% may produce shortness of breath and headache and concentrations of 10% can produce unconsciousness and death from oxygen deficiency. Adequate ventilation will provide sufficient protection from any carbon dioxide accumulations. Carbon monoxide is a colourless, odourless, tasteless gas which, when inhaled, combines with haemoglobin to form carboxyhaemoglobin which interferes with the oxygen-carrying capacity of blood. Symptoms include headache, dizziness, drowsiness, nausea, vomiting, collapse, coma and death. Carbon monoxide attacks the central nervous system, lungs, blood and cardiovascular system. Do not enter any area where accumulations of these gases are suspected without appropriate breathing apparatus.

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Product Name : **TITAN 2000 EMULSION**

Not classified as hazardous according to criteria of NOHSC

<b>Respiratory Protection</b>	If engineering controls are not effective in controlling airborne exposure then suitable respiratory protective equipment should be used. Reference should be made to Australian Standards AS/NZS 1715, Selection, Use and maintenance of Respiratory Protective Devices; and AS/NZS 1716, Respiratory Protective Devices. Final choice of appropriate respiratory protection will vary according to individual circumstances. This can include methods of handling, and engineering controls as determined by appropriate risk assessments.
<b>Eye Protection</b>	Safety glasses with side shields or goggles should be worn as described in Australian Standard AS/NZS 1337 - Eye Protectors for Industrial Applications. Final choice of appropriate eye/face protection will vary according to individual circumstances. This can include methods of handling, and engineering controls as determined by appropriate risk assessments.
<b>Hand Protection</b>	Wear gloves of impervious material such as NEOPRENE, conforming to AS/NZS 2161: Occupational protective gloves - Selection, use and maintenance. Final choice of appropriate glove type will vary according to individual circumstances. This can include methods of handling, and engineering controls as determined by appropriate risk assessments.
<b>Body Protection</b>	Suitable workwear should be worn to protect personal clothing, eg cotton overalls buttoned at neck and wrist. When large quantities are handled the use of plastic aprons and rubber boots is recommended.
<b>Eng. Controls</b>	Use in a well ventilated area.
<b>Hygiene Measures</b>	Ensure a high level of personal hygiene is maintained when using this product. Always wash hands before eating, drinking, smoking or using the toilet.

## 9. PHYSICAL AND CHEMICAL PROPERTIES

<b>Appearance</b>	Translucent golden emulsion, oily to touch.
<b>Melting Point</b>	Not applicable
<b>Boiling Point</b>	Not applicable
<b>Solubility in Water</b>	Insoluble but dispersible with water jets.
<b>Specific Gravity (H2O=1)</b>	1.36 - 1.40 g/cm <sup>3</sup>
<b>Vapour Pressure</b>	Not applicable
<b>Flash Point</b>	Not applicable
<b>Flammability</b>	Combustible. Eliminate all ignition sources.
<b>Flammable Limits LEL</b>	Not applicable

## 10. STABILITY AND REACTIVITY

## 11. TOXICOLOGICAL INFORMATION

<b>Toxicology Information</b>	No toxicity data is available for this specific product, however toxicity data found for constituents are stated below: For AMMONIUM NITRATE: Oral LD50 (rat): 2217 mg/kg. (Reference: RTECS).
<b>Inhalation</b>	Inhalation of mists or spray may irritate the nose, throat and respiratory system. May cause dizziness.
<b>Ingestion</b>	Ingestion of large amounts may cause cyanosis, nausea, collapse, vomiting, abdominal pain, rapid heartbeat and breathing, coma, convulsions and death may occur.
<b>Skin</b>	May irritate skin resulting in redness, itching and dermatitis. This product contains a substance (ammonium nitrate) which may be absorbed through intact skin with resultant toxic effects.

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Infosafe No.	LPSA2	Issue Date : April 2004	ISSUED by DYNONOB
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Product Name : **TITAN 2000 EMULSION**

Not classified as hazardous according to criteria of NOHSC

<b>Eye</b>	May irritate eyes. On eye contact this product may cause tearing, stinging, blurred vision, and redness.
<b>Chronic Effects</b>	Repeated or prolonged exposure may cause irritant contact dermatitis. Overexposure can cause nausea and vomiting, headache and collapse.

## 12. ECOLOGICAL INFORMATION

<b>Environ. Protection</b>	Avoid contaminating waterways.
<b>Mobility</b>	Not available
<b>Persistence / Degradability</b>	Not available
<b>Bioaccumulation</b>	Not available
<b>Ecotoxicity</b>	No ecotoxicity data is available for this specific product, however toxicity data for constituents are stated below: For Ammonium Nitrate: Ammonium Nitrate was evaluated at 5, 10, 25 and 50mg (NH <sub>4</sub> )/L. The fertility of Daphnia magna was decreased at 50 mg/L. Post embryonic growth of crustacea was impaired at 10, 25 and 50 mg/L. 40 hr LC50 (Aspergillus niger): 15 mg/L (36°C).

## 13. DISPOSAL CONSIDERATIONS

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# Material Safety Data Sheet

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Infosafe No. LPSA2 Issue Date : April 2004 ISSUED by DYNONOB

Product Name : **TITAN 2000 EMULSION**

Not classified as hazardous according to criteria of NOHSC

## DISPOSAL:

Destruction of explosives must be carried out by suitably qualified personnel. If necessary, the relevant statutory authorities must be notified. In all circumstances, detonation is the preferred method of disposal.

## DETONATION:

The explosives to be destroyed must be placed in direct contact with fresh priming charge in a hole which is at least 0.6 m deep and then adequately stemmed. No detonators are to be inserted into defective explosives. Personnel must be evacuated to a safe distance in accordance with relevant local regulations prior to initiation of the charge.

NOTE: Detonations in loose or stony ground may be expected to cause fly rock.

## BURNING:

Burning may result in the detonation of explosives. Burning explosives produces toxic fumes eg. oxides of nitrogen and carbon.

Make a sawdust bed or trail adequate for the quantity of explosives to be burned approximately 250mm wide and 25mm deep, upon which the explosive will be laid. If sawdust is not available, newspaper may be used. Normal precautions should be taken against the spread of fire.

Individual trails should not be closer together than 600mm and should contain not more than 12kg of explosive.

Trails should be side-by-side, not in a line, and not more than four should be set up at one time.

Remove any explosive that is not to be burnt to a distance of at least 300m.

Sufficient diesel oil (never petrol or other highly flammable liquid) should be used to thoroughly wet the sawdust (or paper). At least 4L per trail is recommended.

Light the trail from a long rolled paper 'wick' which should be placed downwind and in contact with the 1m of trail which is not covered with explosive.

The wind should blow so that the flame from the wick (and later from the burning explosives) will blow away from the unburned explosives as detonation is more likely to occur if the explosives are preheated by the flame.

If plastic igniter cord (slow) is available, its use for lighting is recommended instead of paper. One end should be coiled into or under the paper and the other end lit from a minimum distance of 7m from the trail. Retire to at least 300m or to a safe place.

Do not return to the site for at least 30 min after the burning has apparently finished.

If the fire goes out do not approach for at least 15 minutes after all traces of fire has gone. Do not add more diesel oil unless certain that the flame is completely extinguished.

## 14. TRANSPORT INFORMATION

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Infosafe No. LPSA2 Issue Date : April 2004 ISSUED by DYNONOB

Product Name : **TITAN 2000 EMULSION**

Not classified as hazardous according to criteria of NOHSC

Road and Rail Transport:

UN-No : 3375

Class : 5.1

Hazchem code : 1[Y]E

Packing group : Packing Group II

Proper Shipping Name: AMMONIUM NITRATE EMULSION, intermediate for blasting explosives, liquid.

This material is classified as a Class 5.1 Dangerous Good according to the Australian Code for the Transport of Dangerous Goods.

Class 5.1 oxidising agents are incompatible in a placard load with any of the following:

- Explosives (class 1), Flammable Gases (class 2.1),
- Toxic Gases (class 2.3), Flammable Liquids (class 3),
- Flammable Solids (4.1),
- Spontaneously Combustible Substances (class 4.2),
- Dangerous When Wet Substances (class 4.3),
- Organic Peroxides (class 5.2),
- Toxic Substances (class 6)(where the toxic substances are fire risk substances),
- Radioactive Substances (class 7),
- Corrosive Substances (class 8),
- Miscellaneous Dangerous Goods (class 9)(where the miscellaneous dangerous goods are fire risk substances), and fire risk substances other than dangerous goods.

U.N. Number 3375

EPG Number 5A1

IERG Number 31

## 15. REGULATORY INFORMATION

### Risk Phrase

### Safety Phrase

S17 Keep away from combustible material.  
S2 Keep out of reach of children.  
S24/25 Avoid contact with skin and eyes.  
S26 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.  
S35 This material and its container must be disposed of in a safe way.  
S37/39 Wear suitable gloves and eye/face protection.

Poisons Schedule Not Scheduled

## 16. OTHER INFORMATION

**DYNO**  
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# Material Safety Data Sheet

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Infosafe No.	LPSA2	Issue Date : April 2004	ISSUED by DYNONOB
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Product Name : **TITAN 2000 EMULSION**

Not classified as hazardous according to criteria of NOHSC

**Contact Person/Point** Mt Thorley Technical Centre  
Telephone: (02) 6574 2500  
Fax: (02) 6574 6849  
DISCLAIMER: The information and suggestions above concern explosive products which should only be dealt with by persons having appropriate technical skills, training and licences. The results depend to a large degree on the conditions under which the products are stored, transported and used.  
While Dyno Nobel Asia Pacific makes every effort to ensure the details contained in the data sheet are as current and accurate as possible the conditions under which its products are used are not within Dyno Nobel Asia Pacific Limited's control. Each user is responsible for being aware of the details in the data sheet and the product applications in the specific context of the intended use. Buyers and users assume all risk, responsibility and liability arising from the use of this product and the information in this data sheet. Dyno Nobel Asia Pacific Limited is not responsible for damages of any nature resulting from the use of its products or reliance upon the information. Dyno Nobel Asia Pacific Limited makes no express or implied warranties other than those implied mandatory by Commonwealth, State or Territory legislation.

**SDS History** SDS created: April 2004.  
...End Of MSDS...

**DYNO**  
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Groundbreaking Performance

AMMONIA (ANHYDROUS)			ICSC: 0414
Date of Peer Review: March 1998 (cylinder)			
CAS #	7664-41-7	NH <sub>3</sub>	
RTECS #	BO0875000	Molecular mass: 17.03	
UN #	1005		
EC Index #	007-001-00-5		
TYPES OF HAZARD / EXPOSURE	ACUTE HAZARDS / SYMPTOMS	PREVENTION	FIRST AID / FIRE FIGHTING
FIRE	Flammable.	NO open flames, NO sparks, and NO smoking.	In case of fire in the surroundings: use appropriate extinguishing media.
EXPLOSION	Gas/air mixtures are explosive.	Closed system, ventilation, explosion-proof electrical equipment and lighting.	In case of fire: keep cylinder cool by spraying with water.
EXPOSURE		AVOID ALL CONTACT!	
Inhalation	Burning sensation. Cough. Laboured breathing. Shortness of breath. Sore throat. Symptoms may be delayed (see Notes).	Ventilation, local exhaust, or breathing protection.	Fresh air, rest. Half-upright position. Artificial respiration may be needed. Refer for medical attention.
Skin	Redness. Skin burns. Pain. Blisters. ON CONTACT WITH LIQUID: FROSTBITE.	Cold-insulating gloves. Protective clothing.	ON FROSTBITE: rinse with plenty of water, do NOT remove clothes. Refer for medical attention.
Eyes	Redness. Pain. Severe deep burns.	Face shield or eye protection in combination with breathing protection.	First rinse with plenty of water for several minutes (remove contact lenses if easily possible), then take to a doctor.
Ingestion			
SPILLAGE DISPOSAL		PACKAGING & LABELLING	
Evacuate danger area! Consult an expert! Ventilation. NEVER direct water jet on liquid. Remove gas with fine water spray. Personal protection: gas-tight chemical protection suit including self-contained breathing apparatus.		<b>EU Classification</b> Symbol: <u>T</u> , <u>N</u> R: <u>10-23-34-50</u> S: <u>(1/2-)-9-16-26-36/37/39-45-61</u> <b>UN Classification</b> UN Hazard Class: 2.3 UN Subsidiary Risks: 8	
EMERGENCY RESPONSE		STORAGE	
Transport Emergency Card: TEC (R)-20S1005 or		Fireproof. Separated from oxidants, acids, halogens.	

20G2TC  
NFPA Code: H3; F1; R0;

Cool. Keep in a well-ventilated room.

**IPCS**  
International  
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BACK**

AMMONIA (ANHYDROUS)		ICSC: 0414
IMPORTANT DATA		
<b>PHYSICAL STATE; APPEARANCE:</b> COLOURLESS COMPRESSED LIQUEFIED GAS, WITH PUNGENT ODOUR.	<b>ROUTES OF EXPOSURE:</b> The substance can be absorbed into the body by inhalation.	
<b>PHYSICAL DANGERS:</b> The gas is lighter than air.	<b>INHALATION RISK:</b> A harmful concentration of this gas in the air will be reached very quickly on loss of containment.	
<b>CHEMICAL DANGERS:</b> Shock-sensitive compounds are formed with mercury, silver and gold oxides. The substance is a strong base, it reacts violently with acid and is corrosive. Reacts violently with strong oxidants and halogens. Attacks copper, aluminum, zinc and their alloys. Dissolves in water evolving heat.	<b>EFFECTS OF SHORT-TERM EXPOSURE:</b> The substance is corrosive to the eyes, the skin and the respiratory tract. Inhalation of high concentrations may cause lung oedema (see Notes). Rapid evaporation of the liquid may cause frostbite.	
<b>OCCUPATIONAL EXPOSURE LIMITS:</b> TLV: 25 ppm as TWA; 35 ppm as STEL; (ACGIH 2004). MAK: 20 ppm, 14 mg/m³; Peak limitation category: I (2); Pregnancy risk group: C; (DFG 2004).		
PHYSICAL PROPERTIES		
Boiling point: -33°C Melting point: -78°C Relative density (water = 1): 0.7 at -33°C Solubility in water, g/100 ml at 20°C: 54 Vapour pressure, kPa at 26°C: 1013 Relative vapour density (air = 1): 0.59	Auto-ignition temperature: 651°C Explosive limits, vol% in air: 15-28	
ENVIRONMENTAL DATA		
The substance is very toxic to aquatic organisms.		
NOTES		
The symptoms of lung oedema often do not become manifest until a few hours have passed and they are aggravated by physical effort. Rest and medical observation is therefore essential. Immediate administration of an appropriate inhalation therapy by a doctor or a person authorized by him/her, should be considered. Turn leaking cylinder with the leak up to prevent escape of gas in liquid state. Card has been partly updated in October 2005. See sections Occupational Exposure Limits, Emergency Response.		
ADDITIONAL INFORMATION		
<b>LEGAL NOTICE</b>	Neither the CEC nor the IPCS nor any person acting on behalf of the CEC or the IPCS is responsible for the use which might be made of this information	
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See Also:

[Ammonia \(EHC 54, 1986\)](#)[Ammonia, anhydrous \(CHEMINFO\)](#)



# Safety (MSDS) data for diesel

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## General

Synonyms: diesel fuel, diesel oil

Molecular formula: depends upon formulation, typically composed of a hydrocarbon mix together with (often proprietary) additives. May contain a dye to indicate, for example, whether or not excise duty has been paid on the product.

CAS No: 68334-30-5

EC No:

## Physical data

Appearance: clear colourless or dyed liquid

Melting point:

Boiling point: typically > 149 C

Vapour density:

Vapour pressure: at 20 C typically < 1 mm

Specific gravity:

Flash point: typically > 52 C

Explosion limits:

Autoignition temperature:

## Stability

Stable. Flammable. Incompatible with strong acids, strong oxidizing agents, halogens.

## Toxicology

Respiratory and skin irritant. The product may contain polycyclic aromatic hydrocarbons which may be carcinogenic. Generally regarded as being of low toxicity unless contact is repeated and/or prolonged.

### Toxicity data

(The meaning of any abbreviations which appear in this section is given [here.](#))

ORL-RAT LD50 >2000 mg kg<sup>-1</sup>

### Risk phrases

(The meaning of any risk phrases which appear in this section is given [here.](#))

R10.

## Personal protection

Avoid skin contact and inhalation. Ensure good ventilation.

[Return to [Physical & Theoretical Chemistry Lab. Safety home page.](#)]






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This information was last updated on April 5, 2005. We have tried to make it as accurate and useful as possible, but can take no responsibility for its use, misuse, or accuracy. We have not verified this information, and cannot guarantee that it is up-to-date.

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# IPCSINTOX Databank

NITRIC ACID		ICSC: 0183	
Date of Peer Review: April 1994			
Concentrated Nitric Acid (70%)			
CAS #	7697-37-2	HNO <sub>3</sub>	
RTECS #	QU5775000	Molecular mass: 63.0	
UN #	2031		
EC #	007-004-00-1		
TYPES OF HAZARD / EXPOSURE	ACUTE HAZARDS / SYMPTOMS	PREVENTION	FIRST AID / FIRE FIGHTING
FIRE	Not combustible but enhances combustion of other substances. Gives off irritating or toxic fumes (or gases) in a fire.	NO contact with flammable substances. NO contact with combustibles or organic chemicals.	In case of fire in the surroundings: NO foam.
EXPLOSION	Risk of fire and explosion on contact with many common organic compounds.		In case of fire: keep drums, etc., cool by spraying with water.
EXPOSURE		AVOID ALL CONTACT!	
Inhalation	Burning sensation. Cough. Laboured breathing. Unconsciousness. Symptoms may be delayed (see Notes).	Ventilation, local exhaust, or breathing protection.	Fresh air, rest. Half-upright position. Artificial respiration may be needed. Refer for medical attention.
Skin	Corrosive. Serious skin burns. Pain. Yellow discolouration.	Protective clothing.	Remove contaminated clothes. Rinse skin with plenty of water or shower. Refer for medical attention.
Eyes	Corrosive. Redness. Pain. Severe deep burns.	Face shield or eye protection in combination with breathing protection.	First rinse with plenty of water for several minutes (remove contact lenses if easily possible), then take to a doctor.
Ingestion	Corrosive. Abdominal pain. Burning sensation. Shock.	Do not eat, drink, or smoke during work. Wash hands before eating.	Do NOT induce vomiting. Give plenty of water to drink. Rest. Refer for medical attention.
SPILLAGE DISPOSAL		PACKAGING & LABELLING	
Evacuate danger area! Consult an expert! Ventilation. Collect leaking liquid in sealable containers. Cautiously neutralize remainder with sodium carbonate. Then wash away with plenty of water. Do NOT absorb in saw-dust or other combustible absorbents. Personal protection:		Unbreakable packaging; put breakable packaging into closed unbreakable container. Do not transport with food and feedstuffs. EU Classification Symbol: <u>O</u> , <u>C</u> R: <u>8-35</u>	

complete protective clothing including self-contained breathing apparatus.	S: (1/2-)-23-26-36-45 Note: [B] <b>UN Classification</b> UN Hazard Class: 8 UN Pack Group: II
<b>EMERGENCY RESPONSE</b>	<b>SAFE STORAGE</b>
Transport Emergency Card: TEC (R)-80S2031-II or 80GO1-I NFPA Code: H 3; F 0; R 0; OX	Separated from combustible and reducing substances, bases, food and feedstuffs, organic chemicals. Cool. Dry. Keep in a well-ventilated room.
<div>      </div> <p>Prepared in the context of cooperation between the International Programme on Chemical Safety and the Commission of the European Communities © IPCS, CEC 2004</p> <p><b>SEE IMPORTANT INFORMATION ON BACK</b></p>	

NITRIC ACID		ICSC: 0183
IMPORTANT DATA		
<b>PHYSICAL STATE; APPEARANCE:</b> COLOURLESS TO YELLOW LIQUID, WITH PUNGENT ODOUR.  <b>CHEMICAL DANGERS:</b> The substance decomposes on warming producing nitrogen oxides. The substance is a strong oxidant and reacts violently with combustible and reducing materials, e.g., turpentine, charcoal, alcohol. The substance is a strong acid, it reacts violently with bases and is corrosive to metals. Reacts very violently with organic chemicals (e.g., acetone, acetic acid, acetic anhydride), causing fire and explosion hazard. Attacks some plastics.  <b>OCCUPATIONAL EXPOSURE LIMITS:</b> TLV: 2 ppm as TWA, 4 ppm as STEL; (ACGIH 2004). MAK: 2 ppm, 5.2 mg/m <sup>3</sup> ; Peak limitation category: I (1); Pregnancy risk group: IIc; (DFG 2004).		<b>ROUTES OF EXPOSURE:</b> The substance can be absorbed into the body by inhalation of its vapour and by ingestion.  <b>INHALATION RISK:</b> A harmful contamination of the air can be reached very quickly on evaporation of this substance at 20° C.  <b>EFFECTS OF SHORT-TERM EXPOSURE:</b> The substance is very corrosive to the eyes, the skin and the respiratory tract. Corrosive on ingestion as well. Inhalation of vapour may cause lung oedema (see Notes).
PHYSICAL PROPERTIES		
Boiling point: 121°C Melting point: -41.6°C Relative density (water = 1): 1.4 Solubility in water: miscible Vapour pressure, kPa at 20°C: 6.4 Relative vapour density (air = 1): 2.2		Relative density of the vapour/air-mixture at 20°C (air = 1): 1.07
ENVIRONMENTAL DATA		
NOTES		

Depending on the degree of exposure, periodic medical examination is suggested. The symptoms of lung oedema often do not become manifest until a few hours have passed and they are aggravated by physical effort. Rest and medical observation are therefore essential. Rinse contaminated clothes (fire hazard) with plenty of water. Other UN 2031 classification with more than 70% nitric acid, hazard class 8, subsidiary hazard 5.1, packing group I.

Card has been partly updated in April 2005. See sections Occupational Exposure Limits, Emergency Response, Notes.

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See Also:

[Nitric acid \(CHEMINFO\)](#)

# Safety (MSDS) data for nitrogen dioxide



## General

Synonyms: dinitrogen tetroxide, nitrogen peroxide, nitrito  
Molecular formula:  $\text{NO}_2$  or  $\text{N}_2\text{O}_4$  (exists as an equilibrium mixture of monomer and dimer at room temperature)  
CAS No: 10102-44-0  
EC No: 233-272-6  
EC Index No: 007-002-00-0

## Physical data

Appearance: reddish brown gas, or yellow-brown liquid, with a pungent odour. Generally stored as a gas or liquid under pressure.  
Melting point:  $-11.2\text{ }^{\circ}\text{C}$   
Boiling point:  $21.1\text{ }^{\circ}\text{C}$   
Vapour density: 3.3 g/l at  $20^{\circ}\text{C}$ , 1 atm.  
Vapour pressure: 1013 hPa  
Critical temperature:  $158\text{ }^{\circ}\text{C}$   
Specific gravity:  
Flash point:  
Explosion limits:  
Autoignition temperature:

## Stability

Stable. Incompatible with nonferrous metals, hydrocarbons, fuels. Oxidizer, so supports combustion.

## Toxicology

Highly toxic by inhalation. Inhalation may be fatal. Corrosive - causes burns. Severe respiratory irritant. Typical PEL 5 ppm. Contact with liquid causes severe eye damage - contact lenses should not be worn if you may be exposed to nitrogen dioxide.

### Toxicity data

(The meaning of any abbreviations which appear in this section is given [here.](#))

ILH-RAT LC50 88 ppm/4h

IHL-GPG LC50 30 ppm/1h

IHL-HMN LCLO 200 ppm/1h

IHL-MUS LC50 1000 ppm/10m

### Risk phrases

(The meaning of any risk phrases which appear in this section is given [here.](#))

R26 R27 R28 R29 R30 R31 R32 R33 R34.

## Transport information

(The meaning of any UN hazard codes which appear in this section is given [here.](#))

UN No 1067. Major hazard class 2.3. Subsidiary hazard classes 5.1, 8.0.

Transport category 1. Not permitted for air freight.

## Personal protection

Safety glasses and good ventilation. Use in a fume hood.

### Safety phrases

(The meaning of any safety phrases which appear in this section is given [here.](#))

S9 S26 S28 S36 S37 S39 S45.

[Return to [Physical & Theoretical Chemistry Lab. Safety home page.](#)]

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This information was last updated on July 9, 2005. We have tried to make it as accurate and useful as possible, but can take no responsibility for its use, misuse, or accuracy. We have not verified this information, and cannot guarantee that it is up-to-date.

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