
# Preliminary Hazard Analysis

## Lot 10201 Hollinsworth Road, Marsden Park

Newcold
Document No. Q16-086
Date 13/04/2017

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Lot 10201 Hollinsworth Road, Marsden Park

Newcold

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# Quality Management

| Issue / Revision | Date | Remarks | Prepared By | Reviewed By |
|---|---|---|---|---|
| A | 11 April 2017 | | Renton Parker | Kevin Blackie |
| 0 | 13 April 2017 | | | |

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# Abbreviations

| Abbreviation | Description |
|---|---|
| ADG | Australian Dangerous Goods Code |
| AS | Australian Standard |
| BMPL | Blackie Mendham Pty Ltd |
| CBD | Central Business District |
| CCPS | Centre for Chemical Process Safety |
| DA | Development Application |
| DGs | Dangerous Goods |
| DGS | Dangerous Goods Store |
| DPE | Department of Planning and Environment |
| HIPAP | Hazardous Industry Planning Advisory Paper |
| HSE | Health and Safety Executive |
| LEL | Lower Explosive Limit |
| PFD | Probability of Failure on Demand |
| PHA | Preliminary Hazard Analysis |
| Pmpy | Per million per year |
| Ppm | Parts per million |
| SEPP | State Environmental Planning Policy |
| TWA | Time Weighted Average |
| WHS | Work Health and Safety |

# Executive Summary

## Background

Newcold is a cold storage operator which has obtained ownership of a site in Marsden Park. Under the previous ownership, the site had approval for a Swires cold storage warehouse development; however, with the change of ownership, a Section 96 (2) application is required.

As the facility is a cold storage facility with freezing capabilities, ammonia will be used in the cooling system. Ammonia is classified as a Class 2.3 Dangerous Good (DG); hence, it is subject to the State Environmental Planning Policy No. 33 (SEPP 33, Ref. [1]). The threshold for SEPP 33 is 5,000 tonnes of anhydrous ammonia which will be exceeded; hence, additional analysis in the form of a Preliminary Hazard Analysis (PHA) would be required to demonstrate the risks of the facility are below permissible criteria.

EMKC, on behalf of Newcold, has commissioned Blackie Mendham Pty Ltd (BMPL) to prepare a PHA for the facility. This document represents the PHA study for the Newcold warehouse at Marsden Park.

## Methodology

The methodology used for the PHA is as follows;

*Hazard Analysis* – A detailed hazard identification was conducted for the site facilities and operations. A hazard identification word diagram was prepared (Appendix A). A qualitative review was then conducted in the main report to determine whether the safeguards were adequate to control the hazard. Incidents identified to have a potential offsite impact were carried forward for further analysis.

*Consequence Analysis* – Incidents carried forward from hazard analysis were subjected to a detailed consequence analysis to determine the severity of offsite impacts. Incidents identified to have an offsite impact exceeding selected criteria (HIPAP No. 4, Ref. [1]) were carried forward for frequency analysis, no further analysis was performed for incidents not exceeding offsite impact criteria (HIPAP No. 4, Ref. [1]).

*Frequency Analysis* – Each incident identified to have potential offsite impact was subjected to a frequency analysis. The analysis considers the initiating event and probability of failure of the safeguards (both hardware and software). The results of the frequency analysis were then carried forward for risk assessment.

*Risk Assessment and Reduction* – The consequence and frequency results for each incident, carried forward for further analysis, were combined to identify the risk. The risks were then compared to the risk criteria published in HIPAP No. 4 (Ref. [1]). Where the criteria were exceeded, a review of the major risk contributors was performed and the risks reassessed incorporating the recommended risk reduction measures. Recommendations were then made regarding risk reduction measures.

*Reporting* – On completion of the study a draft report was developed for review and comment by Newcold. A final report was then developed, incorporating the comments received by Newcold, for submission to the Regulators.

## Hazard Identification

A hazard identification table was developed and is presented in **Appendix A**, which was used to identify potentially hazardous scenarios. Scenarios identified for the site were;

- Ammonia release and toxic dispersion.
- Ammonia release, accumulation and ignition and explosions.

A detailed qualitative review of each scenario was performed to assess the potential for offsite impacts. Following the qualitative review, scenarios that still had potential to impact offsite were carried forwards for consequence analysis.

## Consequence Analysis

Scenarios carried forward for consequence analysis were subject to a detailed assessment of the potential impacts. The following scenario was carried forward for consequence analysis;

- Ammonia release and toxic dispersion.

## Frequency Analysis and Risk Assessment

The ammonia release and dispersion was modelled using DAESIM Risk Assessor to develop iso-risk contours. The contours generated for the facility showed that the maximum risk of a fatality as a result of the release was 1 chance per million per year (pmpy)

## Conclusions

A hazard identification table was developed for warehouse facility to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with a potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

Incidents carried forward for consequence analysis were assessed in detail to estimate the impact distances. Impact distances were developed into scenario contours and overlaid onto the site layout diagram to determine if an offsite impact would occur. The consequence analysis showed that one of the scenarios (ammonia release) would impact over the site boundary and into the adjacent land uses; hence, this incident was carried forward for frequency analysis and risk assessment.

The release scenarios (small, medium, and large releases) were modelled using DAESIM Risk Assessor to generate iso-risk contours for the probability of fatality resulting from an ammonia release. The contours generated showed probability of fatality impacts of 1 chances pmpy extending over the site boundary with lesser probability extending further afield. HIPAP No. 4 (Ref. [1]) publishes acceptable risk criteria at the site boundary of 50 chances pmpy (for industrial sites). Therefore, the probability of a fatality from a full warehouse fire at the site boundary is within the acceptable risk criteria.

No propagation incidents were identified for this warehouse; hence, propagation was not considered as part of the assessment.

Review of the adjacent land uses indicates the Linfox warehouse stores and handles flammable liquids and gases. A review of the FHA for the site indicates the site has a risk profile of 3.53

chances pmpy. The risk profiles for each site may overlap in the public road between the sites. Therefore, the combined probability of fatality between these sites would be 4.53 pmpy which is below the cumulative risk criteria; hence, the Newcold warehouse does not increase the risk profile of the area to an unacceptable level.

Based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the facility would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

## Recommendations

Notwithstanding the conclusions following the analysis of the facility, the following recommendations have been made;

- Include gas detectors and isolation valves within the facility design to isolate the ammonia systems in the event of ammonia detection.
- Inspect and test protection equipment (i.e. isolation valves, gas detectors) at a minimum of once every 6 months

# 1.0 Introduction

## 1.1 Background

Newcold is a cold storage operator which has obtained ownership of a site in Marsden Park. Under the previous ownership, the site had approval for a Swires cold storage warehouse development; however, with the change of ownership, a Section 96 (2) application is required.

As the facility is a cold storage facility with freezing capabilities, ammonia will be used in the cooling system. Ammonia is classified as a Class 2.3 Dangerous Good (DG); hence, it is subject to the State Environmental Planning Policy No. 33 (SEPP 33, Ref. [1]). The threshold for SEPP 33 is 5,000 tonnes of anhydrous ammonia which will be exceeded; hence, additional analysis in the form of a Preliminary Hazard Analysis (PHA) would be required to demonstrate the risks of the facility are below permissible criteria.

EMKC, on behalf of Newcold, has commissioned Blackie Mendham Pty Ltd (BMPL) to prepare a PHA for the facility. This document represents the PHA study for the Newcold warehouse at Marsden Park.

## 1.2 Objectives

The objectives of the PHA project, for the proposed Newcold Development in Western Sydney, NSW, were to:

- complete the PHA according to the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 – Hazard Analysis (Ref. [3]);
- assess the PHA results using the criteria in HIPAP No. 4 – Risk Criteria for Land Use Planning (Ref. [1]); and
- demonstrate compliance of the site with the relevant codes, standards and regulations (i.e. NSW Planning and Assessment Regulation 1979, WHS Regulation, 2011 Ref. [4])

## 1.3 Scope of Services

The scope of work is to complete a PHA study for the Newcold Warehouse located at Lot 10201, Hollinsworth Road, Marsden Park, required by the Planning Regulations for the proposed Newcold Facility in Western Sydney, NSW. The scope does not include any other assessments at the site or any other Newcold facilities or third party owner facilities.

# 2.0 Methodology

## 2.1 Multi-Level Risk Assessment

The Multi-Level Risk Assessment approach (Department of Planning & Environment or DPE, 2011 [5]) has been used as the basis for the study to determine the level of risk assessment required. The approach considered the development in context of its location, the quantity and type (i.e. hazardous nature) Dangerous Goods stored and used, and it's technical and safety management control. The Multi-Level Risk Assessment Guidelines are intended to assist industry, consultants and the consent authorities to carry out and evaluate risk assessments at an appropriate level for the facility being studied.

There are three levels of risk assessment set out in Multi-Level Risk Assessment which may be appropriate for a PHA, as detailed in **Table 2-1**.

**Table 2-1: Level of Assessment PHA**

| Level | Type of Analysis | Appropriate If: |
|---|---|---|
| 1 | Qualitative | No major off-site consequences and societal risk is negligible |
| 2 | Partially Quantitative | Off-site consequences but with low frequency of occurrence |
| 3 | Quantitative | Where 1 and 2 are exceeded |

The Multi-Level Risk Assessment approach is schematically presented in **Figure 2-1**.

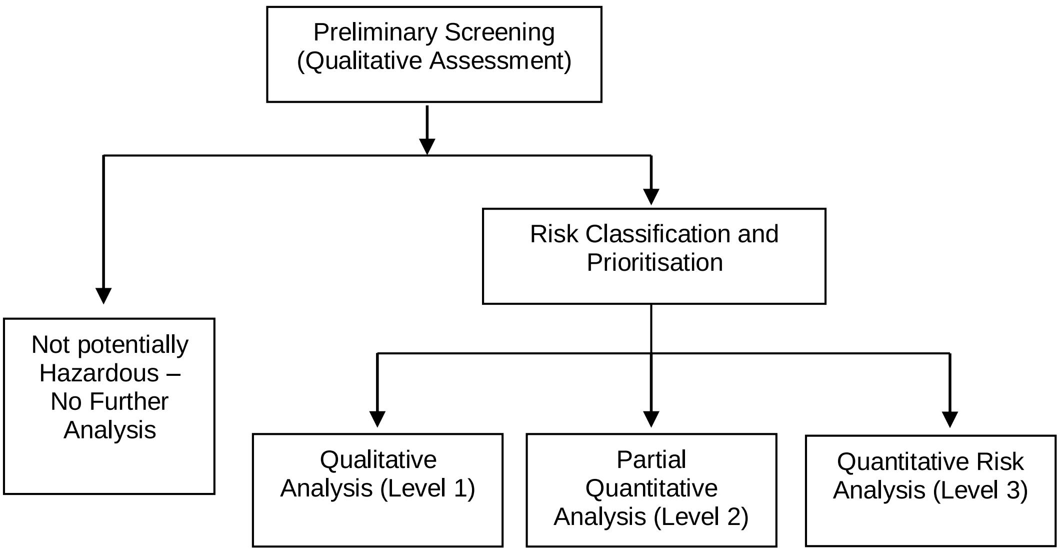



**Figure 2-1: The Multi-Level Risk Assessment Approach**

Based on the type of DGs to be used and handled at the proposed facility, a **Level 2 Assessment** was selected for the Site. This approach provides a qualitative assessment of those DGs of lesser quantities and hazard, and a quantitative approach for the more hazardous materials to be used on-site. This approach is commensurate with the methodologies recommended in "Applying SEPP 33's" Multi Level Risk Assessment approach (DPE, 2011).

## 2.2 Risk Assessment Study Approach

The methodology used for the PHA is as follows;

**Hazard Analysis –** A detailed hazard identification was conducted for the site facilities and operations. Where an incident was identified to have a potential off site impact, it was included in the recorded hazard identification word diagram (**Appendix A**). The hazard identification word diagram lists incident type, causes, consequences and safeguards. This was performed using the word diagram format recommended in HIPAP No. 6 (Ref. [3]).

Each postulated hazardous incident was assessed qualitatively in light of proposed safeguards (technical and management controls). Where a potential offsite impact was identified, the incident was carried into the main report for further analysis. Where the qualitative review in the main report determined that the safeguards were adequate to control the hazard, or that the consequence would obviously have no offsite impact, no further analysis was performed. **Section 4.0** of this report provides details of values used to assist in selecting incidents required to be carried forward for further analysis.

**Consequence Analysis –** For those incidents qualitatively identified in the hazard analysis to have a potential offsite impact, a detailed consequence analysis was conducted. The analysis modelled the various postulated hazardous incidents and determined impact distances from the incident source. The results were compared to the consequence criteria listed in HIPAP No. 4 (Ref. [1]). The criteria selected for screening incidents is discussed in **Section 4.0**.

Where an incident was identified to result in an offsite impact, it was carried forward for frequency analysis. Where an incident was identified to not have an offsite impact, and a simple solution was evident (i.e. move the proposed equipment further away from the boundary), the solution was recommended and no further analysis was performed.

**Frequency Analysis –** In the event a simple solution for managing consequence impacts was not evident, each incident identified to have potential offsite impact was subjected to a frequency analysis. The analysis considered the initiating event and probability of failure of the safeguards (both hardware and software). The results of the frequency analysis were then carried forward to the risk assessment and reduction stage for combination with the consequence analysis results.

**Risk Assessment and Reduction –** Where incidents were identified to impact offsite and where a consequence and frequency analysis was conducted, the consequence and frequency analysis for each incident were combined to determine the risk and then compared to the risk criteria published in HIPAP No. 4 (Ref. [1]). Where the criteria were exceeded, a review of the major risk contributors was performed and the risks reassessed incorporating the recommended risk reduction measures. Recommendations were then made regarding risk reduction measures.

**Reporting –** on completion of the study a draft report was developed for review and comment by Newcold. A final report was then developed, incorporating the comments received by Newcold, for submission to the regulatory authority.

## 3.0 Site Description

### 3.1 Site Location

The site is located at Lot 10201 Hollinsworth Road, Marsden Park which is approximately 47 km west of the Sydney Central Business District (CBD). **Figure 3-1** shows the regional location of the site in relation to the Sydney CBD. Provided in **Figure 3-2** is the layout of the site in Marsden Park.

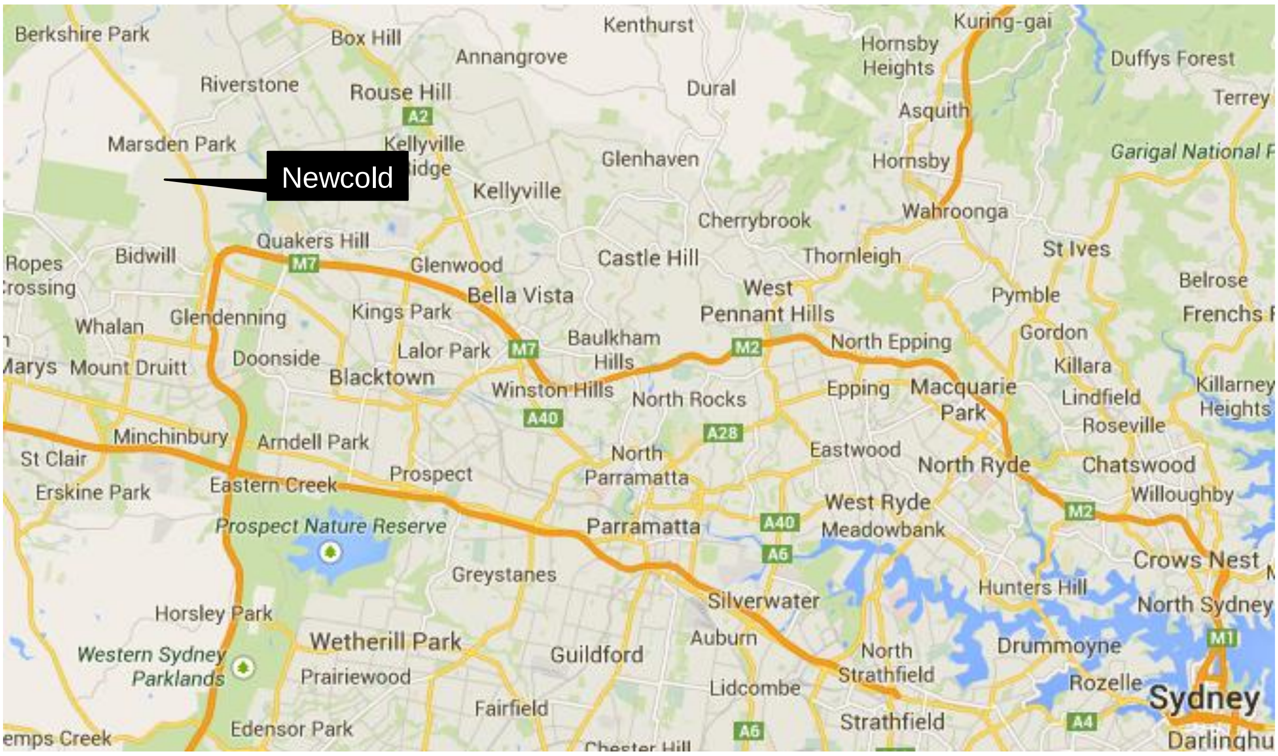



**Figure 3-1: Newcold Regional Site Location**

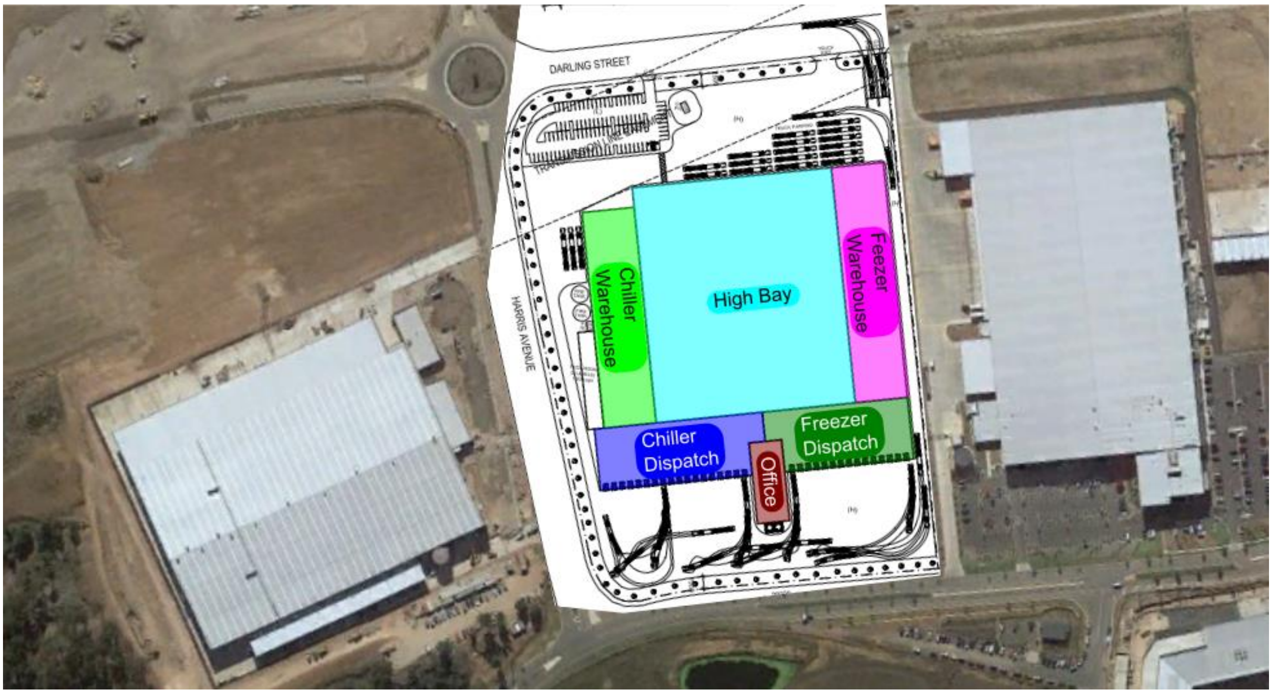



**Figure 3-2: Newcold Site at Marsden Park**

## 3.2 Adjacent Land Uses

The land is located in an industrial area surrounded by the following land uses, which are adjacent to the site:

- North – Vacant land
- South – Vacant land
- East – Warehousing (Reece Civil and Lindt Chocolate)
- West – Linfox Warehousing for Dulux

## 3.3 General Description

The building will consist of an office area, amenities and chiller and freezer warehouse areas in addition to chiller and freezer dispatching areas. The office area will house staff and general operations, and the warehouse will be designed to contain chilled or frozen food products. DG classes and volumes are discussed in **Section 3.4**. **Figure 3-2** can be used to assist in understanding the description provided below.

## 3.4 Refrigeration System Description

The main hazards associated with chilled and frozen storage arise from the refrigeration system which uses an ammonia/direct expansion system. A refrigeration system contains four essential components:

1. Compressor
2. Expansion valve
3. Refrigerant
4. Heat exchanging pipework

**Figure 3-2** has been provided to aid in the description of how the refrigeration system operates to cool a specific area.

It is noted that the refrigeration system containing ammonia has been designed to directly expand in the evaporators of the high bay located at high level, absorbing the heat from the warehouse and providing cooled air which is recirculated within the warehouse.

The refrigeration system at the Newcold facility contains approximately 7 tonnes of ammonia which is constantly cycled through the system.

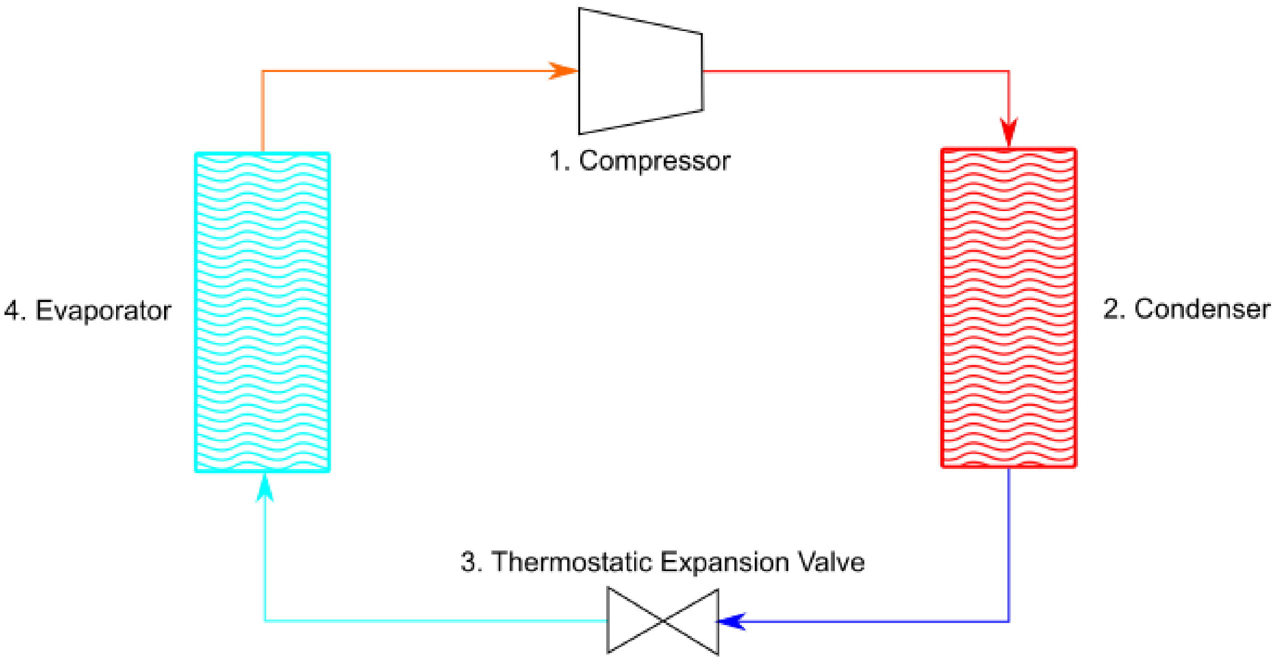



**Figure 3-3: Refrigeration Flow Diagram**

1. Ammonia gas from the evaporator enters the compressor where it is pressurised (red) which increases the temperature of the ammonia gas. The gas travels along the pipework to the condenser.
2. The condenser is coiled to provide a large surface area to allow the hot ammonia gas to dissipate heat. As the gas releases heat through the coils, the gas condenses into a pressurised liquid (dark blue).
3. The pressurised liquid enters the thermostatic expansion valve where it expands across the valve seat, resulting in a sudden drop of pressure of the liquid ammonia and rapid expansion which cools the liquid (light blue).
4. The cooled ammonia enters the evaporator which is coiled to provide a large surface area to facilitate exchange of heat from the warehouse into the ammonia. As the ammonia absorbs heat it boils into a gaseous state.
5. On completion of the cycle, the ammonia gas is drawn into the compressor and the cycle repeats.

## 3.5 Quantities of Dangerous Goods Stored and Handled

As noted, the only DGs stored at the site are involved in the refrigeration system in the form of anhydrous ammonia. There will be 7,000 kg of ammonia utilised in the system.

# 4.0 Hazard Identification

## 4.1 Introduction

A hazard identification table has been developed and is presented at **Appendix A**. This table has been developed following the recommended approach in Hazardous Industry Planning Advisory Paper No .6, Hazard Analysis Guidelines (Ref. [3]). The Hazard Identification Table provides a summary of the potential hazards, consequences and safeguards at the site. The table has been used to identify the hazards for further assessment in this section of the study. Each hazard is identified in detail and no hazards have been eliminated from assessment by qualitative risk assessment prior to detailed hazard assessment in this section of the study.

In order to determine acceptable impact criteria for incidents that would not be considered for further analysis, due to limited impact offsite, the following approach has been applied:

- *Fire Impacts* - It is noted in Hazardous Industry Planning Advisory Paper (HIPAP) No. 4 (Ref. [1]) that a criterion is provided for the maximum permissible heat radiation at the site boundary (4.7 kW/m$^2$) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in a heat radiation less that at 4.7 kW/m$^2$, at the site boundary, are screened from further assessment.

  Those incidents exceeding 4.7 kW/m$^2$ at the site boundary are carried forward for further assessment (i.e. frequency and risk). This is a conservative approach, as HIPAP No. 4 (Ref. [1]) indicates that values of heat radiation of 4.7 kW/m$^2$ should not exceed 50 chances per million per year at sensitive land uses (e.g. residential). It is noted that the closest residential area is over 200 m from the site, hence, by selecting 4.7 kW/m$^2$ as the consequence impact criteria (at the adjacent industrial site boundary) the assessment is considered conservative.

- *Explosion* - It is noted in HIPAP No. 4 (Ref. [2]) that a criterion is provided for the maximum permissible explosion over pressure at the site boundary (7 kPa) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in an explosion overpressure less than 7 kPa, at the site boundary, are screened from further assessment. Those incidents exceeding 7 kPa, at the site boundary, are carried forward for further assessment (i.e. frequency and risk). Similarly, to the heat radiation impact discussed above, this is conservative as the 7 kPa value listed in HIPAP No. 4 relates to residential areas, which are over 200 m from the site(noting that only industrial areas adjoin the proposed facility).

- *Toxicity* – It is noted that toxic materials are not planned for storage at the proposed facility. Hence, toxic impacts are not considered in this study.

- *Property Damage and Accident Propagation* - It is noted in HIPAP No. 4 (Ref. [2]) that a criterion is provided for the maximum permissible heat radiation/explosion overpressure at the site boundary (23 kW/m$^2$/14 kPa) above which the risk of property damage and accident propagation to neighbouring sites must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk to incident propagation, for this study, incidents that result in a heat radiation heat radiation less than 23 kW/m$^2$ and explosion over pressure less than 14 kPa, at the site boundary, are screened from further assessment. Those incidents exceeding 23 kW/m$^2$ at the site boundary are carried forward for further assessment with respect to incident propagation (i.e. frequency and risk).

- *Societal Risk* – HIPAP No. 4 (Ref. [2]) discusses the application of societal risk to populations surrounding the proposed potentially hazardous facility. It is noted that HIPAP No. 4 indicates that where a development proposal involves a significant intensification of population, in the vicinity of such a facility, the change in societal risk needs to be taken into account. In the case of the Newcold facility, there is currently no significant intensification of population around the proposed site and as the site is located in an industrial area, it is expected that a minimal population will surround the site. Notwithstanding this, societal risk has been considered in this study. The closest residential area is located over 200 m from the site.

## 4.2 Properties of Dangerous Goods

The type of DGs and quantities stored and used at the site has been described in **Section 3**. **Table 4-1** provides a description of the DGs stored and handled at the site, including the Class and the hazardous material properties of the DG Class.

**Table 4-1: Properties* of the Dangerous Goods and Materials Stored at the Site**

| Class | Hazardous Properties |
|---|---|
| 2.3 – Toxic gases (Anhydrous Ammonia) | Ammonia is a colourless toxic gas which is highly hydroscopic (i.e. water soluble).<br>At an ammonia concentration of 0.5% (5,000 ppm, Ref. [6]) a fatality will occur within minutes of exposure.<br>Within concentration limits of 15% – 33.6% (150,000 – 336,000 ppm, Ref. [7]) ammonia can ignite given the right conditions, resulting in fire and/or explosion. It is noted that ignition of ammonia is difficult and can only be achieved by a high energy source. In addition, sustained ignition of ammonia (i.e. burning) rarely occurs as the heat of the flame is less than the heat of ignition.<br>Ammonia is used as a raw material for the synthesis of fertilisers, cleaning agent or refrigeration. |

* The Australian Code for the Transport of Dangerous Goods by Road and Rail (Ref. [8]

## 4.3 Hazard Identification

Based on the hazard identification table presented in **Appendix A**, the following hazardous scenarios have been developed:

- Ammonia release and toxic dispersion.
- Ammonia release, accumulation and ignition and explosions.

Each identified scenario is discussed in further detail in the following sections.

## 4.4 Ammonia Release and Toxic Dispersion

### 4.4.1 Ammonia Properties and Toxicology

The inherent hazards of the ammonia refrigeration system arise from the toxic properties of the ammonia gas. Anhydrous ammonia is ammonia in a compressed and/or liquefied form. At atmospheric temperature and pressure ammonia is a pungent, colourless gas and its odour serves as its own warning agent. Ammonia gas is lighter than air but when released from liquid storage tanks it can behave as a heavier than air gas, depending on the fraction of entrained liquid droplets.

If the droplet fraction is less than 4-8%, the gas cloud would be less dense whereas above a droplet fraction of 16-30% the cloud would be more dense than air. Between these critical values, the density of the cloud is determined by the degree of dilution and humidity of the air.

The boiling point of ammonia is -33°C at atmospheric pressure and it can be stored by refrigeration at this temperature or under pressure at ambient temperature.

The nature of ammonia can cause the gas to be lethal in quite low doses. It can cause varying degrees of irritation to the skin or mucous membranes and can temporarily damage the visual and respiratory systems. In sufficient concentrations permanent damage or death would occur. Ammonia gas can dissolve in moisture on the skin and cause a painful burning sensation. In liquid form ammonia can seriously damage the skin. At 25 parts per million (ppm) concentration in air, most people can detect an ammonia odour, but it is not uncomfortable. At 100 ppm, it can cause immediate nose and throat irritation and at 1700 ppm it can cause convulsive coughing and severe eye, nose and throat irritation. At concentration of 2000-5000 ppm fatality can occur within 30 minutes and 5000-10000 ppm causes fatality within minutes (Ref. [9]).

The exposure standard for people in constant contact with ammonia gas is defined as “the airborne concentration of ammonia in the person’s breathing zone, exposure to which, according to current knowledge, should not cause adverse health effects nor cause undue discomfort to nearly all people”. The standard can be expressed as a Time Weighted Average (TWA) which is the “average airborne concentration of ammonia calculated over a normal eight hour working day, for a five day working week”. For ammonia the TWA is 25 ppm, and the Short Term Exposure Limit (STEL) for occupational exposure is 35 ppm. (Ref. [10]).

Because of the irritation caused by exposure to ammonia gas, early warning is often possible before damage is done. With such early warning it is very unlikely that staff or people affected would remain in the area. Furthermore, at such low levels of detection (i.e. 25 ppm) there is very little chance of injury or fatality before people can escape. The main danger arises when the concentration builds up too rapidly for action to be taken or where shelter or escape is impossible. However, this is unlikely at the proposed Newcold facility due to the installation of gas detectors.

### 4.4.2 Selected Ammonia Hazard Concentrations Used for this Study

As indicated in **Section 4.4.1** a release of liquid or vapour from the ammonia system would form a cloud and drift with the prevailing wind and be dispersed by the wind and weather conditions. People who come into contact with the ammonia vapour cloud may be severely injured or killed from inhalation of the toxic vapours. However, the effect of the ammonia of vapours is dependent on the concentration of the vapours in air and the duration of exposure. A probit correlation has been developed to describe the relationship (Ref. [11]), a probit is an expression or function that determines the probability of fatality for exposure to a hazardous event. For an unprotected person, the probit equation for exposure to ammonia is given as:

$$\mathrm{Pr} = 1.85\ln(C^2 t) - 35.9 \qquad \textbf{Eqn 4-1}$$

Where:

T = time of exposure (minutes)

C = Concentration (ppm)

Using the probit relationship shown in **Eqn 4-1**, the values for 100%, 50% and 10% fatality probability were selected and the concentrations calculated using the probit relationship shown above. A time exposure of 30 minutes was selected for the calculations based on the properties of ammonia to cause serious harm. **Table 4-2** indicates the calculated values for each probability.

**Table 4-2: Concentrations of Ammonia for Selected Fatality Probabilities**

| Fatality Probability | Probit | Concentration (ppm) |
|---|---|---|
| 100% | 8 | 25,960 |
| 50% | 5 | 11,540 |
| 10% | 3.7 | 8,120 |

### 4.4.3 Ammonia Hazards (Toxicity)

The types of hazardous incident which could occur, in theory at least, arise from potential releases of ammonia that may result in effects beyond the site boundary. Releases can occur due to leakage from mechanical failure of pipework, vessels, compressors etc., or due to maloperation etc.

In the event of an escape occurring, the effects on people at any particular location will depend upon the concentration of gas at that location, and the duration of exposure. The concentration at any particular point depends upon the wind direction, (i.e. whether the wind is blowing toward the point), the wind speed and the atmospheric conditions (stability).

The main potential leak sources of loss of containment include:

- mechanical damage to the vessels, pipework and associated fittings, compressors, heat exchangers and condensers, and freezer units.
- Corrosion of the ammonia equipment including the above components.
- operational or maintenance errors (e.g. leaking flange gasket through incorrect installation) resulting in the release of ammonia liquid or gas.
- relief valve operation (vented through water tank).

As a release of ammonia may have far reaching effects due to wind dispersion, this incident has been carried forward for further analysis.

## 4.5 Ammonia Release, Accumulation and Ignition and Explosion

There is the potential for an ammonia release to occur within the compressor plant room and for ammonia to accumulate. In the event that the gas is not successfully vented, there is a potential for the cloud to ignite sometime after the release. Ammonia is explosive within the range of 15% to 33.6% in air. Hence, it is possible that the confined gas cloud may explode, destroying the compressor house and initiating a pressure wave which may have farther a field impacts. People may be seriously injured or killed by explosion overpressure or by missiles projected from the explosion site.

To determine whether an explosion is possible, it is necessary to calculate whether an explosive concentration can be attained within the compressor plant room. The concentration of ammonia in the room at any time following the release is given by:

$$C = \frac{m}{v_a}\left[1 - e^{-\frac{v_a}{v}t}\right]$$

Where:

C = Concentration ($kg/m^3$)

M = release rate (kg/s)

$V_a$ = ventilation air flow ($m^3/s$)

V = volume of room ($m^3$)

For a large t, the maximum concentration in the room is:

$$C = \frac{m}{v_a}$$

The compressor plant room has a volume of approximately 2,700 $m^3$ and there is 15 air changes per hour. Therefore, the ventilation air flow is 11.25 $m^3/s$. For a Lower Explosive Limit (LEL) concentration of 15%, mass concentration is 0.11 $kg/m^3$. Therefore, to achieve this concentration at a ventilation rate of 11.25 $m^3/s$ the system must be release 1.25 kg/s.

The vapour release rates shown in **Appendix D** for all credible failures in the compressor house (i.e. flange leak, 20 mm instrument nozzle leak etc.) were less than this amount, showing that LEL concentrations in the compressor room would not occur. It is noted that the credible cases are leaks and not full ruptures; hence, release rates would be through areas <5 mm area.

Notwithstanding this assessment, ammonia is extremely hard to ignite and is a relatively stable compound. It begins to dissociate at approximately 450°C at atmospheric pressure. Experiments conducted in the United States showed that an ammonia air mixture in a standard quartz test container does not ignite at less than 850°C. Conditions favourable for ignition are seldom encountered during normal operation due to the high temperature of ignition required. At the proposed Newcold facility, the likelihood of reaching a flammable mixture and the required ignition temperature is negligible. Therefore, the event was not carried forward for further assessment.

# 5.0 Consequence Analysis

## 5.1 Incidents Carried Forward for Consequence Analysis

The following incident was identified to have potential to impact off site:

- Ammonia release and toxic dispersion.

This incident has been assessed in the following section.

## 5.2 Ammonia Release and Toxic Dispersion

There are numerous sources of release in the ammonia system. Each of these potential sources of release have been reviewed in the following subsections.

### 5.2.1 Pipework Incidents

Cox, Lees and Ang (Ref. [12]) note that the estimation of hole size resulting in a leak of material from a system is the most difficult problem as it is not usual for records to be kept on the size of leaks. They indicate that from their studies the generally accepted method of hole size estimation is based partly on engineering considerations and partly on expert judgement. The following selection of hole sizes displayed in **Table 5-1** were taken directly from, or derived from the methods discussed by, Cox, Lees and Ang ((Ref. [12])

**Table 5-1: Hole Sizes Based on Incident**

| Incident | Hole Size |
|---|---|
| Major Rupture | Equivalent to pipe diameter |
| Major Leak | 20 mm diameter |
| Minor Leak | 5 mm diameter |

### 5.2.2 Valves

The majority of valve failures leading to external leaks occur through the valve stem and valve bonnet to body gasket. Leaks at the valve stem occur through failure of the stem gland packing and are limited to minor releases similar to a small hole (about 5 mm diameter).

Leaks at the bonnet to body gasket have the potential to be larger due to gasket failure and have been modelled as a medium sized release represented by a hole 20 mm diameter. The robust nature of valves (i.e. heavier section of material in the valve body) makes the likelihood of rupture very low if not negligible, especially where pressures are relatively low.

Corrosion can, however, create pinholes in valve bodies leading to external leaks. These have also been modelled as 5 mm holes for small leaks and 20 mm holes for larger leaks. In light of the relatively low pressure of operation at the proposed facility and, hence, the low likelihood of valve rupture we have not developed this scenario further in this assessment.

### 5.2.3 Flanges

Cox, Lees and Ang (Ref. [12]) indicate that flange failures occur in one of two ways; a small leak from a failed gasket or a loss of a section of gasket resulting in a major leak. For flanges a 5 mm hole has been estimated to represent the gasket leak and a 20 mm hole has been estimated to represent a partial loss of gasket. The proposed system design will minimise flange use by using welded pipeline where ever possible. Flanges will only be used to connect valves or equipment to the pipework system.

### 5.2.4 Heat Exchanges and Condensers

Each of the ammonia cooling components in the system comprises a series of tubes/plates and/or a vessel through which the ammonia passes. The ammonia is passed through on one side of the unit with a cooled medium on the other. Failure of any single component would most likely occur at the pipework inlet to the cooler where pipework failure could result in small weld leaks, medium sized holes and ruptures, these incidents have been included in the pipework scenarios discussed above.

Failure of tubes or other cooler internal components would result in a leak of ammonia into the cooled medium (water etc.) resulting in dilution of the ammonia and no release. However, in the event of a water pump failure, a release of ammonia could occur through water side of the circuit.

The hole sizes selected for cooler component are the same as those used for pipework failure and have been used to estimate the release rates in this equipment.

### 5.2.5 Pumps

The failure of pumps mainly occurs in the pump seal area and in the casing. For this study these two failure modes were selected to represent pump failures. A hole size of 5 mm equivalent diameter was estimated to represent a seal leak and a hole diameter of 20 mm was estimated to represent a casing leak. It is assumed that both pumps within the system operate at very low pressures (<200 kpa), hence, the potential for major casing rupture was considered to be negligible. The more likely failure would be seal and casing leaks.

### 5.2.6 Compressors

The non-electronic parts reliability data base (Ref. [13]), indicates that of the leaks recorded for compressors only one can be regarded as large enough to contribute to holes in the 0-50 mm range, there is no detailed breakdown of the failure modes in this or other data bases. Hence, we two incidents for this equipment have been selected; failure of the seals, resulting in a leak of equivalent hole diameter of 5 mm and a hole in and around the connections at the cylinder heads resulting in a 20 mm hole.

The compressor house ventilation air is directed to the cooling tower as part of the cooling air, and to neutralise any ammonia vapour leaked in the compressor house. Therefore, a release to atmosphere could only occur if there was a leak in the compressor house, and a failure of the cooling tower circulation at the same time.

### 5.2.7 Incident Release Rates

The release of ammonia in liquid form will result in some of the released material immediately forming a vapour and some falling directly to the ground, forming a pool. The material falling directly to the ground will absorb heat from the surrounding area and evaporate, adding to the vapour immediately formed from the release. As the release continues, the pool of ammonia grows to a stage where the evaporation rate is equivalent to the release rate of the liquid. Hence, there comes a stage where equilibrium is reached and the vapour from the release plus the vapour from the pool reaches a constant release rate.

The release rates have been estimated using the above methodology and are listed in **Appendix D**. The release rates were estimated for each section of pipework and each component in the system. The release rates shown in **Appendix D** are for the equilibrium release condition which would be conservative, considering it would take some time for the estimated release rate to build up to the levels shown.

### 5.2.8 Ammonia Release and Dispersion

The majority of ammonia in the system is in liquid form. Hence, in the unlikely event that ammonia is released, some would immediately flash into gas whilst the remaining liquid would fall to the ground and form a pool. The pool of ammonia would absorb heat from its surroundings and evaporate, adding to the gas flashing from the release point. The total release rate would therefore be the summation of the flashing gas and the release from the pool.

The formed cloud above the release point would be dispersed by the prevailing wind and weather conditions. The weather data was collected from the Bureau of Meteorology for the Sydney Basin and used in the model for gas dispersion (explained below).

For each of the release scenarios developed above, the dispersion characteristics were assessed using DAESIM Risk Assessor which incorporates HEGADAS which is a dense gas dispersion model. This model is widely used throughout the world and has been verified in use in many studies.

**Appendix D**. lists the release scenarios including release rates and pool diameters for the incidents developed above. The release rates listed in this appendix are for the combined effects of flashing gas and pool evaporation.

# 6.0 Frequency Analysis

## 6.1 Incidents Carried Forward for Frequency Analysis

The following item has been carried forwards for frequency analysis;

- Ammonia release and toxic dispersion.

This incident has been assessed in the following section.

## 6.2 Ammonia Release and Toxic Dispersion

The failure frequencies for each of the components identified in **Section 5.0** are provided in the following subsections.

### 6.2.1 Generic Failure Frequencies

Various failure rate data bases were reviewed to collect data for the failure scenarios in pipework and other equipment used in the ammonia system. The list of equipment shown in **Table 6-2** was developed using generic failure data obtained from suitable databases. The general failure rates selected from the data bases are shown in **Appendix B**.

### 6.2.2 Release Frequencies

The incidents discussed above relate to failures of equipment and the potential for release. As part of the plant safety features, Newcold propose to install gas detectors located throughout the facility. These detectors will be connected to alarm systems and to isolation valves. The isolation valves will isolate each major ammonia system and the leak area. This will limit the potential for continued releases ensuring release incidents will not grow to significant proportions. However, there is a potential for gas detectors, isolation valves and alarms to fail when activated, and although a protection system is installed it may not be effective if components are in a failed state when required to operate.

The values selected for individual protection system component failure probability is shown in **Table 6-1.**

**Table 6-1: Protection System Component Failure Probability**

| Component | Failure Probability | Source |
|---|---|---|
| Gas detector fails on demand | 0.0002 | Oreda (2002) |
| Emergency isolation valve fails on demand | 0.004 | HSE |
| Manual isolation valve cannot be closed | 0.0004 | HSE |

To account for the failure probabilities of protection equipment and operator response, event trees have been developed and are shown at **Appendix B**. The probability that the protection system fails when required was calculated to be $2.02 \times 10^{-4}$.

This probability was used to develop the release frequencies shown in **Table 6-2**.

**Table 6-2: Failure and Release Frequencies**

| Equipment | Hole Size | Failure Frequency ($x10^{-6}$/yr) | Probability Protection Fails | Release Frequency ($x10^{-6}$/yr) | Remarks |
|---|---|---|---|---|---|
| Pipework | Small | 30/m | $2.02x10^{-4}$ | 0.01008 | Cox et al (Ref. [12]) |
| | Medium | 6/m | $2.02x10^{-4}$ | 0.002016 | Cox et al (Ref. [12]) |
| | Rupture | 0.3/m | $2.02x10^{-4}$ | 0.000101 | Cox et al (Ref. [12]) |
| Valves | Small | 1,000 | $2.02x10^{-4}$ | 0.336 | Cox et al (Ref. [12]) |
| | Medium | 100 | $2.02x10^{-4}$ | 0.0336 | Cox et al (Ref. [12]) |
| Flanges | Small | 1,000 | $2.02x10^{-4}$ | 0.336 | Cox et al (Ref. [12]) |
| | Medium | 100 | $2.02x10^{-4}$ | 0.0336 | Cox et al (Ref. [12]) |
| Heat Exchanger | Small | 7,800 | $2.02x10^{-4}$ | 2.6208 | IEEE 16.1.1 |
| | Medium | 780 | $2.02x10^{-4}$ | 0.26208 | IEEE 16.1.1 |
| Separators* | Small | 30 | - | 30 | Nusey and Page |
| | Medium | 3 | - | 3 | Nusey and Page |
| Pumps | Seal | 3,000 | $2.02x10^{-4}$ | 1.008 | Cox et al (Ref. [12]) |
| | Casing | 300 | $2.02x10^{-4}$ | 0.1008 | Cox et al (Ref. [12]) |
| Compressor | Seal | 350 | $2.02x10^{-4}$ | 0.1176 | NPRD (Ref. [13]) |
| | Casing | 35 | $2.02x10^{-4}$ | 0.01176 | NPRD (Ref. [13]) |

*Release incidents at the separator vessels would be difficult to isolate as the failure incidents have been assumed to occur in the separator shell, hence, isolation valves would not be able to prevent the release of the vessel contents.

Three release scenarios were valuated small, medium and large releases. Event trees have been developed for each of the scenarios based on the information provided in **Table 6-2**. The release frequency for each scenario has been summarised in

**Table 6-1: Release Scenario Event Frequency**

| Release Size | Frequency |
|---|---|
| Small | $53.7x10^{-6}$ p.a. |
| Medium | $6.59x10^{-6}$ p.a. |
| Large | $0.63x10^{-6}$ p.a. |

# 7.0 Risk Assessment

## 7.1 Method of Risk Assessment

The assessment of risk is performed by combining the consequence and frequency of an event. This results in the presentation of risk as the consequence per unit time. An example of this is the consequence of fatality from an identified hazardous incident. By determining the fatality effects of the incident (i.e. the distance from the incident at which fatalities will be realised) and estimating the frequency of the incident (i.e. on an annual basis) the two values can be combined to give an estimate of the risk of fatalities per year.

For simplistic assessments (i.e., assessments with only a small number of hazardous incidents) calculations can be performed by hand and the risk to selected targets can be easily calculated. However, as facilities become more complex, the number of calculations grows significantly and cannot be readily performed by hand. Hence, computer models are used to process the vast number of calculations required to develop risks in complex plants.

To assess the cumulative risks from a facility, a grid is developed on a plot plan of the site and surrounding area (including the adjacent land uses). At each point on the grid, the risks are assessed and accumulated for each of the potentially hazardous incidents. The points of constant risk on the grid are connected to develop contours of risks.

The contours are normally developed for the risk levels as published in HIPAP No. 4 (Ref. [2]). These values are listed in **Table 7-1**.

**Table 7-1: Risk Criteria for Land Use Safety Planning**

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

## 7.2 Risk Contours

Risk contours were calculated for the following cases:

- Individual risk of fatality of 0.5, 1 and 50 chances in a million per year (pmpy).
- Risk of acute physiological response on exposure (200 ppm) of 50 chances pmpy.
- Risk of injury on exposure (500 ppm) of 10 chances pmpy.

The fatality risk contours are provided in **Figure 7-1**. A review of the fatality contours indicates that the fatality risk is in the immediate region of the release and is heavily driven by the small release scenario. A review of the impact distances for injury and irritation indicates that only medium and large release scenarios could impact residential areas. The overall combined frequency of these incidents is 7.22 chances per million per year. Therefore, the combined impact from these scenarios is less than the 10 chances pmpy for injury and 50 chances pmpy for irritation. This does not consider the probability of wind direction or stability class; hence is a conservative assessment.

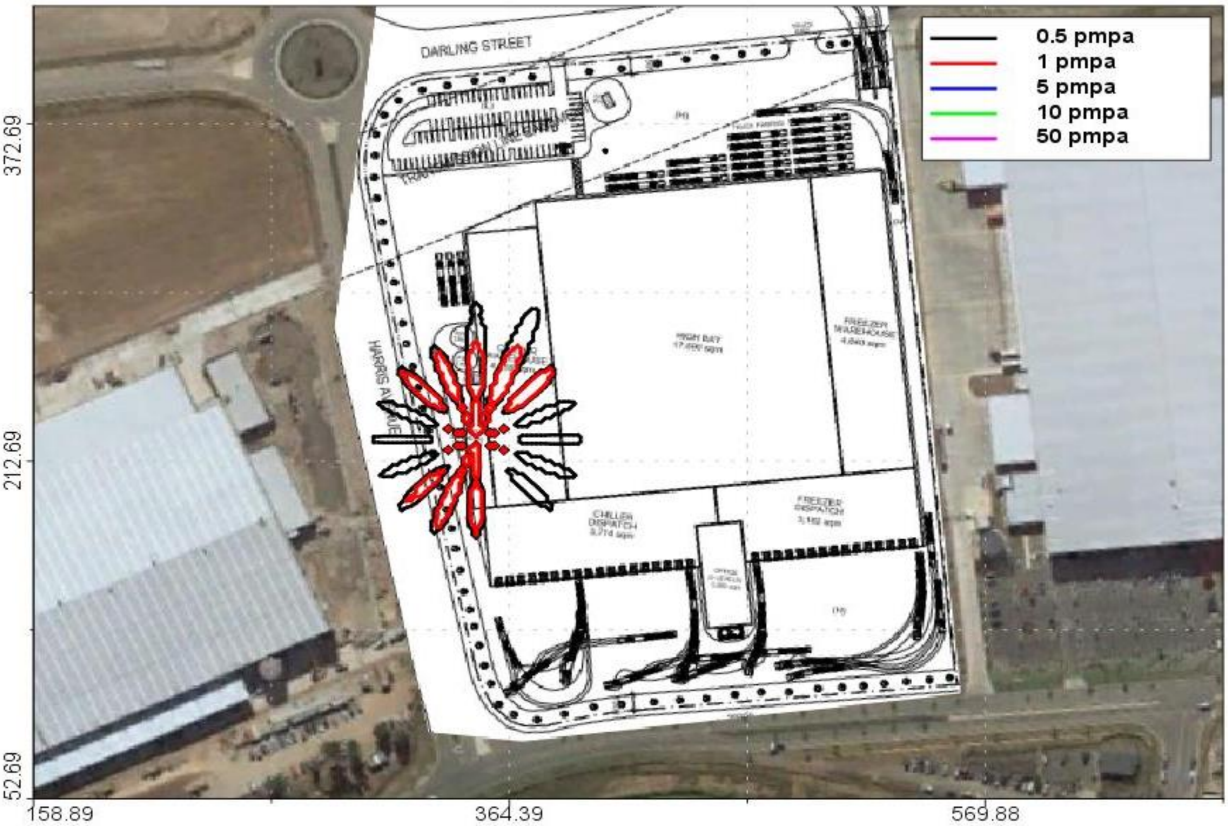



**Figure 7-1: Individual Fatality Risk Contours**

## 7.3 Societal Risk

Societal risk analysis combines the consequence and frequency data with the population information to indicate the cumulative frequency (F) of 'n' or more fatalities (n). Hence, in order to conduct a societal risk assessment, it is necessary to determine the affected population within the effects distance of the hazard. A review of the results indicates that only medium or large releases scenarios could impact the closets residences. The frequency of these events were 7.22 pmpy.

The closest residence is approximately 200 m from the site. A review of the input data indicates the wind blows in the direction of this residence approximately 15% of the time which is a conservatism estimate as not all wind stabilities result in impacts at a distance sufficient to impact the residence. At the concentrations experience at the residence, the fatality % is approximately 10%. Therefore, the probability of fatality at the closest residence is 7.22 x 0.15 x 0.1 = 0.11 pmpy.

Considering the low probability of fatality of this scenario, the low density of population in the area, and the lower fatality probabilities of other scenarios, the societal risks would not be significant. Hence, a societal risk curve was not developed.

# 8.0 Conclusion and Recommendations

## 8.1 Conclusions

A hazard identification table was developed for warehouse facility to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with a potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

Incidents carried forward for consequence analysis were assessed in detail to estimate the impact distances. Impact distances were developed into scenario contours and overlaid onto the site layout diagram to determine if an offsite impact would occur. The consequence analysis showed that one of the scenarios (ammonia release) would impact over the site boundary and into the adjacent land uses; hence, this incident was carried forward for frequency analysis and risk assessment.

The release scenarios (small, medium, and large releases) were modelled using DAESIM Risk Assessor to generate iso-risk contours for the probability of fatality resulting from an ammonia release. The contours generated showed probability of fatality impacts of 1 chances pmpy extending over the site boundary with lesser probability extending further afield. HIPAP No. 4 (Ref. [1]) publishes acceptable risk criteria at the site boundary of 50 chances pmpy (for industrial sites). Therefore, the probability of a fatality from a full warehouse fire at the site boundary is within the acceptable risk criteria.

No propagation incidents were identified for this warehouse; hence, propagation was not considered as part of the assessment.

Review of the adjacent land uses indicates the Linfox warehouse stores and handles flammable liquids and gases. A review of the FHA for the site indicates the site has a risk profile of 3.53 chances pmpy. The risk profiles for each site may overlap in the public road between the sites. Therefore, the combined probability of fatality between these sites would be 4.53 pmpy which is below the cumulative risk criteria; hence, the Newcold warehouse does not increase the risk profile of the area to an unacceptable level.

Based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the facility would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

## 8.2 Recommendations

Notwithstanding the conclusions following the analysis of the facility, the following recommendations have been made;

- Include gas detectors and isolation valves within the facility design to isolate the ammonia systems in the event of ammonia detection.
- Inspect and test protection equipment (i.e. isolation valves, gas detectors) at a minimum of once every 6 months.

# 9.0 References


[1] NSW Department of Planning and Environment, “Applying SEPP33 – Hazardous and Offensive Developments,” NSW Department of Planning and Environment, Sydney, 2011.

[2] Department of Planning, “Hazardous Industry Planning Advisory Paper No. 4 - Risk Criteria for Land Use Safety Planning,” Department of Planning, Sydney, 2011.

[3] Department of Planning, “Hazardous Industry Planning Advisory Paper No. 6 - Guidelines for Hazard Analysis,” Department of Planning, Sydney, 2011.

[4] NSW WorkCover, “Work Health and Safety Regulation,” NSW WorkCover, Lisarow, 2011.

[5] NSW Department of Planning & Infrastructure, “Multi-Level Risk Assessment,” 2011.

[6] Standards Australia, AS/NZS 2022:2003 - Anhydrous ammonia - storage and handling, Sydney: Standards Australia, 2003.

[7] Standards Australia, AS/NZS 60079.20.1:2012 - Material Characteristics for Gas and Vapour Classification – Test Methods and Data, Sydney: Standards Australia, 2012.

[8] National Transport Commission (NTC), “Australian Code for the Transport of Dangerous Goods by Road & Rail, 7th Edition,” 2011.

[9] United Kingdom Institution of Chemical Engineers, “Ammonia Toxicity Monograph, A second report of the toxicity working party,” United Kingdom Institution of Chemical Engineers, Rugby, 1988.

[10] Safe Work Australia, “Workplace Expsoure Standards for Airborne Contaminants,” Safe Work Australia, Canberra, 2013.

[11] F. P. Lees, Loss Prevention in the Process Industries, London: Butterworth-Heinemann, 2005.

[12] A. W. Cox, F. P. Lees and M. L. Ang, “Classification of Hazardous Locations,” Institution of Chemical Engineers, Rugby, Warwickshire, 1991.

[13] Rome Laboratories, “Non-electric Parts Reliability Data,” Rome Laboratories, New York, 1980.

# Appendix A

## Hazard Identification Table

## A1. Hazard Identification

| Area/Operation | Hazard Cause | Hazard Consequence | Safeguards |
|---|---|---|---|
| Ammonia system | • Tank or equipment failure | • Ammonia leak resulting in toxic cloud | • Gas detectors<br>• Alarm systems on gas detection sounding in the control area, security gate and at the local fire brigade.<br>• Sprinkler systems fitted in the compressor house.<br>• Isolation valves fitted in the system activated by gas detection.<br>• Regularly maintained refrigeration system. |

# Appendix B

## Generic Failure Frequency and Event Trees

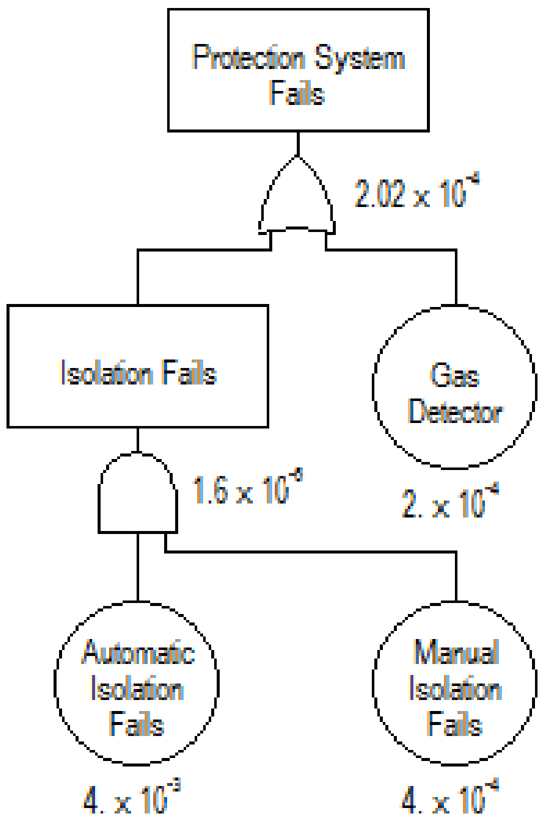
## B1. Generic Failure Frequencies and Probabilities

| Equipment | Failure Frequency ($x10^{-6}$) | | | Remarks |
|---|---|---|---|---|
| | Pinhole | Hole | Rupture | |
| Pipework | 30/m | 6/m | 0.3/, | Cox Lees Ang pg 39 |
| Valves | 1,000 | 100 | 0 | Cox Lees Ang pg 39 |
| Flanges | 1,000 | 100 | 0 | Cox Lees Ang pg 39 |
| Heat Exchanges | 7,800 | 780 | 0 | IEEE 16.1.1 |
| Separators | 30 | 3 | 0 | Nussey & Page |
| Pumps | 3,000 | 300 | 0 | Cox Lees Ang pg 39 |
| Compressors | 350 | 35 | 0 | NPDS |
| **Equipment** | **Failure Probability** | | | **Remarks** |
| Gas detector fails on demand | 0.0002* | | | Oreda |
| ESD fails on demand | 0.004 | | | HSE |
| Manual valve fails to close | 0.0004^ | | | HSE |

*Assuming testing of twice per year

^Assuming 1 order of magnitude lower than automatic

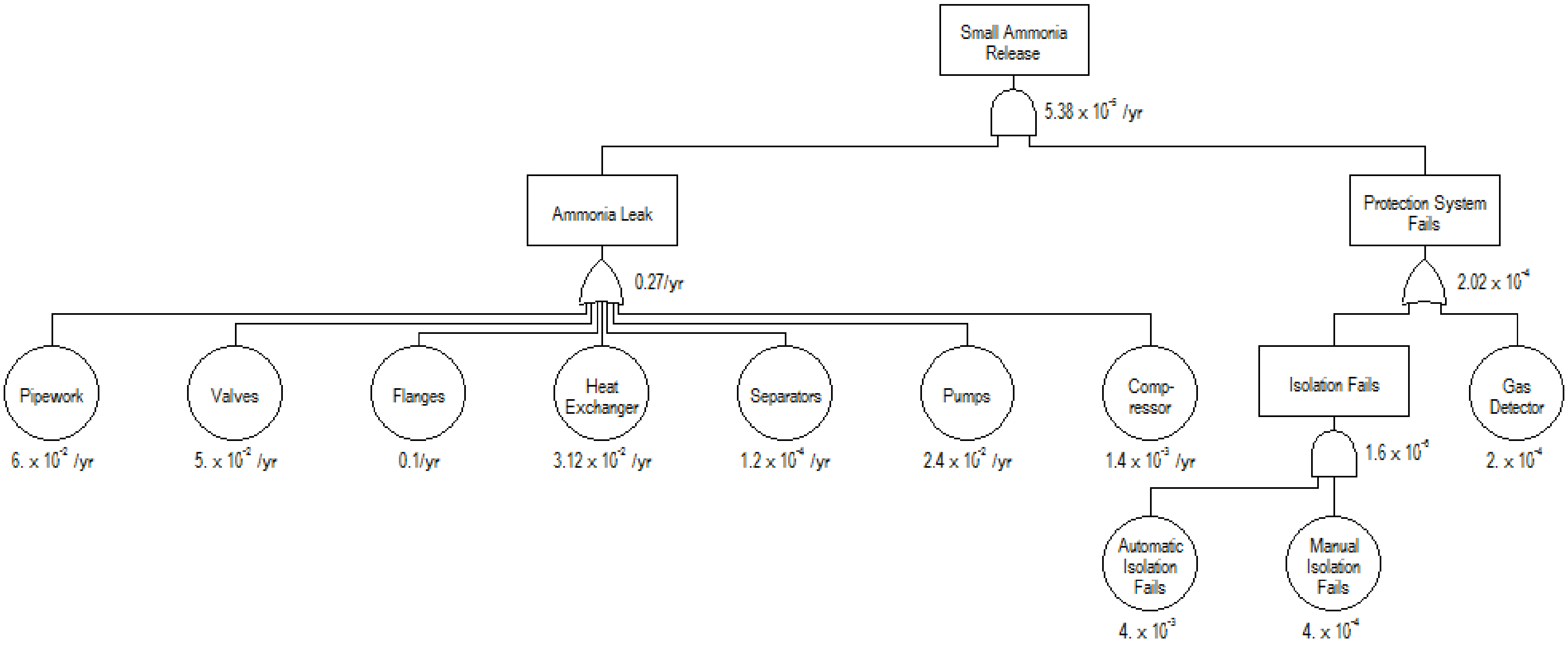
## B2. Protection System Fails



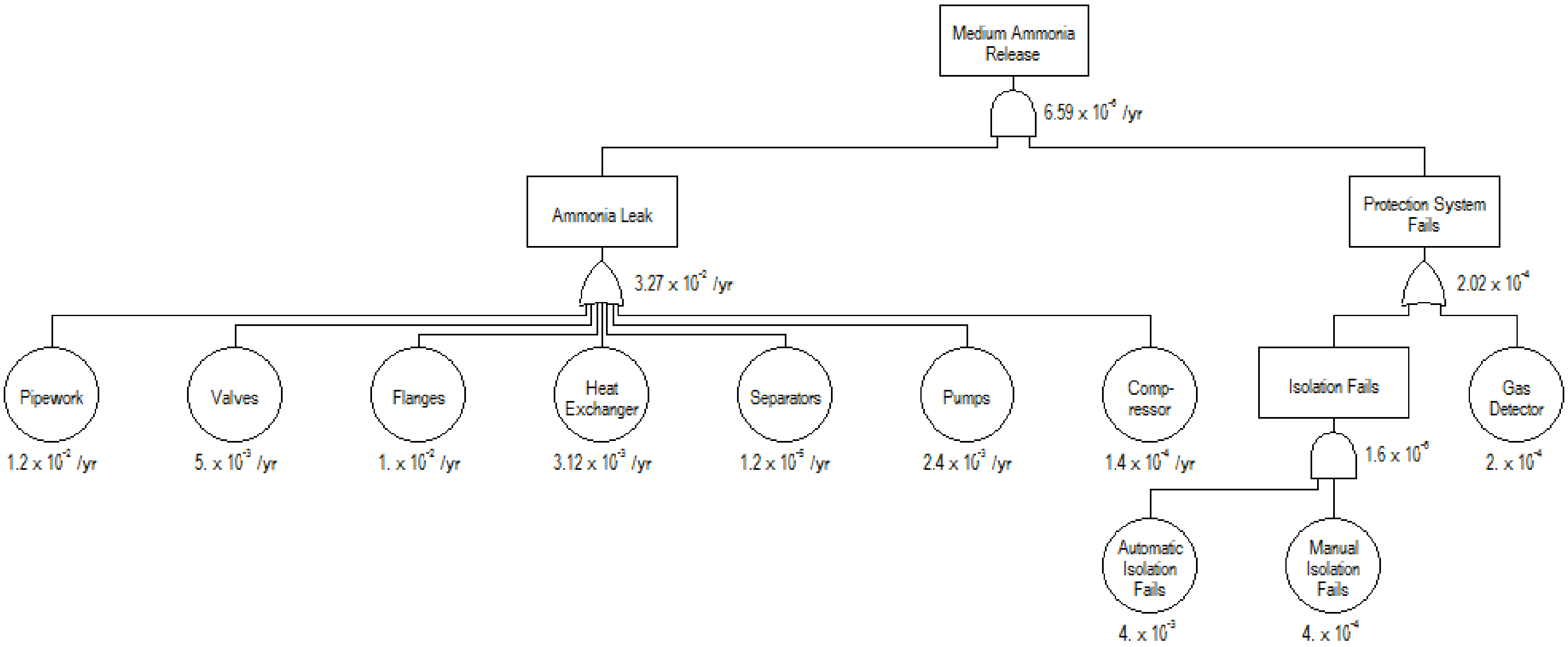
## B3. Assumed Equipment Used in Risk Assessment

| Equipment | Assumed Equipment in System |
| --- | --- |
| Pipework | 2,000 m |
| Valves | 50 |
| Flanges | 100 |
| Heat Exchanges | 4 |
| Separators | 4 |
| Pumps | 4 |
| Compressors | 4 |

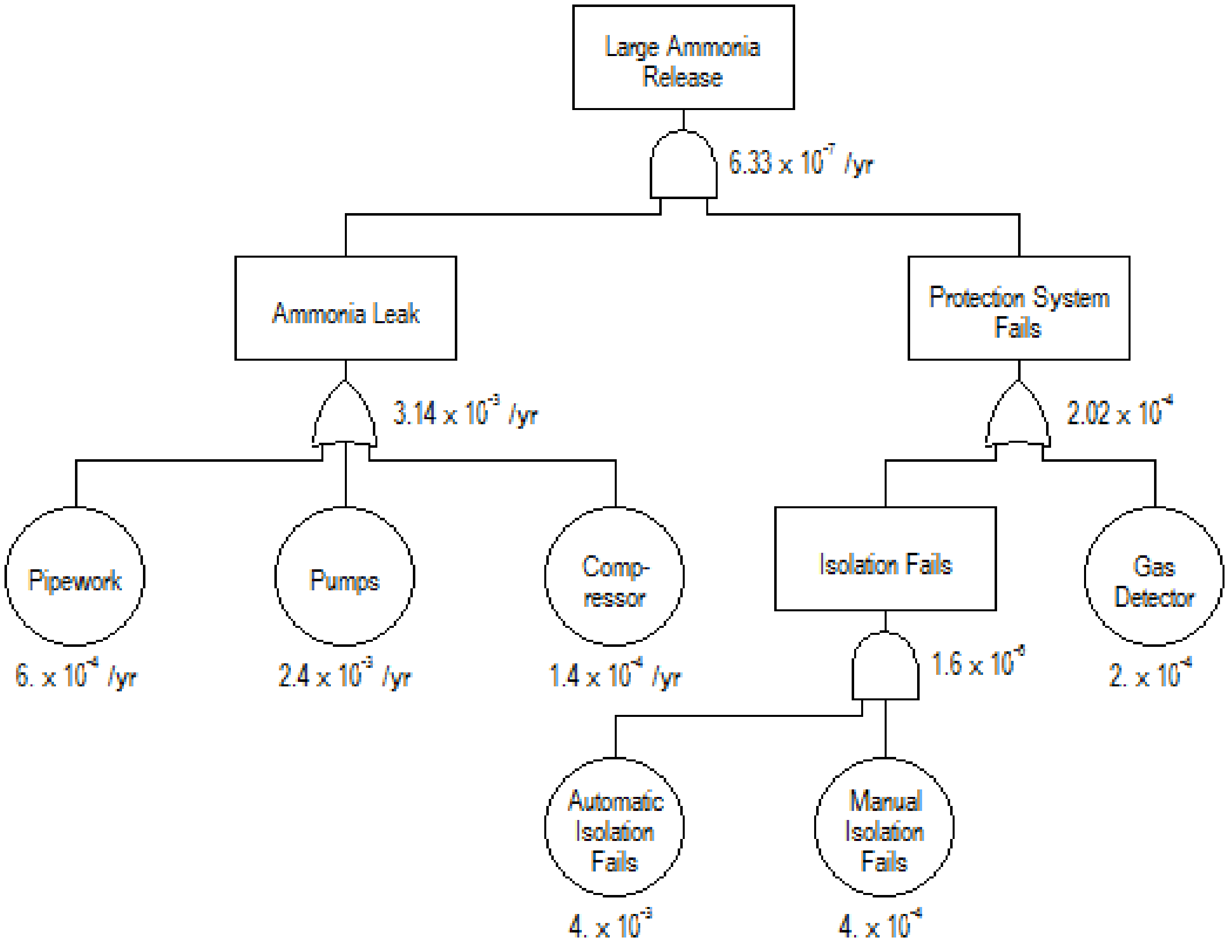
## B4. Small Ammonia Release



## B5. Medium Ammonia Release



## B6. Large Ammonia Release



# Appendix C

## Meteorological Data

## C1. Wind Class, Stabilities and Directions for Western Sydney

| Stability Class | Wind direction from (%) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | NNE | NE | ENE | E | ESE | SE | SSE | S | SSW | SW | WSW | W | WNW | NW | NNW | Total |
| A1.5 | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 2.7 |
| B3 | 1.0 | 1.3 | 0.7 | 0.5 | 0.3 | 0.4 | 0.5 | 0.6 | 0.9 | 0.7 | 0.5 | 0.4 | 0.2 | 0.2 | 0.2 | 0.6 | 9.0 |
| C3 | 1.3 | 1.8 | 1.1 | 0.7 | 0.5 | 0.7 | 0.9 | 0.9 | 1.5 | 1.5 | 1.0 | 0.4 | 0.5 | 0.3 | 0.4 | 0.7 | 14.2 |
| D3 | 1.8 | 1.8 | 1.3 | 1.1 | 1.0 | 1.6 | 2.6 | 2.6 | 4.1 | 5.4 | 3.9 | 1.7 | 2.5 | 2.2 | 1.7 | 1.0 | 36.3 |
| E1.5 | 0.7 | 0.5 | 0.6 | 0.5 | 0.6 | 0.4 | 0.6 | 0.7 | 1.6 | 2.2 | 1.3 | 0.7 | 0.6 | 0.7 | 0.4 | 0.4 | 12.5 |
| F1.5 | 1.7 | 1.5 | 1.5 | 1.0 | 0.8 | 0.7 | 0.6 | 1.3 | 3.4 | 4.3 | 2.5 | 1.2 | 1.2 | 1.2 | 1.5 | 1.2 | 25.6 |
| **Total** | **6.8** | **7.2** | **5.4** | **4.0** | **3.4** | **3.9** | **5.4** | **6.3** | **11.7** | **14.4** | **9.3** | **4.5** | **5.0** | **4.7** | **4.3** | **4.0** | **100** |

# Appendix D

## Release Rates

## D1. Ammonia Release Rates

| Hole Size (mm) | Release Rate (kg/s) | Pool Diameter (m) |
|---|---|---|
| 65 | 94.3 | 24 |
| 50 | 55.8 | 19 |
| 20 | 8.93 | 7.5 |
| 5 | 0.56 | 2 |

Temperature taken as 5ºC and pressure at 1,100 kPa.