Preliminary Hazard Analysis

5 Millner Avenue, Horsley Park

DHL Supply Chain (Australia) Pty Ltd
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DHL Supply Chain (Australia) Pty Ltd

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B	22 Jun 17	Incorporated proposed changes to DG quantities to be stored at the site		Kevin Blackie
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Abbreviations

Abbreviation	Description
ADG	Australia Dangerous Goods Code
ALARP	As Low As Reasonably Practicable
CBD	Central Business District
CCPS	Centre for Chemical Process Safety
DA	Development Application
DG	Dangerous Goods
ESFR	Early Suppression Fast Response
HIPAP	Hazardous Industry Planning Advisory Paper
HSE	Health and Safety Executive
LEL	Lower Explosive Limit
LPG	Liquefied Petroleum Gas

Abbreviation	Description
MHF	Major Hazard Facility
OIE	Oakdale Industrial Estate
PFD	Probability of Failure on Demand
PHA	Preliminary Hazard Analysis
pmpy	Per million per year
SEP	Surface Emissive Power
SEPP33	State Environmental Planning Policy No. 33
SSC	Spread Sheet Calculator
WHS	Work Health and Safety

Executive Summary

Background

DHL Supply Chain (Australia) Pty Ltd (DHL) operates a warehouse within the Oakdale Industrial Estate in Western Sydney, NSW which stores and handles a range of materials including products classified as Dangerous Goods (DGs). As part of the initial Development Application (DA), the facility was approved for several classes of DGs including Class 2.1, 3, 5, 8 and 9. As part of the operations, new customers will be storing product in the warehouse which are of DG classes currently not approved for storage in the warehouse. In addition, the currently approved volumes of DG classes in the warehouse may not be adequate for future customers.

To ensure compliance with the Environmental Planning Regulations 2000 and to future proof the facility, DHL has proposed to submit a new DA seeking approval for additional DG classes and volumes to ensure ongoing compliance accommodating the changing requirements of DHL's customers.

DHL has engaged Blackie Mendham Pty Ltd (BMPL) to prepare an updated Preliminary Hazard Analysis (PHA) to assess the risks associated with the increased volumes and classes of DGs to be stored as part of future proofing and compliance exercise.

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 – The updated report was developed based on the proposed changes to the facility for submission to the Regulatory Authority.

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;

- Flammable material or gas release, delayed ignition and flash fire or explosion.
- Flammable material spill, ignition and racking fire.
- LPG release (from aerosol), ignition and racking fire.
- Forklift loading/unloading, damaged packaged, flammable release, ignition and pallet fire.
- Full warehouse fire and toxic smoke emission.
- Dangerous goods liquid spill, release and environmental incident.
- Warehouse fire, sprinkler activation and potentially contaminated water release.
- Decomposition of organic peroxides and fire or explosion.
- Fire involving toxic substances and toxic smoke dispersion.

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 scenarios were carried forward for consequence analysis;

- Flammable liquid spill, ignition and racking fire.
- LPG release (from aerosol), ignition and racking fire.
- Forklift loading/unloading, damaged package, flammable release, ignition and pallet fire.
- Full warehouse fire and toxic smoke emission.
- Fire involving toxic substances and toxic smoke dispersion.

The impacts estimated for each of the scenarios were overlaid on the site layout diagram to assess offsite impacts. The analysis indicated the racking fires would be controlled and suppressed by the sprinkler systems and would not impact over the site boundary; however, in the event the sprinkler systems failed to activate a fire could grow to consume the entire warehouse. A full warehouse fire was determined to impact over the site boundary; hence, this incident was carried forward for further analysis.

Frequency Analysis and Risk Assessment

It was identified that a full warehouse fire may impact over the site boundary and therefore the probability of a fire occurring and the likelihood of a fatality were assessed. The analysis showed that the fatality risk at the site boundary was 3.53 chances in a million per year (pmpy).

The frequency of a toxic smoke dispersion would occur at a rate equal to that for a full warehouse fire which was identified to be 3.53 chances 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 (full warehouse fire) would impact over the site boundary and into the adjacent land use; hence, this incident was carried forward for frequency analysis and risk assessment.

The frequency analysis and risk assessment showed that the full warehouse fire would have a fatality risk of 3.53 chances per million per year (pmpy) at the site boundary, with lesser risk at further distances from the boundary. HIPAP No. 4 publishes acceptable risk criteria at the site boundary of 50 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.

In addition, the analysis of smoke resulting in irritation or injury at the surrounding land uses was assessed and found to be 3.53 pmpy. The acceptable criterion for irritation or injury is 10 pmpy for short term exposure and 50 pmpy for overall exposure. Therefore, this criterion is not exceeded and is within the acceptable criteria.

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 recommendation has been made:

- Multiple spill kits should be provided around the DG store to ensure spills can be cleaned up immediately following identification
- The fire pumps should be started at least once per month and the system operated at full pump pressure during this monthly test
- The site emergency plan should include response to spills and spill clean-up procedures

1.0 Introduction

1.1 Background

DHL Supply Chain (Australia) Pty Ltd (DHL) operates a warehouse within the Oakdale Industrial Estate in Western Sydney, NSW which stores and handles a range of materials including products classified as Dangerous Goods (DGs). As part of the initial Development Application (DA), the facility was approved for several classes of DGs including Class 2.1, 3, 5, 8 and 9. As part of the operations, new customers will be storing product in the warehouse which are of DG classes currently not approved for storage in the warehouse. In addition, the currently approved volumes of DG classes in the warehouse may not be adequate for future customers.

To ensure compliance with the Environmental Planning Regulations 2000 and to future proof the facility, DHL has proposed to submit a new DA seeking approval for additional DG classes and volumes to ensure ongoing compliance accommodating the changing requirements of DHL's customers.

DHL has engaged Blackie Mendham Pty Ltd (BMPL) to prepare an updated Preliminary Hazard Analysis (PHA) to assess the risks associated with the increased volumes and classes of DGs to be stored as part of future proofing and compliance exercise.

1.2 Objectives

The objectives of the PHA update for Warehouse 2B in Western Sydney, NSW, were to:

- complete the PHA according to the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 – Hazard Analysis (Ref. [2]).
- assess the PHA results using the criteria in HIPAP No. 4 – Risk Criteria for Land Use Planning (Ref. [1]).
- demonstrate compliance of the site with the relevant codes, standards and regulations (i.e. NSW Planning and Assessment Regulation 1979, WHS Regulation, 2011)

1.3 Scope of Services

The scope of work is to complete a updated PHA study required by the Planning Regulations for the existing DHL Facility in Western Sydney, NSW. The scope does not include any other assessments at the site or any other DHL facilities or third party owner facilities.

2.0 Methodology

2.1 Multi-Level Risk Assessment

The Multi-Level Risk Assessment approach (Ref. [3]), although published by the NSW Department of Planning and Environment, 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 the facility'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**.

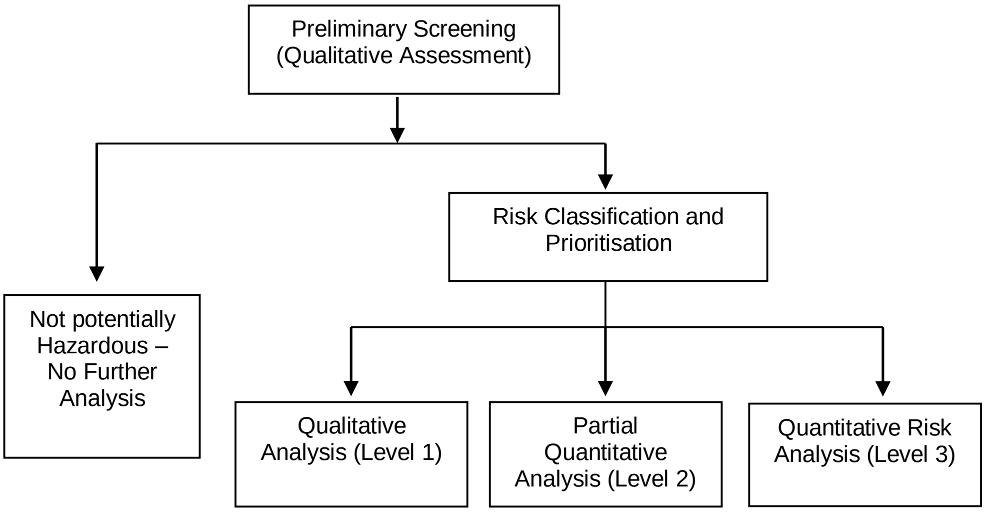

Figure 2-1: The Multi-Level Risk Assessment Approach

Based on the type of DGs to be stored, handled and used 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.

2.2 Risk Assessment Study Approach

The methodology used for the PHA is indicated in HIPAP No. 6 (Ref. [2]) is presented below:

<u>Hazard Analysis</u> – 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. [2]).

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 4.1** 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 – The updated report was developed based on the proposed changes to the facility for submission to the Regulatory Authority.

3.0 Site Description

3.1 Site Location

The site is located at Millner Avenue which is situated within the Oakdale Industrial Estate (OIE) at Horsley Park which is approximately 58 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.

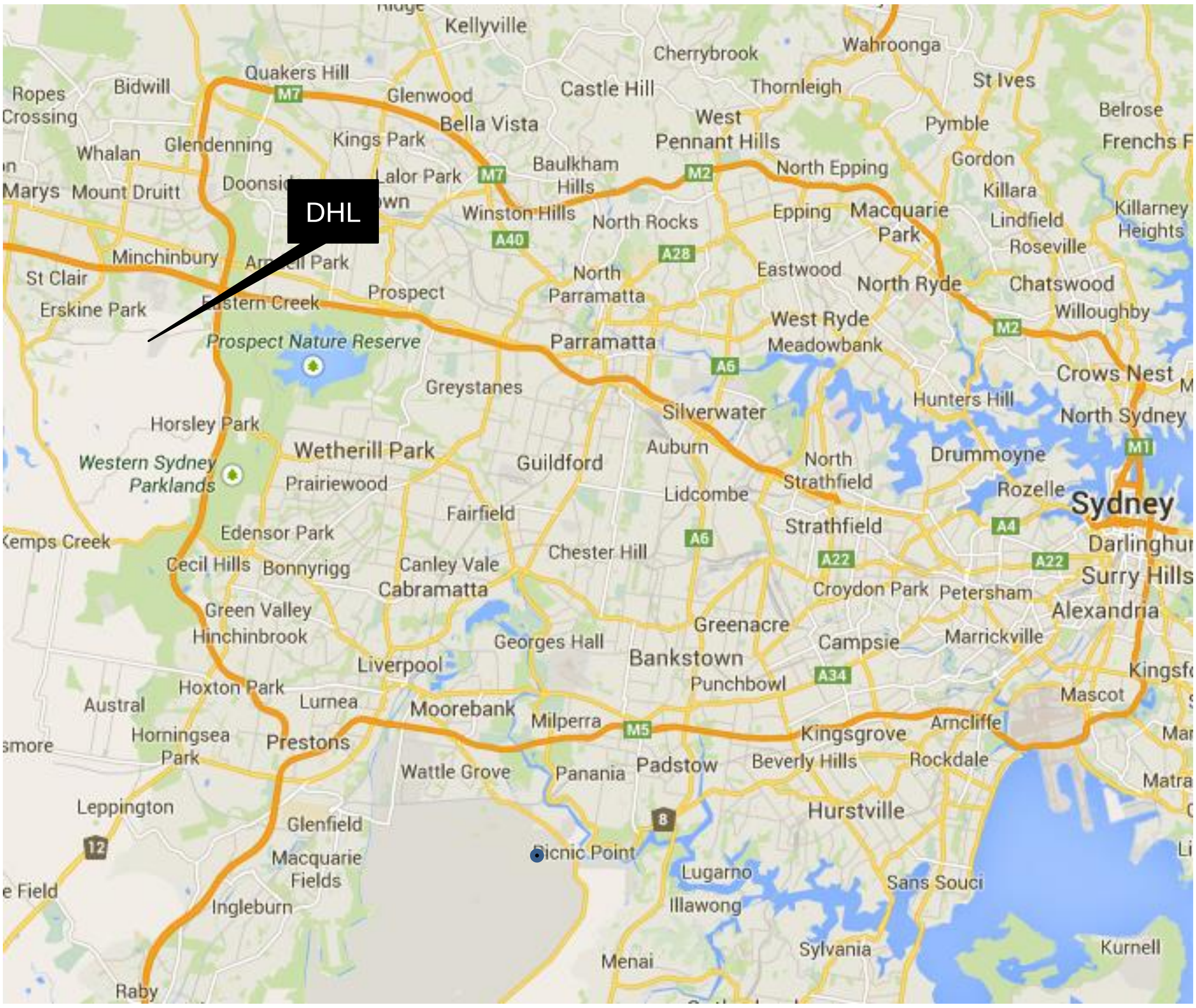

Figure 3-1: DHL Site Location

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 – Building 1C occupied by DHL.
- South – Stormwater treatment swale servicing OIE.
- East – Transport building occupied by DHL.
- West – Riparian zone maintained by Goodman.

3.3 General Description

The building consists of an office area, amenities and warehouse area including a Dangerous Goods (DG) storage area. The office area houses staff and general operations, and the warehouse has been designed to contain a mixture of general products and DGs in retail packaging stored on racking. DG classes and volumes are discussed in **Section 3.5**. **Figure 3-2** can be used to assist in understanding the description provided below.

3.4 Existing Warehouse Design and Operations

The warehouse has a floor area of approximately 29,500 m^2 including a DG store area of 2,660 m^2. The warehouse area contains pallet racking capable of storing 6 pallets high. The DG store area walls were constructed from 240/240/240 FRL panels which penetrate through the roof by 0.5 m where the wall share a common space with the remainder of the warehouse, to provide a completely separate fire compartment. The DG Store area is further compartmentalised through the use of an internal 240/240/240 FRL wall (also penetrating 0.5 m through the roof) creating two fire compartments within the DG Store area (DGS1 & DGS2).

The larger store (DGS1) contains Class 2.1 and Class 3 DGs and has been designed according to AS 1940-2004 (Ref. [4]). The store is protected by base building specified Early Suppression Fast Response (ESFR) sprinklers in addition to in-rack scheme A sprinklers designed according to FM Global Data Sheet 7-31 (Ref. [5]). The store is also fitted with hose reels with foam making capabilities.

The storage is bunded to be able to contain 155 m^3, which encompasses the requirements for a package store from AS 1940-2004 (Ref. [4]) in addition to 20 minutes of fire water. The store is ventilated to prevent the accumulation of vapours and ignitions sources within DGS1 are controlled according to AS/NZS 60079.14:2009 series (Ref. [6]).

DGS2 contains Class 5.1, Class 8 and Class 9 DGs with the DGs within this location stored and handled according to AS/NZS 3833:2007 (Ref. [7]). The DGs in DGS2 are protected by the ESFR system and will be partially bunded to contain 25 m^3 of product and fire water. Any over flow of fire water from this store is contained within the premises via isolation of the discharge valve.

Several products to be stored in the warehouse are temperature sensitive and will deteriorate if heated above 25^{o}C. To ensure product integrity, the DG bunker remains open allowing cooled air to enter the DG store providing adequate cooling. Air from within the DG store is extracted and ventilated to prevent the recirculation of flammable vapours within the warehouse space.

The warehouse has approval to operate 24 hours a day, 7 days a week; however, operations tend to occur between 6 am – 6 pm, Monday to Friday. The site is occupied by 50 office staff during business hours and approximately 150 personnel working within the warehouse depending on shift rotation.

3.5 Existing Dangerous Goods Storage

Provided in **Table 3-1** is a summary of the DG holdings that are currently approved for storage in the warehouse.

Table 3-1: Existing Approved Dangerous Goods Stored Classes and Quantities

Class	Packing Group	Quantity (L or kg)	DG Location
2.1 (aerosols)	N/A	90,000 kg (weight of LPG*)	DGS1
3	II & III	900,000 L	
5.1	II & III	45,000 kg	DGS2
8	II & III	20,000 kg	
9	III	10,000 kg	

*The LPG in an aerosol is the propellant is approximately 25% of the total product weight.

3.6 Proposed Changes to Classes and Quantities

Provided in **Table 3-2** is a summary of the proposed changes to the classes and quantities to be stored at the site.

Table 3-2: Proposed Classes and Quantities to be Stored

Class	Packing Group	Quantity (L or kg)	DG Location
2.1 (aerosols)	N/A	90,000 kg (weight of LPG*)	DGS1
2.2	N/A	200,000 L #	
3	II & III	900,000 L	
4.1	II & III	75,000 kg	
5.1	II & III		DGS2
5.2^	II & III		
6.1	II & III		
8	II & III	200,000 kg	General Warehouse
9	III	100,000 kg #	

* The LPG in an aerosol is the propellant is approximately 25% of the total product weight.

Package volume (note: not subject to SEPP 33)

^ No temperature controlled organic peroxides will be stored

To facilitate picking and packing operations, small storages of each class of DG product stored will be located throughout the warehouse. Location of each storage are shown in **Figure 3-2** with the commodities for ‘customers’ summarised in **Table 3-2**.

Table 3-2: General Warehouse Storages

Customer	Class	Maximum Pallets	Maximum Quantity
1	2.1	6	6,000 L*
2	4.1	6	6,000 kg
3	3	8	8,000 L
4	2.1	1	1,000 L*
	3	1	1,000 L

Customer	Class	Maximum Pallets	Maximum Quantity
	4.1	1	1,000 kg
5	3	3	3,000 L
6	2.1	1	1,000 L*
	3	5	5,000 L
	6.1	1	1,000 L
	8	-	200,000 L
	9	-	100,000 L

*Package volume

The products and commodities stored comply with the definitions of retail packages; hence, the facility may be operated as a Retail Distribution Centre (RDC) as permitted by AS/NZS 3833:2007 (Ref. [7]). The main requirements associated with RDC storages involve fire protection and containment of potentially contaminated liquids within the premises of the facility.

A review of **Table 3-2** indicates 31,000 L or kg or flammable products will be stored in the general warehouse spaces. Per Table 9.3 of AS/NZS 3833:2007, the required fire protection is extinguishers, hydrants and fire hose reels. The facility is fitted with an ESFR sprinkler system in addition to extinguishers, hydrants and hose reels. Therefore, the fire protection system far exceeds the requirements for protection for the general warehouse storages.

In terms of spill containment, the site has been designed to contain the full volume of spills and sprinkler discharge in the event of a fire for a period of 90 minutes. Therefore, it is considered that all spills associated with the storage of DGs would be contained within the site premises as required.

3.7 Aggregate Quantity Ratio

Where more than one class of dangerous goods are stored and handled at the site an AQR exists. This ratio is calculated using **Equation 1**;

$$AQR = \frac{q_x}{Q_x} + \frac{q_y}{Q_y} + [\ldots] + \frac{q_n}{Q_n}$$ **Equation 1**

Where:

- x,y […] and n are the dangerous goods present
- q_x, q_y, […] and q_n is the total quantity of dangerous goods x, y, […] and n present.
- Q_x, Q_y, […] and Q_n is the individual threshold quantity for each dangerous good of x, y, […] and n

Where the ratio AQR exceeds a value of 1, the site would be considered a Major Hazard Facility (MHF).

Using **Equation 1** and the quantities of DGs stored, the AQR is calculated as follows;

$$AQR = \frac{90}{200} + \frac{900}{50000} + \frac{75}{200} = 0.83$$

The facility would be 83% of an MHF; hence, it would not be classified as a MHF.

3.8 Dangerous Goods Locations

Figure 3-2 shows the location of DGs within the DG bunkers while **Figure 3-3** shows the locations where the DGs are stored within the facility.

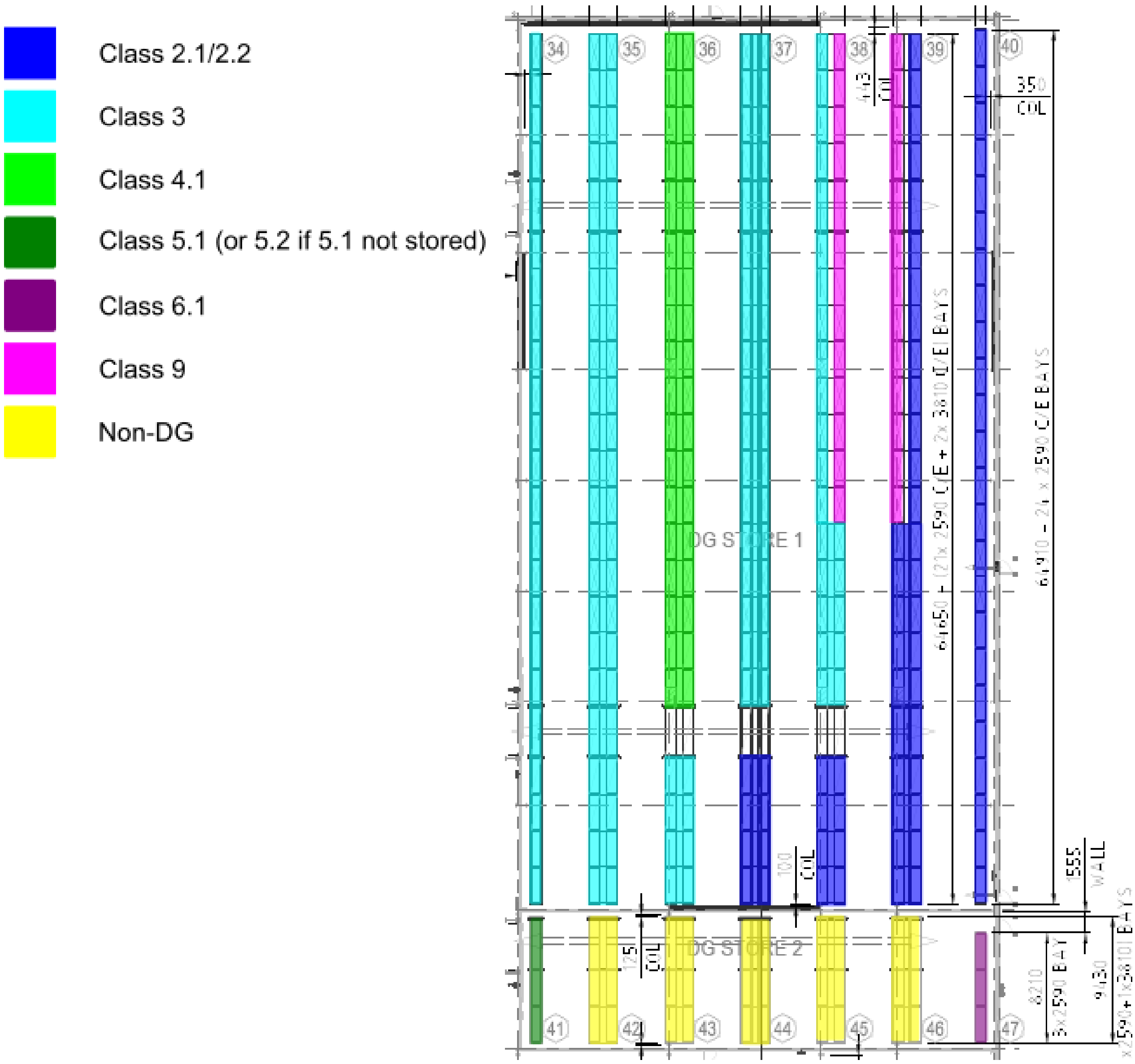

Figure 3-2: Racking Layout

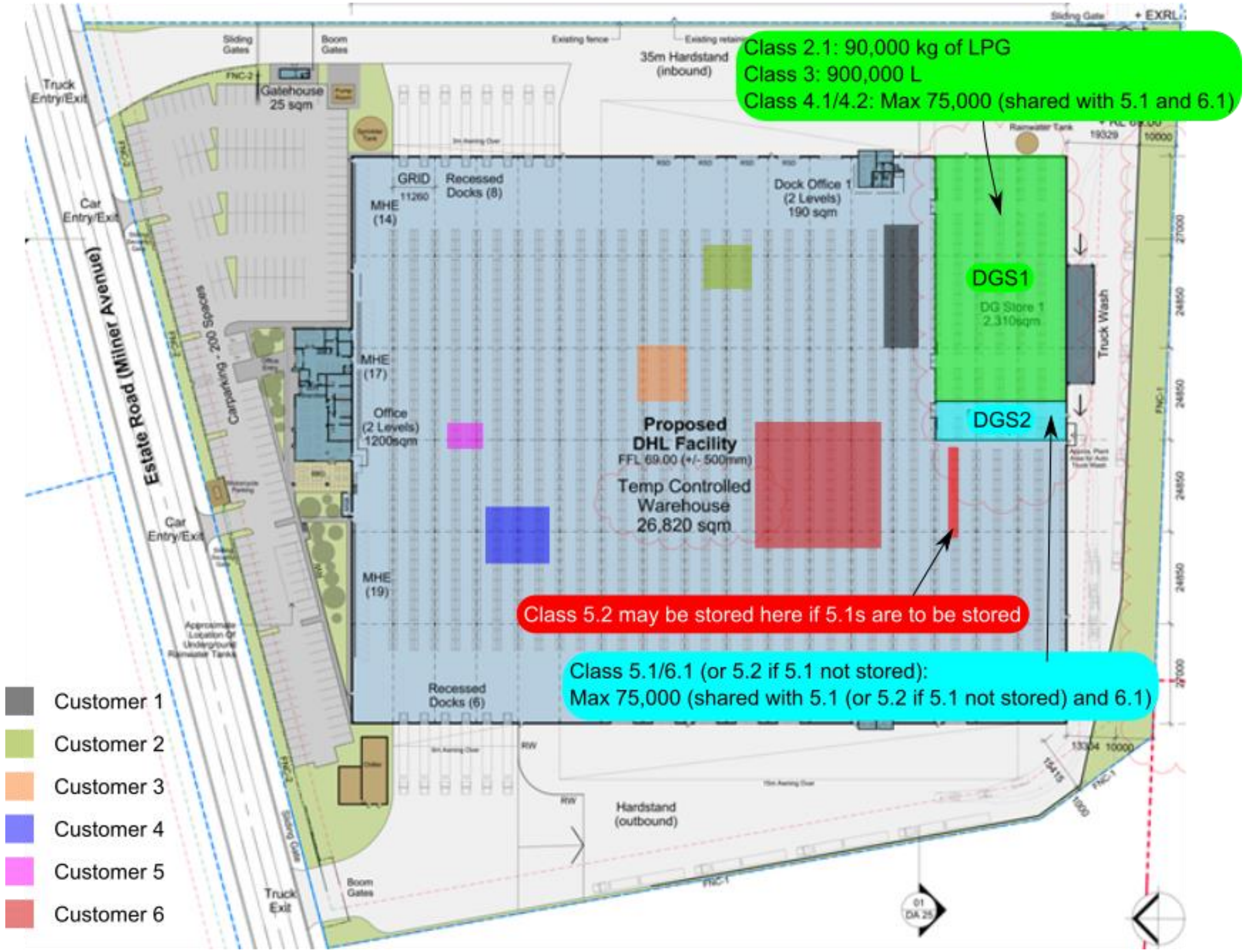

Figure 3-3: Building 2B at Oakdale Industrial Estate

4.0 Hazardous 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. 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 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 500 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. [1]) 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). Similar 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 500 m from the site (noting that only industrial areas adjoin the proposed facility).

- *Toxicity* – Toxic products will be stored in the warehouse; hence, toxic impacts from combustion of these products will be assessed for irritation, injury and fatality.

- *Property Damage and Accident Propagation* - It is noted in HIPAP No. 4 (Ref. [1]) 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. [1]) 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 DHL 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. Hence, societal risk has not been considered in this study. The closest residential area is located over 500 m away 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
2.1 – Flammable Gases	Class 2.1 includes flammable gases which are ignitable when in a mixture of 13 per cent or less by volume with air or have a flammable range with air of at least 12 percentage points regardless of the lower flammable limit. Ignited gas may result in explosion or flash fire.
2.2 – Non-Flammable, Non-Toxic Gases	Class 2.2 includes gases which are non-flammable, non-toxic such as nitrogen, helium, etc. Risks posed by these products are based on storage of gases under pressure but pose no flammability or toxic issues.
3 – Flammable Liquids	Class 3 includes flammable liquids which are liquids, or mixtures of liquids, or liquids containing solids in solution or suspension (for example, paints, varnishes, lacquers, etc.) which give off a flammable vapour at temperatures of not more than 60°C closed-cup test or not more than 65.6°C open-cup test. Vapours released may mix with air and if ignited, at the right, concentration will burn resulting in pool fires at the liquid surface.
4.1 – Flammable solid	Flammable solid materials are materials that may burn when exposed to an ignition source, examples of flammable solids include matches and some waxes.
5.1 – Oxidising Agents	Class 5.1 materials will combust but these materials include substances which can in a fire event, liberate oxygen and could accelerate the burning of other combustible or flammable materials. Releases to the environment may cause damage to sensitive receptors within the environment.
5.2 – Organic Peroxides	Organic peroxides are liable to exothermic decomposition at normal or elevated temperatures. The decomposition can be initiated by heat, contact with impurities (e.g. acids, heavy-metal compounds, amines), friction or impact. The rate of decomposition increases with temperature and varies with the organic peroxide formulation. Decomposition may result in the evolution of harmful, or flammable, gases or vapours. For certain organic peroxides, the temperature must be controlled during transport. Some organic peroxides may decompose explosively, particularly if confined. This characteristic may be modified by the addition of diluents or by the use of appropriate packagings. Many organic peroxides burn vigorously.
6.1 – Toxic substances	Toxic substances are substances that are liable either to cause death or serious injury or to harm human health if swallowed or inhaled or by skin contact.

Class	Hazardous Properties
8 – Corrosive Substances	Class 8 substances (corrosive substances) are substances which, by chemical action, could cause damage when in contact with living tissue (i.e. necrosis), or, in case of leakage, may materially damage, or even destroy, other goods which come into contact with the leaked corrosive material. Releases to the environment may cause damage to sensitive receptors within the environment.
9 – Miscellaneous DGs	Class 9 substances and articles (miscellaneous dangerous substances and articles) are substances and articles which, during transport present a danger not covered by other classes. Releases to the environment may cause damage to sensitive receptors within the environment.

* 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:

- Flammable material or gas release, delayed ignition and flash fire or explosion.
- Flammable material spill, ignition and racking fire.
- LPG release (from aerosol), ignition and racking fire.
- Forklift loading/unloading, damaged packaged, flammable release, ignition and pallet fire.
- Full warehouse fire and toxic smoke emission.
- Dangerous goods liquid spill, release and environmental incident.
- Warehouse fire, sprinkler activation and potentially contaminated water release.
- Decomposition of organic peroxides and fire or explosion.
- Fire involving toxic substances and toxic smoke dispersion.

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

4.3.1 Flammable Material Spill or Gas Release, Delayed Ignition and Flash Fire or Explosion

As noted in **Section 3.5**, flammable materials (Class 3 & 4) will be held at the site for storage and distribution. There is potential that a flammable material spill could occur in the warehouse area due to an accident (packages dropped from forklift, punctured by forklift tines) or deterioration of packaging. If a flammable material spill occurred, the material may begin to evaporate (depending on the material flashpoint and ambient temperature). Where materials do evaporate, there is a potential for accumulation of vapours, forming a vapour cloud above the spill.

If the spill is not identified, the cloud may continue to accumulate, eventually contacting an ignition source. If the cloud is confined (i.e. pallet racking and stored products) the vapour cloud may explode, or, if it is unconfined, it may result in a flash fire which would burn back to the flammable material spill, resulting in a pool fire.

A similar scenario could occur with the release of liquefied petroleum gas (LPG) from an aerosol; however, the formation of a gas cloud would occur immediately as the LPG would instantly flash to gas following release from the canister. It is noted that the potential for a release of LPG is low as aerosol canisters are pressure tested during manufacture and filling; hence, release would predominately result from damaged product rather than deterioration.

A review of the product list to be stored at DHL indicates that the majority of the products are small packages (< 1 L for aerosols and < 20 L for flammable materials). Therefore, the release from a single flammable liquid container would result in a release <20 L. For aerosols, the quantity of LPG propellant used is approximately 25% of the weight of the product hence, for a 1 L product approximately 250 mL of LPG would be released. The associated vapour cloud formed by the release of gas or flammable liquid would be insufficient to result in offsite impacts from ignition.

Packages are inspected for damage upon receipt at the loading dock before they are transported into the warehouse. This minimises the likelihood that a damaged package is incorrectly stored. Once stored inside the warehouse, deterioration or damage are unlikely to occur.

To minimise the likelihood that a flammable vapour cloud may contact an ignition source, the electrical equipment within the DG store hazardous zone will be installed according to the requirements of AS/NZS 60079.14:2009 (Ref. [6]).

The site operates from approximately 6 am to 6 pm, Monday to Friday; hence, if a spill occurred, it would be identified by personnel working in the warehouse during these times where it could be immediately cleaned up. To ensure appropriate cleaning equipment is available, ***it is recommended that multiple spill kits be provided around the DG store to ensure spills can be cleaned up immediately following identification.***

Based on the warehouse design (ventilation, controlled ignition sources, etc.), operation practices and the storage of small packages, the risk of a vapour cloud being generated that is large enough to ignite and impact over the site boundary, by way of a vapour cloud explosion or a flash fire, is considered to be low (if not negligible); hence, this hazard has not been carried forward for further analysis.

4.3.2 Flammable Material Spill, Ignition and Racking Fire

As noted in **Section 4.3.1**, it is considered that there is a low potential for a package to leak resulting in a flammable material spill and there are several controls in place to minimise the likelihood of a damaged container entering the warehouse and additional controls to minimise the potential that ignition of a flammable material spill could occur.

If a flammable material spill was to occur (e.g. dropped drum/container during handling) and it was ignited (e.g. by the forklift), the fire would initially be small due to the majority of packages stored being 20 L or less. While a fire would be limited in size, heat generated may impact adjacent packages which may deteriorate and release their contents contributing additional fuel to the fire. As the fire grows, ESFR sprinklers would activate controlling the fire within the sprinkler array and cooling adjacent packages preventing deterioration and reducing the potential for fire growth.

Based on the limited fire size, the design of the warehouse and the installed fire systems, the risks of this incident impacting over the site boundary are considered to be low. Notwithstanding this, this incident has be carried forward for further analysis to demonstrate the likely impact of an ESFR sprinkler controlled fire is within the site boundary.

4.3.3 LPG Release (from Aerosol), Ignition and Racking Fire

As noted in **Section 4.3.1**, the potential for release of LPG from an aerosol is considered low due to the quality assurance testing on aerosol canisters during the filling process. The release of LPG would likely result from damage to aerosols during transport and storage rather than from deterioration. Packages are inspected upon delivery and an accident involving aerosols would trigger an additional inspection to verify that damage did not occur.

Notwithstanding this, there is the potential for a release of LPG to occur within the storage racking. Due to the hazardous area rated equipment within the area and protocols it is considered unlikely for an ignition to occur; however, in the event that an ignition of a LPG release did occur a fire could result.

The fire would consume the packaging with the generated heat impacting the adjacent aerosols. As the LPG within the adjacent aerosols expands the canisters may rupture releasing LPG which would ignite and rocket the canister throughout the aerosol cage potentially spreading the fire.

As the fire grows, the ESFR and in-rack sprinklers will activate to suppress the fire and cool adjacent packages to minimise the potential for aerosol rupture and rocketing. Activation of this system would control the fire within the sprinkler array as specified by testing conduct by FM Global in Data Sheet 7-31 (Ref. [5]).

A fire within the aerosol racking would be unlikely to impact over the site boundary; notwithstanding this, this incident has been carried forward for consequence analysis.

4.3.4 Forklift Loading/Unloading, Damaged Package, Flammable Release, Ignition and Pallet Fire

Pallets will be loaded and unloaded via forklift outside of the warehouse. Delivered products may be temporarily stored on pallets in a transit area prior to relocation into the warehouse. Conversely, pallets may be located temporarily during dispatch operations.

During relocation of pallets there is the potential for forklift tines to puncture the product or for the pallets to be dropped resulting in damage. If the packages are damaged they may release flammable liquid or gases which could ignite resulting in a pallet fire.

The potential for a fire to occur within the transit area is considered to be low and based on the quantity of material on a pallet the impact is unlikely to impact off site. Notwithstanding this, this incident has been carried forward for consequence analysis to verify the likely impacts from a pallet fire.

4.3.5 Full Warehouse Fire

There is potential that if a flammable liquid pool fire occurred and the fire protection system failed to activate, a small fire may escalate as radiant heat impacts adjacent packages which may deteriorate, releasing additional fuel to the fire. In the event of a fire the fire doors would automatically close upon detection isolating the fire within the DG bunker. Therefore the potential for a full warehouse fire to occur is considered to be low; notwithstanding this, this incident has been carried forward to assess the impact of a full warehouse fire in the event the fire is not fully contained within the bunker and spreads through the warehouse.

4.3.6 Dangerous Goods Liquid Spill, Release and Environmental Incident

There is potential that a spill of the liquid DGs (Class 3, 5.1, 8 and 9) could occur at the site which if not contained could be released into the public water course resulting in a potential environmental incident.

To prevent spills escaping from the warehouse store, the DG bunkers will be bunded to contain a portion of the package store according to the relevant standard. DGS1 will be able to contain 155 m^3 while DGS2 will be able to contain 25 m^3. In addition, the site drainage is designed to be isolated, using a penstock isolation valve, preventing release of spills or liquids from the facility into the water course.

As noted, the volumes of the packages are small (< 20 L) and the facility has been designed with a bunded area, and drain isolation system, allowing the containment of any spills within the premises; hence, in the event of a release the full volume will be contained within the warehouse area. As a spill would be contained within the bund/site drainage there is no potential for an environmental incident to occur; hence, this incident has not been carried forward for further analysis.

4.3.7 Warehouse Fire, Sprinkler Activation and Potentially Contaminated Water Release

In the event of a fire, the ESFR sprinkler system will activate discharging fire with water to control and suppress the fire. Contact of the fire water with DGs may result in contamination which, if released to the local watercourse, could result in environmental damage. The ESFR system delivers approximately 5 m^3/min of water which, if operated for a long period, may result in overflow of site bunding and potential release. The facility has been designed to be able to contain all DG spills and liquid effluent resulting from the management of an incident (i.e. fire) within the premises.

The '*Best Practice Guidelines for Contaminated Water Retention and Treatment Systems*" (Ref. 14) provides guidance as to how much water should be able to be retained within the premises. The time suggested by the guidelines indicates the premises should be able to contain 90 minutes of fire water; which, at 5 m^3/min would result in 450 m^3 of water. The DG DGS1 has been designed to contain 20 minutes of fire water while DGS2 has been designed to contain a portion of the fire water with the rest being contained within the warehouse area.

The site is fitted with a shut-off valve which isolates the site drainage system preventing liquid effluent from discharging from the premises. In addition, any water discharging from the containment system passes through an interceptor (oil removal facility adjacent to the premises).

Based on the design and contaminated for the premises, there is adequate fire water retention to meet the '*Best Practice Guidelines for Contaminated Water Retention and Treatment Systems*" (Ref. [9]), hence, this incident has not been carried forward for further analysis.

4.3.8 Decomposition of Organic Peroxide and Fire or Explosion

Organic peroxides may be stored at the site; however, it is noted only non-temperature controlled organic peroxides will be stored. This substantially reduces the risk profile of these products as decomposition during storage within a warehouse is reduced as it does not require continuous power operation to maintain cooling.

As the non-temperature controlled organic peroxides will be stored there is a reduced risk of thermal decomposition which may result in fire or explosion. The organic peroxides will be stored in retail packages; hence, the potential for rapid decomposition resulting in overpressure is unlikely to occur. In addition, the storage racking does not provide sufficient confinement for pressure to build up; hence, explosion is not considered a credible scenario. Notwithstanding this, in the event of thermal decomposition of products, sufficient heat may be generated which may ignite packaging. While this is considered unlikely, it is a possibility. In the event of a fire, the sprinkler system would activate to control and suppress the scenario and would result in a fire profile similar to a flammable gas or liquid fire scenario. Therefore, this scenario has will be assessed as part of the analysis for flammable gases and liquids.

In terms of initiating incident and propagation, the organic peroxides are separated from DG classes requiring 3 m separation and are kept in separate compounds (in terms of Class 5.1s) or provided with substantial separation to other storages of DG classes. Therefore, it is considered that interaction between the Class 5.2s and other DG classes is unlikely to occur.

It is noted that Class 5.1s are not currently in the stock rotation for DHL; hence, the Class 5.2s will be stored in DGS2 while this remains the case in the location of the Class 5.1s. In the event that Class 5.1s return to the stock rotation, the Class 5.2s will be stored in the main warehouse area to ensure appropriate separation and segregation.

Based on the analysis provided it is considered there are sufficient controls for minimising interactions between Class 5.2s and other classes and sufficient protection (in the form of sprinklers) to mitigate and control the scenario. Notwithstanding this, a fire scenario could occur and would be similar in impact to a sprinkler controlled flammable gas/liquid fire. Therefore, this specific incident will not be individually assessed; however, the results estimated for the flammable gas/liquid fires would be applicable to this fire scenario.

4.3.9 Fire Involving Toxic Substances and Toxic Smoke Dispersion

The toxic substances are stored in a separate concrete panelled cut-off room which will protect them from direct exposure to a full warehouse fire. Notwithstanding this, if the fire continues, the concrete panelling may deteriorate resulting in radiant heat impact on the toxic products which may begin to burn releasing toxic smoke. In addition, class 6.1s may be stored in the general warehouse for picking of orders which may be involved in a full warehouse fire resulting in toxic smoke emission. As there is the potential for offsite incidents resulting from toxic smoke exposure, this incident has been carried forward for further analysis.

5.0 Consequence Analysis

5.1 Incidents Carried Forward for Consequence Analysis

Four incidents were identified to have potential to impact off site:

- Flammable liquid spill, ignition and racking fire.
- LPG release (from aerosol), ignition and racking fire.
- Forklift loading/unloading, damaged package, flammable release, ignition and pallet fire.
- Full warehouse fire and toxic smoke emission.
- Fire involving toxic substances and toxic smoke dispersion.

Each incident has been assessed in the following sections.

5.2 Flammable Liquid Spill, Ignition and Racking Fire

There is the potential for a fire to develop in the flammable liquid section of the DG store resulting in a racking fire. As the fire grows the ESFR sprinklers would activate suppressing and controlling the fire while cooling adjacent packages minimising the potential for lateral spread due to radiant heat. A detailed analysis has been conducted in **Appendix B** and the radiant heat impact distances estimated for this scenario are presented in **Table 5-1**.

Table 5-1: Heat Radiation from a Flammable Liquid Racking Fire

Heat Radiation (kW/m^2)	Distance (m)
35	8.5
23	10.4
12.6	13.8
4.7	22.2
3.0	27.6
2.1	32.7

As shown in **Figure 5-1**, the radiant heat impacts at 4.7 kW/m^2 are contained within the site boundary and would not pose a fatality risk at the site boundary; hence, this incident has not been carried forward for further analysis.

5.3 LPG Release (From Aerosol), Ignition and Racking Fire

A damaged aerosol canister could result in the release of LPG which if ignited may result in a fire. As the fire grows the radiant heat may impact adjacent aerosol storage heating the LPG within aerosol cans which may rupture rocketing the canisters around the aerosol store. The heat generated from the fire will activate the ESFR sprinklers and the in-rack sprinklers which will suppress and control the fire while cooling adjacent packages minimising the potential for lateral fire spread due to radiant heat. A detailed analysis has been conducted in **Appendix B** and the radiant heat impact distances estimated for this scenario are presented in **Table 5-2**.

Table 5-2: Heat Radiation from an Aerosol Racking Fire

Heat Radiation (kW/m^2)	Distance (m)
35	10.1
23	12.1
12.6	16.0
4.7	25.5
3.0	31.5
2.1	37.5

As shown in **Figure 5-1**, the radiant heat impacts at 4.7 kW/m^2 are contained within the site boundary and would not pose a fatality risk at the site boundary; hence, this incident has not been carried forward for further analysis.

5.4 Forklift Loading/Unloading, Damaged Package, Flammable Release, Ignition and Pallet Fire

Materials on a pallet could be damaged during transfer between the delivery/despatch vehicles and the racking area (i.e. collision with racks, other forklifts trucks, etc.). Where the damage occurs within the warehouse, the ESFR sprinklers would activate, controlling the fire and preventing fire growth and spread. However, where the damage occurs externally to the warehouse, the fire may continue for a time before the onsite emergency response can be activated or Fire & Rescue NSW (FRNSW) can arrive and attend to the fire. Hence, a single pallet fire could occur in the delivery/despatch area externally to the warehouse.

A detailed analysis has been conducted in **Appendix B** and the radiant heat impact distances estimated for this scenario are presented in **Table 5-3**.

Table 5-3: Heat Radiation from a Pallet Fire

Heat Radiation (kW/m^2)	Distance (m)
35	3.2
23	3.8
12.6	5.0
4.7	7.8
3.0	9.7
2.1	11.4

As shown in **Figure 5-1**, the radiant heat impacts at 4.7 kW/m^2 are contained within the site boundary and would not pose a fatality risk at the site boundary; hence, this incident has not been carried forward for further analysis.

5.5 Full Warehouse Fire

If a fire occurs within the DG store and the sprinkler systems fail to activate, the fire will spread throughout the warehouse and is unlikely to be contained and would likely consume the entire warehouse. A detailed analysis has been conducted in **Appendix B** and the radiant heat impact distances estimated for this scenario are presented in **Table 5-4**.

Table 5-4: Radiant Heat Impact Distances from a Full Warehouse Fire

Heat Radiation (kW/m^2)	Distance (m)
35	Maximum heat flux is 20*
23	Maximum heat flux is 20*
12.6	80.5
4.7	134.2
3.0	169.5
2.1	203.6

*Based on the research by Mudan & Croche reported in Lees (Ref. [10]) & Cameron/Raman (Ref. [11])

As shown in **Figure 5-2**, the radiant heat impacts at 4.7 kW/m^2 extend over the site boundary; hence, there is the potential for a fatality at the site boundary to occur. Therefore, this incident has been carried forward for further analysis. In addition, the radiant heat at 23 kW/m^2 would not be present due to the smokey portion of the flame limited the radiant heat emitted from the flame surface. As 23 kW/m^2 is not expected to occur, incident propagation is not expected to occur.

5.6 Fire Involving Toxic Substances and Toxic Smoke Dispersion

A detailed analysis has been performed in **Section B7** of **Appendix B** to estimate the impact of toxic products of combustion on the surrounding area. In addition, it was concluded that due to the relatively low quantity of toxic products that may be stored in the warehouse, and a substantial portion of toxic products involved in a fire will actually be combusted, the results generated from the assessment of toxic bi-products would provide a conservative analysis when applied to uncombusted toxic products.

Provided in **Table 5-5** is a summary of several toxic products of combustion which may be present in the smoke plume and their acceptable concentration of exposure for the Acute Exposure Guideline Levels (AEGL). These levels provide guidance on exposure concentrations for general populations, including susceptible populations over a range of exposure times to assist in the assessment of releases which may result in a toxic exposure.

Provide below is a summary of the AEGL tiers of exposure:

- **AEGL-3** is the airborne concentration, expressed as parts per million (ppm) or milligrams per cubic meter (mg/m^3), of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.
- **AEGL-2** is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
- **AEGL-1** is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

Selection for fatality or serious injury is based on an AEGL-3 values with injury values selected as those based on AEGL-2. It is noted the report AEGL values are based on 30-minute exposure.

Table 5-5: Concentrations of Toxic Products of Combustion from a Smoke Plume

Pollutant	Fatality or Serious Injury (ppm)	Injury (ppm)	Concentration (ppm)
Carbon monoxide	600	150	20.9
Nitric Dioxide	25	15	19.6
Hydrogen cyanide	21	10	21.7
Hydrogen chloride	210	43	16.1
Sulphur dioxide	30	0.75	9.2

The analysis indicates except for hydrogen cyanide, all quantities are below the AEGL-3 values. It is noted the analysis conducted is based on the primary toxic bi-product (carbon monoxide) which forms at rates higher than other toxic bi-products. Therefore, application of this result to other components is considered conservative. Therefore, the concentration of hydrogen cyanide is likely to be lower than that reported. In addition, the concentration taken is at the point of release; however, the smoke plume will disperse over the 500 m required to travel to impact residential populations; therefore, it is considered the concentration at residential areas would fall below the AEGL-3 concentration; hence, a fatality would be unlikely to occur as a result of this incident.

With reference to injury, all value except for nitric dioxide, hydrogen cyanide and sulphur dioxide are below the AEGL-2 concentration. Similar to the above discussion, the concentrations are likely to disperse substantially prior to impacting the residential populations; hence, an injury is unlikely to occur.

Nonetheless, as an impact may occur, these incidents have been carried forward for further analysis.

5.7 Heat Radiation Contours

Figure 5-1 shows the radiant heat contours for the sprinkler controlled fire scenarios in the flammable liquid and aerosol sections of the DG store. Representative fires have been placed to illustrate a fire could occur anywhere within the DG racking. The contours from these fire scenarios do not impact over the site boundary; hence, these scenarios have not been carried forward for further analysis.

Figure 5-2 shows the radiant heat contours from a full warehouse fire. Based on this analysis, it can be seen that the radiant heat generated from a full warehouse fire would impact over the site boundary; hence this incident has been carried forward for further analysis.

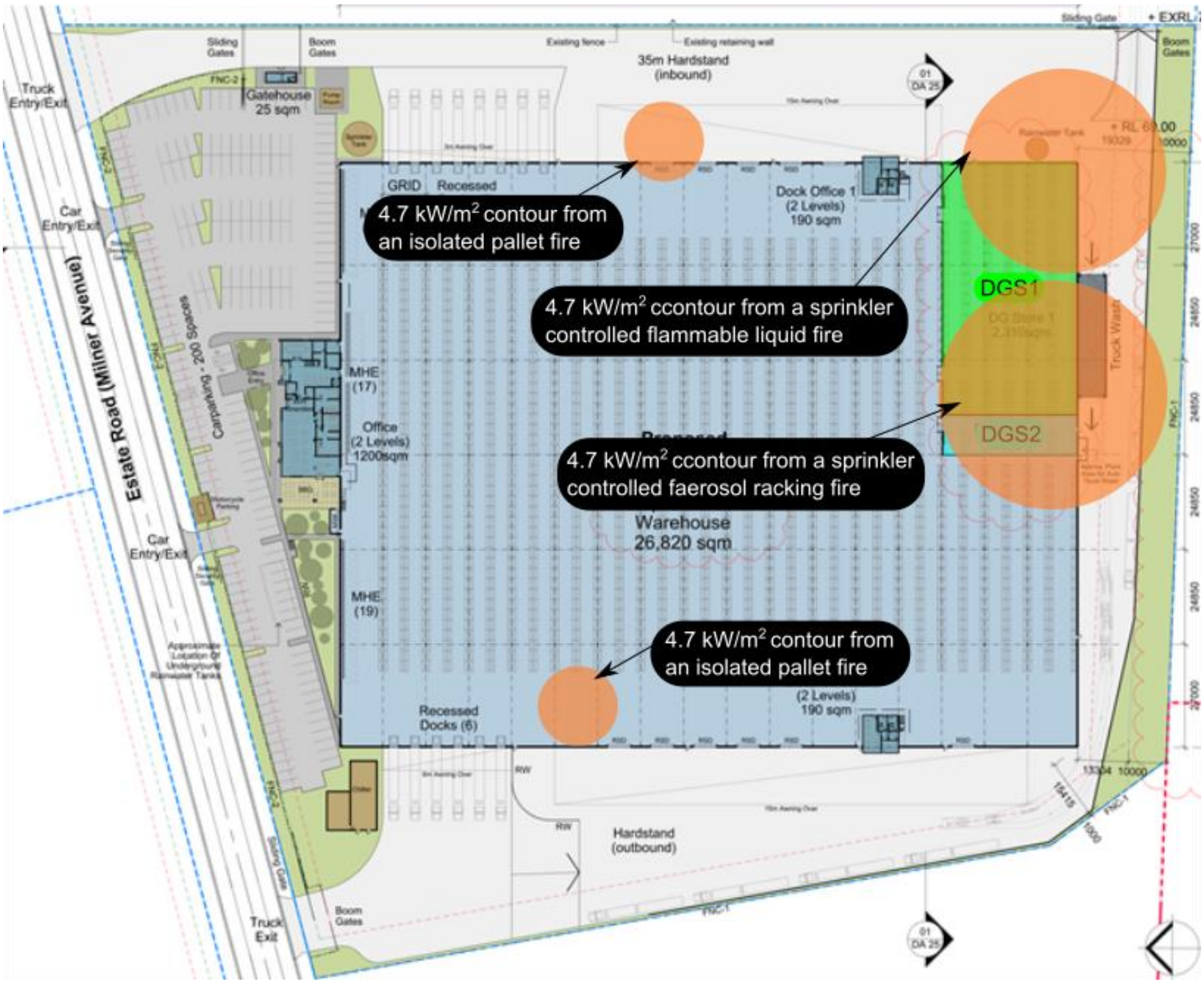

Figure 5-1: Radiant Heat Contours at 4.7 kW/m² from Sprinkler Controlled Fires

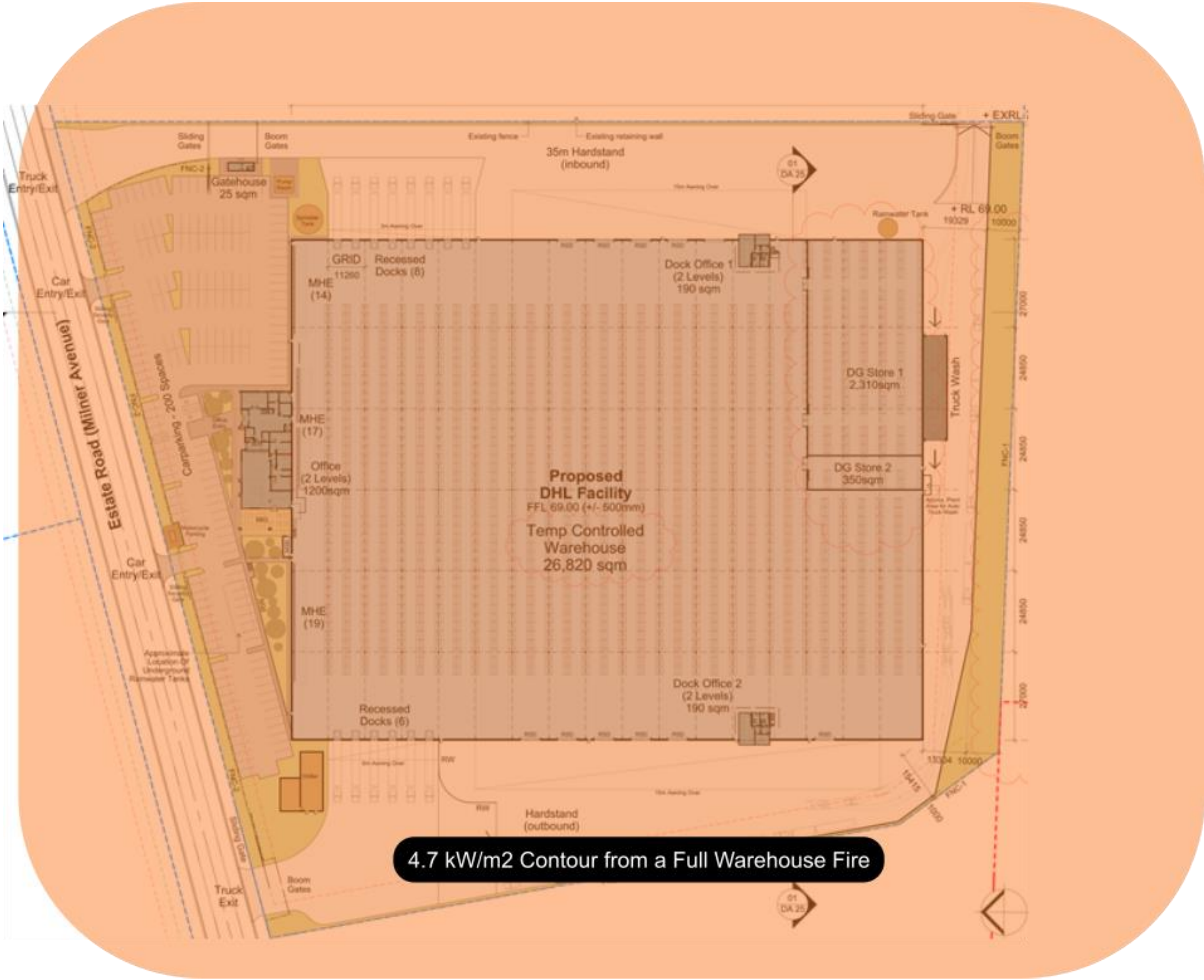

Figure 5-2: Radiant Heat Contours at 4.7 kW/m² from a Full Warehouse Fire

6.0 Frequency Analysis and Risk Assessment

6.1 Incidents Carried Forward for Frequency Analysis

The following items have been carried forward for frequency analysis:

- Full warehouse fire.
- Fire involving toxic substances and toxic smoke dispersion.

This incident has been assessed in the following section.

6.2 Full Warehouse Fire Frequency and Risk Assessment

The frequency of a full warehouse fire at the site can be estimated from a number of sources (e.g. general warehouse fire frequencies or the summation of individual fire frequencies for each of the initiating fire events). As this is a preliminary hazard analysis, the fire frequency has been selected from general fire frequency data.

A detailed fire frequency analysis has been conducted in **Appendix C**. The results of this analysis indicate that an initiating fire frequency would be in the order of $1x10^{-3}$ p.a.

It is noted that the Linfox site is fitted with multiple automatic sprinkler systems that will initiate on fire detection, controlling the fire and preventing the fire growth to a full warehouse fire. The Centre for Chemical Process Safety (CCPS) provides failure rate data for water fire protection systems including all components (pump, distribution system, nozzles, seals, piping, controls and base plate) of 9.66 per 10^6 hours (Ref. [12]). The hourly failure rate is converted to failures per annum by:

Failures per Annum = Failures per hour x 8760 hours per year

Failures per Annum = $9.66x10^{6}$ x 8760 = 0.085

The system will only operate when a fire is detected; hence, the system operates in demand mode. The protection system will be tested monthly totalling 12 tests per annum. The probability of failure on demand (PFD) is estimated using:

$$PFD = \frac{1}{2}\lambda_{du}\left(\frac{1}{t}\right)$$

Where:

λ_{du} = dangerous undetected failures of a component

t = 1/number of test intervals per annum

PFD = 0.5 (0.085) (1/12) = 0.00353

Hence, the frequency of a full fire within the warehouse is the frequency of an initiating fire x the probability of fail on demand (PFD) of the automatic fire fighting system as shown in **Figure 6-1**.

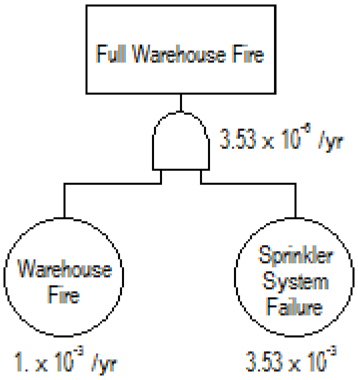

Figure 6-1: Full Warehouse Fire Fault Tree

Conservatively assuming a 100% chance of fatality at the site boundary for a person exposed to radiant heat from a full warehouse fire, the probability of fatality at the site boundary becomes $3.53x10^{-6}$ x 1 = $3.53x10^{-6}$ chances of fatality per year or 3.53 chances of a fatality in a million per year (pmpy).

6.3 Fire Involving Toxic Substances and Toxic Smoke Dispersion

6.3.1 Fatality Assessment

A review of the concentrations in **Table 5-5** indicates hydrogen cyanide is the only species which may exceed the fatality concentration. Therefore, this component will be used as an indicative component for the assessment.

To estimate the probability of fatality it is necessary to review the susceptibility to personnel exposed to toxic species which may occur downwind from the release. Tolerance to an exposure (i.e. radiant heat or toxicity) differs across a population which may be estimated using Probit analysis. For radiant heat exposure, the Probit equation is shown in **Eqn 6-1**.

$$Y = K_1 + K_2 lnV \qquad \textbf{Eqn 6-1}$$

Where:

- K_1 = -9.8
- K_2 = 1
- $V = C^nT$
- C = Concentration (ppm)
- n = 2.4
- t = time (30 minutes)

The value obtained from the Probit equation is then read from the graph shown in **Figure 6-1**. Which yields the percentage of fatality for personnel exposed to the input concentration.

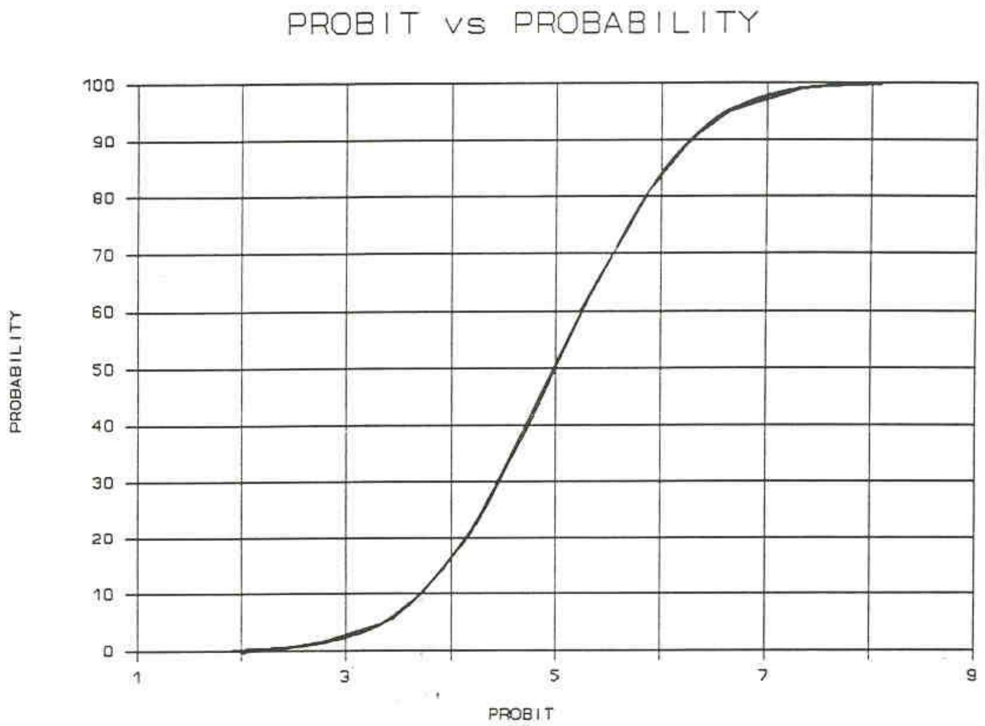

Figure 6-2: Probit vs Probability

The maximum concentration is 21.7 ppm at the source of release. Substituing this value into **Eqn 6-1** with an exposure period of 30 minutes yields a probit of 0.98 which when compared to **Figure 6-1** results in a probability of fatality of 0%. Therefore, the probability of a fatality based on a full warehouse fire involving toxic products would be 0 pmpy.

6.3.2 Injury Assessment

While a fatality would not occur as a result of the exposure, an injury may still result. Assuming an injury rate of 100% when exposed to hydrogen cyanide at a concentration of 21.7 ppm for 30 minutes, the injury rate would tend toward the frequency of the full warehouse fire. The frequency of this incident is 3.53 pmpy; hence, the frequency of an injury downwind of the incident would be 3.53 pmpy.

6.4 Comparison Against Risk Criteria

The NSW Department of Planning and Environment has issued a guideline on the acceptable risk criteria (Ref. [1]). The acceptable risk criteria published in the guideline relates to injury, fatality and property damage. The values in the guideline present the maximum levels of risk that are permissible at the land use under assessment. The adjacent land use would be classified as an industrial site as it is restricted access and only industrial operations are permitted to occur in this area. For industrial facilities, the maximum permissible fatality risk is 50 pmpy. The assessed highest fatality risk is 3.53 pmpy at the closest site boundary (eastern boundary); hence, the highest risk is within the permissible criteria and therefore all other risk points beyond the boundary would be within the acceptable criteria.

The criteria for injury from exposure to smoke or toxic species is 10 chances pmpy for short term exposure and for irritation the criteria is 50 chances pmpy. The probability of injury was found to be 3.53 pmpy which is below the acceptable criteria of 10 pmpy.

Based on the estimated fatality and injury risk, conducted in the analysis above, the risks associated with fatality, injury and nuisances at the closest residential area are not considered to be exceeded.

7.0 Conclusions and Recommendations

7.1 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 (full warehouse fire) would impact over the site boundary and into the adjacent land use; hence, this incident was carried forward for frequency analysis and risk assessment.

The frequency analysis and risk assessment showed that the full warehouse fire would have a fatality risk of 3.53 chances per million per year (pmpy) at the site boundary, with lesser risk at further distances from the boundary. HIPAP No. 4 publishes acceptable risk criteria at the site boundary of 50 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.

In addition, the analysis of smoke involving toxic products or toxic bi-products of combustion resulted in an injury risk of 3.53 pmpy. The acceptable criterion for injury is 10 pmpy, therefore, this criterion is not exceeded and is within the acceptable criteria.

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.

7.2 Recommendations

Notwithstanding the conclusions following the analysis of the facility, the following recommendation has been made:

- Multiple spill kits should be provided around the DG store to ensure spills can be cleaned up immediately following identification
- The fire pumps should be started at least once per month and the system operated at full pump pressure during this monthly test
- The site emergency plan should include response to spills and spill clean-up procedures

8.0 References

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

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[3] Department of Planning, Multi-Level Risk Assessment, Sydney: Department of Planning, 2011.

[4] Standards Australia, AS 1940-2004 - Storage and Handling of Flammable and Combustible Liquids, Sydney: Standards Australia, 2004.

[5] FM Global, "FM Global Data Sheet 7-31: Storage of Aerosol Products," 2016.

[6] Standards Australia, AS/NZS 60079.14:2009 - Explosive Atmospheres Part 14: Electrical Installations, Design, Selection and Erection, Sydney: Standards Australia, 2009.

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Appendix A

Hazard Identification Table

A1. Hazard Identification Table

Area/Operation	Hazard Cause	Hazard Consequence	Safeguard
Warehouse	• Dropped pallet • Damaged packaging (receipt or during storage) • Deterioration of packaging	• Release of Class 2.1, 2.2, 3, 4, 5.1, 5.2, 6.1, 8 or 9 DGs to the environment	• Small retail sized packages (<20 L) • Inspection of packages upon delivery to the site. • Trained forklift operators. • Storage of DGs within AS 1940-2004 (Ref. [4]) compliant Store.
	• Dropped pallet • Damaged packaging (receipt or during storage) • Deterioration of packaging	• Spill of flammable liquids, evolution of flammable vapour cloud ignition and vapour cloud explosion/flash fire • Spill of flammable liquids, ignition and pool fire/racking fire • Production of toxic smoke if Class 6.1 DGs are involved in the fire.	• Small retail sized packages (<20 L) • Inspection of packages upon delivery to the site • Control of ignition sources according to AS/NZS 60079.14:2009 (Ref. [6]) • Automatic fire protection system • First attack fire-fighting equipment (e.g. hose reels & extinguishers) • Fire detection systems • Storage of DGs within AS 1940-2004 (Ref. [4]) compliant Store.
	• Heating of Class 2.1 from a general warehouse fire	• Rupture, ignition and explosion/rocketing of cylinder within warehouse spreading fire	• Aerosols stored in AS 1940-2004 (Ref. [4]) compliant DG Store, protected by 240/240/240 FRL walls. • In-rack sprinklers according to FM Global Data Sheet 7-31 (Ref. [5]) • Automatic fire protection system (ESFR)

	• Thermal decomposition of Class 5.2 products	• Pressurisation and explosion • Ignition of packaging and fire	• Stored in retail packages (minimises potential for large scale incident) • Insufficient confinement for explosion • Fire detection systems • Inspection of packages upon delivery to the site • Automatic fire protection system (ESFR)
Sprinkler activation	• Fire activates ESFR resulting in fire water release and potential contaminated fire water offsite	• Environmental impact to surrounding areas (e.g. stormwater drainage)	• Dangerous Goods Stores are bunded to contain in excess of the maximum required fire water, per AS 1940-2004 (Ref. [4]). • Site drainage is isolated containing water overflow within facility
Pallet Loading/Unloading	• Dropped containers from the pallet • Impact damage to containers on the pallet (collision with racks or other forklifts)	• Spill of flammable liquids, evolution of flammable vapour cloud ignition pool, fire under the pallet • Full pallet fire as a result of fire growth	• Trained & licensed forklift drivers • First attack fire-fighting equipment (hose reels & extinguishers) • ESFR sprinklers if incident occurs internally • No potential for fire growth beyond the single pallet (limited stock externally)

Appendix B

Consequence Analysis

B1. Incidents Carried forward for Consequence Analysis

The following incidents are assessed for consequence impacts.

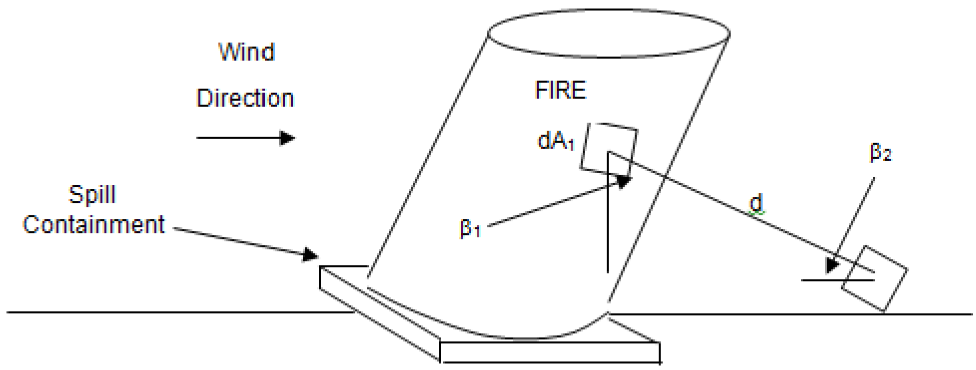
- Flammable liquid spill, ignition and racking fire.
- LPG release (from aerosol), ignition and racking fire.
- Forklift loading/unloading, damaged package, flammable release, ignition and pallet fire.
- Full warehouse fire and toxic smoke emission.
- Fire involving toxic substances and toxic smoke dispersion.

Each incident has been assessed in the sections below.

B2. Spreadsheet Calculator (SSC)

The SSC is designed on the basis of finite elements. The liquid flame area is calculated as if it is a circle to find the radius for input into the SSC model.

The SSC is designed on the basis of finite elements. The liquid flame area is calculated as if it is a circle to find the radius for input into the SSC model. **Appendix Figure B-1** shows a typical pool fire, indicating the target and fire impact details.



Appendix Figure B-1: Heat Radiation on a Target from a Cylindrical Flame

A fire in a bund or at a tank roof will act as a cylinder with the heat from the cylindrical flame radiating to the surrounding area. A number of mathematical models may be used for estimating the heat radiation impacts at various distances from the fire. The point source method is adequate for assessing impacts in the far field; however, a more effective approach is the view factor method, which uses the flame shape to determine the fraction of heat radiated from the flame to a target. The radiated heat is also reduced by the presence of water vapour and the amount of carbon dioxide in air. The formula for estimating the heat radiation impact at a set distance is shown in **Equation B-1**. (Ref. [11]).

$$Q = EF\tau \quad \textbf{Equation B-1}$$

Where:

- Q = incident heat flux at the receiver (kW/m^2)
- E = surface emissive power of the flame (kW/m^2)
- F = view factor between the flame and the receiver
- τ = atmospheric transmissivity

The calculation of the view factor (F) in Equation 1 depends upon the shape of the flame and the location of the flame to the receiver. F is calculated using an integral over the surface of the flame, S. The formula can be shown as (Ref. [11]):

$$F = \int\int_S \frac{\cos\beta_1 \cos\beta_2}{\pi d^2}$$ **Equation B-2**

Equation B-2 may be solved using the double integral or using a numerical integration method in spread sheet form. This is explained below.

For the assessment of pool fires, a Spread Sheet Calculator (SCC) has been developed, which is designed on the basis of finite elements. The liquid flame area is calculated as if the fire is a vertical cylinder, for which the flame diameter is estimated based on the fire characteristics (e.g. contained within a bund). Once the flame cylindrical diameter is estimated, it is input into the SSC model. The model then estimates the flame height, based on diameter, and develops a flame geometric shape (cylinder) on which is performed the finite element analysis to estimate the view factor of the flame. **Appendix Figure B-1** shows a typical pool fire, indicating the target and fire impact details.

The SSC integrates the element dA_1 by varying the angle theta θ (the angle from the centre of the circle to the element) from zero to 90^o in intervals of 2.5 degrees. Zero degrees represents the straight line joining the centre of the cylinder to the target (x0, x1, x2) while 90^o is the point at the extreme left hand side of the fire base. In this way the fire surface is divided up into elements of the same angular displacement. Note the tangent to the circle in plan. This tangent lies at an angle, gamma, with the line joining the target to where the tangent touches the circle (x4). This angle varies from 90^o at the closest distance between the liquid flame (circle) and the target (x0) and gets progressively smaller as θ increases. As θ increases, the line x4 subtends an angle phi Φ with x0. By similar triangles we see that the angle gamma γ is equal to 90- θ - Φ . This angle is important because the sine of the angle give us the proportion of the projected area of the plane. When γ is 90^o, sin(γ) is 1.0, meaning that the projected area is 100% of the actual area.

Before the value of θ reaches 90^o the line x4 becomes tangential to the circle. The fire cannot be seen from the rear and negative values appear in the view factors to reflect this. The SSC filters out all negative contributions.

For the simple case, where the fire is of unit height, the view factor of an element is simply given by the expression in **Equation B-3** (Derived from **Equation B-2**):

$$VF = \Delta A \frac{\sin\gamma}{\pi \times X4 \times X4}$$ **Equation B-3**

Where ΔA is the area of an individual element at ground level.

Note: the denominator (π. x4. x4) is a term that describes the inverse square law for radiation assumed to be distributed evenly over the surface of a sphere.

Applying the above approach, we see the value of x4 increase as θ increase, and the value of sin(γ) decreases as θ increase. This means that the contribution of the radiation from the edge of the circular fire drops off quite suddenly compared to a view normal to the fire. Note that the SSC adds up the separate contributions of **Equation B-3** for values of θ between zero until x4 makes a tangent to the circle.

It is now necessary to do two things: (i) to regard the actual fire as occurring on top of a fire wall (store) and (ii) to calculate and sum all of the view factors over the surface of the fire from its base to its top. The overall height of the flame is divided into 10 equal segments. The same geometric technique is used. The value of x4 is used as the base of the triangle and the height of the flame, as the height. The hypotenuse is the distance from target to the face of the flame (called X4'). The angle of elevation to the element of the fire (alpha α) is the arctangent of the height over the ground distance. From the cos(α) we get the projected area for radiation. Thus there is a new combined distance and an overall equation becomes in **Equation B-4** (Derived from **Equation B-3**):

$$VF = \Delta A \frac{\sin\gamma \times \cos\alpha}{\pi \times X4 \times X4}$$ **Equation B-4**

The SCC now turns three dimensional. The vertical axis represents the variation in θ from 0 to 90º representing half a projected circle. The horizontal axis represents increasing values of flame height in increments of 10%. The average of the extremes is used (e.g. if the fire were 10 m high then the first point would be the average of 0 and 1 i.e. 0.5 m), the next point would be 1.5 m and so on).

Thus the surface of the flame is divided into 360 equal area increments per half cylinder making 720 increments for the whole cylinder. Some of these go negative as described above and are not counted because they are not visible. Negative values are removed automatically.

The sum is taken of the View Factors in **Equation B-4**. Actually the sum is taken without the ∆A term. This sum is then multiplied by ∆A which is constant. The value is then multiplied by 2 to give both sides of the cylinder. This is now the integral of the incremental view factors. It is dimensionless so when we multiply by the emissivity at the "face" of the flame (or surface emissive power, SEP), which occurs at the same diameter as the fire base (pool), we get the radiation flux at the target.

The SEP is calculated using the work by Mudan & Croche (Ref. [10] & Ref. [11]) which uses a weighted value based on the luminous and non-luminous parts of the flame. The weighting is based on the diameter and uses the flame optical thickness ratio where the flame has a propensity to extinguish the radiation within the flame itself. The formula is shown in **Equation B-5**.

$$SEP = E_{max}e^{-sD} + E_s(1 - e^{-sD})$$ **Equation B-5**

Where;

E_{max} = 140

S = 0.12

E_s = 20

D = pool diameter

The only input that is required is the diameter of the pool fire and then estimation for the SEP is produced for input into the SSC.

The flame height is estimated using the Thomas Correlation (Ref. [13]) which is shown in **Equation B-6**.

$$H = 42d_p\left[\frac{\dot{m}}{\rho_a\sqrt{gd_p}}\right]^{0.61}$$ **Equation B-6**

Where;

d_p = pool diameter (m)

ρ_a = density of air (1.2 kg/m^3 at 20^{o}C)

$\dot{m}$ = burning rate (kg/m^2.s)

g = 9.81 m/s^2

Appendix Table B-1 provides noteworthy heat radiation values and the corresponding physical effects of an observer exposed to these values (Ref. [1]).

Appendix Table B-1: Heat Radiation and Associated Physical Impacts

Heat Radiation (kW/m^2)	Impact
35	• Cellulosic material will pilot ignite within one minute's exposure • Significant chance of a fatality for people exposed instantaneously
23	• Likely fatality for extended exposure and chance of a fatality for instantaneous exposure • Spontaneous ignition of wood after long exposure • Unprotected steel will reach thermal stress temperatures which can cause failure • Pressure vessel needs to be relieved or failure would occur
12.6	• Significant chance of a fatality for extended exposure. High chance of injury • Causes the temperature of wood to rise to a point where it can be ignited by a naked flame after long exposure • Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure
4.7	• Will cause pain in 15-20 seconds and injury after 30 seconds exposure (at least second degree burns will occur)
3.0	• Fire fighters are to be able to operate in their BA uniform for periods of up to 10 minutes (Ref. [14]).
2.1	• Minimum to cause pain after 1 minute

B3. Flammable Liquid Spill, Ignition and Racking Fire

In the event that a flammable liquid package is damaged and flammable liquid is released the volatile component will vaporise which may contact an ignition source resulting in a pool fire. As the fire grows it may accelerate the deterioration of other packages resulting in failure and release of additional flammable material and combustion of packaging.

As heat and smoke is generated from the fire, the ESFR sprinkler system will activate 12 sprinkler heads which will dowse the area in water containing the fire within the sprinkler array and cooling adjacent packages prevent fire spread due to radiant heat. The design area of the sprinkler system has an approximate diameter of 9 m which has been used as a conservative estimate of the fire diameter.

The following information was input into the models;

- Equivalent fire diameter – 9 m

- Burning rate – 0.0667 kg/m^2.s (this value encompasses a large range of flammable liquid burning rates and is considered conservative due to the nature of the flammable liquids stored, Ref. [10])

The models provided the following information for the Flammable Liquid Racking Fire;

- SEP – 60.8 kW/m^2
- Flame Height – 16.5 m (from model without roof restriction)

The results of the analysis are shown in **Appendix Table B-2**.

Appendix Table B-2: Heat Radiation from a Flammable Liquid Racking Fire

Heat Radiation (kW/m^2)	Distance (m)
35	8.5
23	10.4
12.6	13.8
4.7	22.2
3.0	27.6
2.1	32.7

B4. LPG Release (From Aerosol), Ignition and Racking Fire

The release of LPG from a damaged package could result in a fire if the release ignited. The fire would begin to grow expanding LPG within other aerosols which may rupture, ignite and rocket around the aerosol store. The store is fitted with ESFR sprinklers and in-rack sprinklers to suppress the fire and cool adjacent packages to minimise the potential for rocketing.

As mentioned in **Section B3** the ESFR has a sprinkler area of approximately 9 m in diameter. This diameter will be used to estimate the potential impacts from a fire, noting that this is considered conservative as the full 9 m area will not contribute to the fire.

The following information was input into the models;

- Equivalent fire diameter – 9 m
- Burning rate – 0.099 kg/m^2.s (this value is for LPG which is considered conservative for use as approximately 25% of the aerosols is LPG, which will be consumed quickly and the fire would predominately be a combustible material fire from the packaging, Ref. [10])

The models provided the following information for the LPG Racking Fire;

- SEP – 60.8 kW/m^2
- Flame Height – 16.5 m (from model without roof restriction)

The results of the analysis are shown in **Appendix Table B-3**.

Appendix Table B-3: Heat Radiation from an Aerosol Racking Fire

Heat Radiation (kW/m^2)	Distance (m)
35	10.1
23	12.1
12.6	16.0

Heat Radiation (kW/m^2)	Distance (m)
4.7	25.5
3.0	31.5
2.1	37.5

B5. Pallet Fire in Unloading/Loading Area

There is the potential for a fire to occur in a pallet during loading or unloading. The fire has been conducted based on aerosols which contain LPG and is considered to be conservative as aerosols will rupture and the LPG will be ignited and will not be a sustained burning of LPG. In addition, LPG has a higher burning rate than the majority of flammable liquids resulting in a larger fire and greater surface for emission of radiant heat.

The dimensions for a pallet are 1.2 m x 1.2 m, giving a total area of 1.44 m^2. These dimensions have been used to estimate an equivalent circular diameter to estimate the SEP for input into the SSC.

$$A = L \times W = 1.2 \times 1.2 = 1.44\ m^2$$

$$D = \sqrt{\frac{4 \times 1.44}{\pi}} = 1.35\ m$$

The following information was estimated and was input into the SSC:

- Equivalent diameter: 1.35 m;
- SEP: 122 kW/m^2;
- Burning rate: 0.099 kg/m^2.s (Burning rate for LPG Ref. [10]);
- Flame height: 5.64 m

Provided in **Appendix Table B-4** are the results generated by the SSC.

Appendix Table B-4: Heat Radiation Impacts from a Pallet Fire

Heat Radiation (kW/m^2)	Distance (m)
35	3.2
23	3.8
12.6	5.0
4.7	7.8
3.0	9.7
2.1	11.4

B6. Full Warehouse Fire

If the fire protection system fails (ESFR for flammable liquids or ESFR and in-racks for aerosols), there is the potential that a fire could develop into a full warehouse fire. The warehouse storage area (including the DG Stores) has approximate dimensions of 194 m by 153 m. The model can be used up to an aspect ratio (length divided by width) of 2.5. The warehouse has an aspect ratio of 1.3 which is appropriate for use in the model.

The actual area of the warehouse is 29,500 m^2 which has been used to estimate the equivalent circular diameter for input into the SEP and flame height model. This methodology is considered conservative as approximately 1/3 of the area used is aisle space and would not contribute to the fire, and the DG stores are fire isolated, thereby also not expected to participate in a fire scenario.

$$D = \sqrt{\frac{4 \times 29500}{\pi}} = 193.8\,m$$

The following information was input into the models;

- Equivalent fire diameter – 193.8 m
- Burning rate – 0.0667 kg/m^2.s (this value is based primarily on flammable liquids and is considered extremely conservative as the predominant material in the fire would be combustible packaging rather than flammable liquids , Ref. [10])

The models provided the following information for the warehouse fire;

- SEP – 20 kW/m^2
- Flame Height – 139.6 m (from model without roof restriction)

Provided in **Appendix Table B-5** are the results generated by the SSC.

Appendix Table B-5: Heat Radiation Impacts from a Full Warehouse Fire

Heat Radiation (kW/m^2)	Distance (m)
35	Maximum heat flux is 20*
23	Maximum heat flux is 20*
12.6	80.5
4.7	134.2
3.0	169.5
2.1	203.6

B7. Fire Involving Toxic Substances and Toxic Smoke Dispersion

During the fire, uncombusted toxic products may be present in the smoke plume or toxic bi-products may be generated which will be dispersed in the smoke plume. It is necessary to assess the associated impacts of the smoke plume downwind of the facility as it may have far reaching impacts on the wider community. When assessing the downwind impacts of the fire plume, the main contributors to the dispersion are:

- The fire size (diameter) and energy released as convective heat
- The atmospheric conditions such as wind speed, relative humidity, atmospheric stability and ambient temperature.

These parameters interact to determine the buoyancy of the smoke plume (vertical rise) which is controlled by the convective energy within the smoke plume in addition to the atmospheric conditions. The atmospheric conditions will vary from stable conditions (generally night time) to unstable conditions (high insolation from solar radiation) which results in substantial vertical mixing which aids in the dispersion. Contributing to this is the impact of wind speed which will limit the vertical rise of a plume but may exacerbate the downwind impact distance.

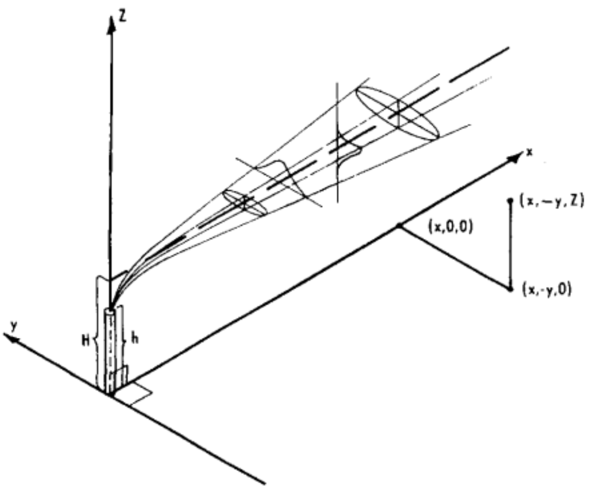
The atmospheric conditions are classified as Pasquill Guifford's Stability categories which are summarised in **Appendix Table B-10** (Ref. [15]).

Appendix Table B-10: Pasquill's Stability Categories

Surface wind speed at 10 m height (m/s)	Insolation			Night	
	Strong	Moderate	Slight	Thinly overcast or ≥50% cloud	<50% cloud.
<2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Generally, the most onerous conditions are F conditions which result in stable air masses and typically have inversion characteristics. Inversion characteristics occur when a warm air mass sits above a cold air mass. Typically, hot air will rise due to lower density than the bulk air; however, in an inversion, a warm air mass sits above the cooler denser air; hence, as the warm air rises through the cold mass it hits a 'wall' of warmer air preventing vertical mixing above this point. In a fire scenario, the hot smoke plume will cool as it rises; however, if it encounters an inversion, it will begin to run along this boundary layer preventing vertical mixing and allowing the smoke plume to spread laterally for substantial distances.

A smoke plume is buoyant, and will disperse laterally and vertically as it rises essentially following a Gaussian dispersion as shown in **Appendix Figure B-2** (Ref. [15]).



Appendix Figure B-2: Co-Ordinate System for Gas Dispersion

Ian Cameron, professor of Risk Engineering at the University of Queensland, has developed a risk assessment tool known as Risk Assessor produced by DAESIM Technologies. The tool has numerous risk engineering applications; however, the component of interest for this assessment is the smoke plume modelling from fire scenarios. The model has been developed based on a Gaussian dispersion model accounting for modifications to the plume drag coefficients required to model a plume dispersion from a warehouse fire (Ref. [15]).

The model requires several inputs which have been summarised in **Appendix Table B-11** with the associated value input as part of this modelling exercise. As noted, the more onerous conditions occur during stable air conditions which allow far reaching effects with reduced dispersion due to low air velocities and vertical mixing. The industry standard for modelling this scenario is selection of F1.5 (F stability at 1.5 m/s wind velocity) which has been adopted for this assessment.

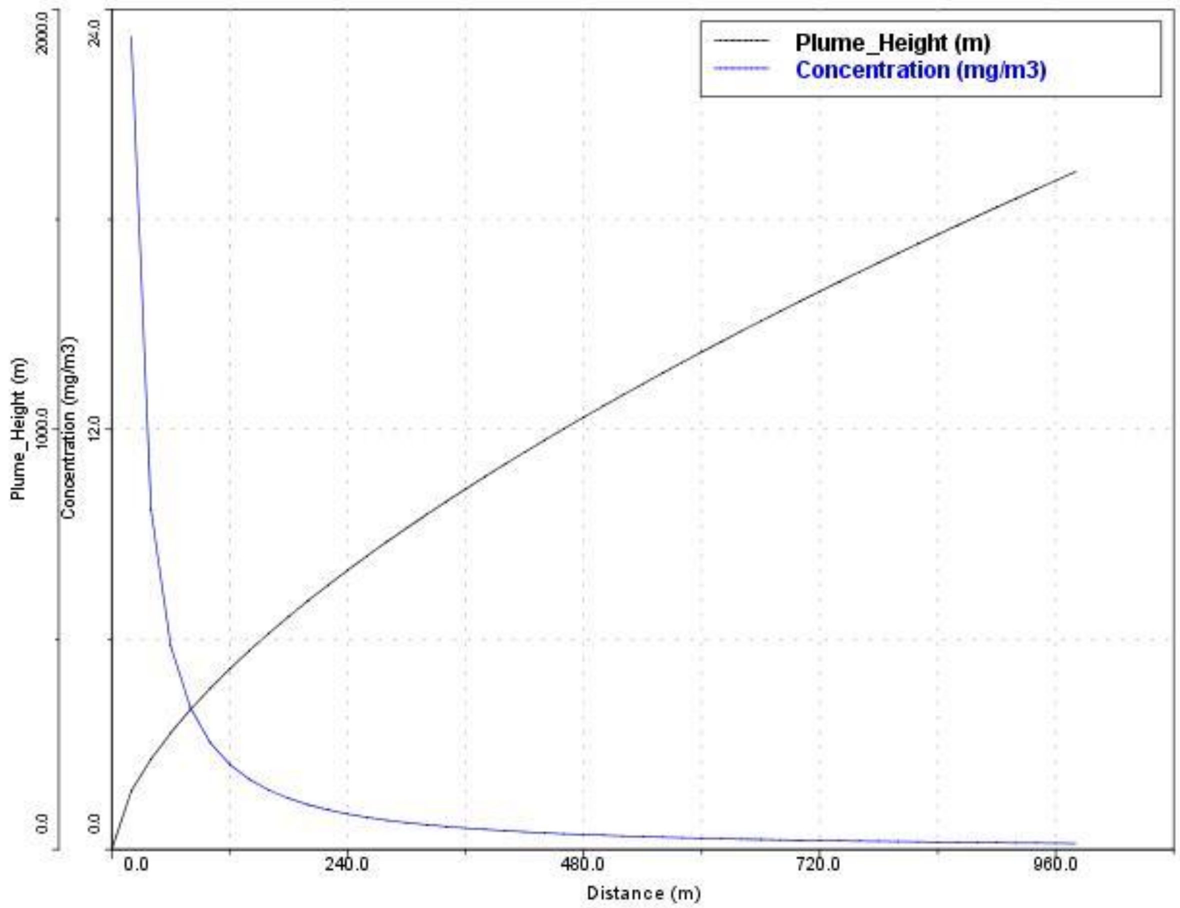
Appendix Table B-11: Input Data for Plume Gaussian Dispersion

Input	Selected Values	Justification
Max burning rate (kg/m^2.s)	0.0667	Taken from full warehouse fire above
Fire equivalent Diameter (m)	193.8	Equivalent diameter of the warehouse
Heat of combustion (kJ/kg)	45,000	Heat of combustion for combustible liquid (diesel) Ref. [16]
Fraction energy radiated	0.5	Conservative assumption based on high radiant heat blocking which occurs from dense smoke
Pollutant Rate (kg/s)	70,835	Burning rate multiplied by area multiplied by 6 (number of racks) multiplied by 6 (number of surfaces on a pallet that can burn)
Wind speed (m/s)	1.5	Industry standard
Stability	F	Industry standard

Provided in **Appendix Figure B-3** is an overlayed plot of plume smoke concentrations and plume height with distance. The analysis is based on the F stability; however, the Gaussian dispersion is unable to model temperature inversions. The response of the smoke plume to an inversion will depend on the height that the plume interacts with the inversion. At low altitudes, the smoke plume will have substantial heat and will ‘punch through’ the inversion and continue a Gaussian dispersion as expected. However, with increasing height, the plume will cool which may equalise at a temperature less than the inverted air mass. Subsequently, the plume will level out at the point of the inversion.

The worst-case concentration occurs in the initial phases of the fire and rapidly decrease with distance from the fire. It has been assumed that an inversion occurs at low level and the plume has insufficient heat to ‘punch through’ the inversion and remains trapped relatively close to the ground. A maximum value of 24 mg/m^3 has been selected per **Appendix Figure B-3** that may impact the surrounding area with regards to potential toxic bi-products of combustion.

Toxic products are a minor quantity of materials stored within the warehouse. Therefore, the mass of other products burning generating toxic bi-products of combustion is likely to far exceed the quantity of toxic products that could be released in the smoke plume considering the majority of the toxic products will be combusted. Therefore, it is considered conservative to apply the toxic bi-products of combustion concentration to any toxic products stored in the warehouse.



Appendix Figure B-3: Plume Concentration and Plume Height vs Distance

It is also noted the primary toxic product of combustion is carbon monoxide which is the species estimated by the model. To provide a more complete, and conservative analysis, this concentration is applied to other toxic bi-products of combustion for review against assessment criteria.

Provided in **Appendix Table B-12** is a summary of several toxic products of combustion which may be present in the smoke plume and their acceptable concentration of exposure for the Acute Exposure Guideline Levels (AEGL). These levels provide guidance on exposure concentrations for general populations, including susceptible populations over a range of exposure times to assist in the assessment of releases which may result in a toxic exposure.

Provide below is a summary of the AEGL tiers of exposure:

- **AEGL-3** is the airborne concentration, expressed as parts per million (ppm) or milligrams per cubic meter (mg/m^3), of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.
- **AEGL-2** is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
- **AEGL-1** is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects.

However, the effects are not disabling and are transient and reversible upon cessation of exposure.

Selection for fatality or serious injury is based on an AEGL-3 values with injury values selected as those based on AEGL-2. It is noted the report AEGL values are based on 30-minute exposure.

Appendix Table B-12: Concentration of Toxic Products of Combustion in Smoke Plume

Pollutant	Fatality or Serious Injury (ppm)	Injury (ppm)	Concentration (ppm)
Carbon monoxide	600	150	20.9
Nitric Dioxide	25	15	19.6
Hydrogen cyanide	21	10	21.7
Hydrogen chloride	210	43	16.1
Sulphur dioxide	30	0.75	9.2

Appendix C

Warehouse Fire Frequency Estimation

C1. Estimation of the Frequency of a Full Warehouse Fire

A review of readily available warehouse fire frequency information was conducted and a number of direct sources were identified. These were:

- Health and Safety Executive (HSE) in the United Kingdom [Hymes & Flynn, UKAEA - SRD/HSE R578, 2002] – this document lists the major warehouse fire frequency to be 2.5×10^{-3} p.a.;
- Baldwin, Accident Analysis and Prevention (Vol.6) – indicates a serious fire frequency in warehouses to be in the order of 1×10^{-3} p.a.;
- Environmental Impact Assessment Report for the Commission of Inquiry into Proposed Manufacturing Plant by WR Grace Australia Ltd., Kurnell, Sydney, October 1987 – indicates a fire frequency of 4.6×10^{-3} per warehouse year; and
- VROM 2005, Guidelines for quantitative risk assessment CPR 18E (Purple Book), Publication Series on Dangerous Substances (PGS 3), The Netherlands. – 4×10^{-4} p.a.

It is noted that the mix of overseas data and local data (albeit some is dated) correlates to indicate a fire frequency in warehouses to be in the order of 1×10^{-3} to 4×10^{-4}. The data presented in the reports reviewed was for general warehouses, where stringent controls for spill and ignition sources (such as flame and explosion proof fittings, bunding, smoking and naked flame controls, isolation of power supplied on warehouse closure, etc.) were not part of the warehouse hazard controls. Hence, for a DG warehouse, containing specific ignition and fire control systems, it would be expected that a major fire would occur with a lesser frequency than that of general warehouses. Notwithstanding this, to ensure a conservative assessment has been provided within the study, the estimated initiating fire frequency for the DHL facility has been estimated as 1×10^{-3} p.a. (i.e. the upper end of the range).

Selected Initiating Fire Frequency = 1×10^{-3} p.a.