Warehouse 2B
Millner Avenue, Oakdale Industrial Estate

DHL
Millner Avenue, Oakdale Industrial Estate

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Preliminary Hazard Analysis

DHL

Warehouse 2B, Oakdale Industrial Estate

RAWRiSK Engineering

Report Details

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EXECUTIVE SUMMARY

INTRODUCTION

DHL proposes to develop a new warehouse at the Oakdale Industrial Estate in Western Sydney, NSW. The project will comprise a warehouse with hardstand and awnings, including the provision for offices and other ancillary areas. The facility will store a range of Dangerous Goods (DGs); including flammable gases and liquids, oxidising agents and corrosives.

A review of the application guide to State Environmental Planning Policy No. 33 (SEPP33, Ref. 1) indicates the facility would exceed the threshold criteria for the storage of DGs resulting in a classification for the site of potentially hazardous. To demonstrate that the facility is not in fact hazardous, it is necessary to prepare a Preliminary Hazard Analysis (PHA) for the site in support of the Development Application (DA).

Goodman, on behalf of DHL, has commissioned RAWRiSK Engineering to prepare a PHA for the facility. This document represents the PHA study for the DHL warehouse.

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. 2) were carried forward for frequency analysis, no further analysis was performed for incidents not exceeding offsite impact criteria (HIPAP No. 4, Ref. 2).

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. 2). Where the criteria were exceeded, a review of the major risk contributors was performed and the risks reassessed incorporating the recommended risk reduction measures. Recommendations were then made regarding risk reduction measures.

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

HAZARD IDENTIFICATION

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

- Flammable liquid or gas release, delayed ignition and flash fire or explosion;
- Flammable liquid 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; and
- Warehouse fire, sprinkler activation and potentially contaminated water release.

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 ANLAYSIS

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 packaged, flammable release, ignition and pallet fire; and
- Full warehouse fire and toxic smoke emission.

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).

CONCLUSIONS

The risk analysis identified that the only incident which has the potential to impact offsite is a full warehouse fire. The assessment identified that the full warehouse fire would have a fatality risk of 3.53 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 risk of a fatality from a full warehouse fire at the site boundary is within the acceptable risk criteria.

Based on the analysis conducted, the risks at the site boundary are not considered to be exceeded; hence, the facility would only be classified as a potentially hazardous facility.

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; and
- The site emergency plan should include response to spills and spill clean-up procedures.

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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
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

1 INTRODUCTION

1.1 BACKGROUND

DHL proposes to develop a new warehouse at the Oakdale Industrial Estate in Western Sydney, NSW. The project will comprise a warehouse with hardstand and awnings, including the provision for offices and other ancillary areas. The facility will store a range of Dangerous Goods (DGs); including flammable gases and liquids, oxidising agents and corrosives.

A review of the application guide to State Environmental Planning Policy No. 33 (SEPP33, Ref. 1) indicates the facility would exceed the threshold criteria for the storage of DGs resulting in a classification for the site of potentially hazardous. To demonstrate that the facility is not in fact hazardous, it is necessary to prepare a Preliminary Hazard Analysis (PHA) for the site in support of the Development Application (DA).

Goodman, on behalf of DHL, has commissioned RAWRiSK Engineering to prepare a PHA for the facility. This document represents the PHA study for the DHL warehouse.

1.2 OBJECTIVES

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

- complete the PHA according to the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 – Hazard Analysis (Ref. 3);
- assess the PHA results using the criteria in HIPAP No. 4 – Risk Criteria for Land Use Planning (Ref. 2) and HIPAP No.10 – Land Use Safety Planning (Ref.14);
- 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 WORK

The scope of work is to complete a PHA study required by the Planning Regulations for the proposed 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 METHODOLOGY

2.1 MULTI LEVEL RISK ASSESSMENT

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

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

Table 2-1: Level of Assessment PHA

LEVEL	TYPE OF ANALYSIS	APPROPRIATE IF:
1	Qualitative	No major off-site consequences and societal risk is negligible
2	Partially Quantitative	Off-site consequences but with low frequency of occurrence
3	Quantitative	Where 1 and 2 are exceeded

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

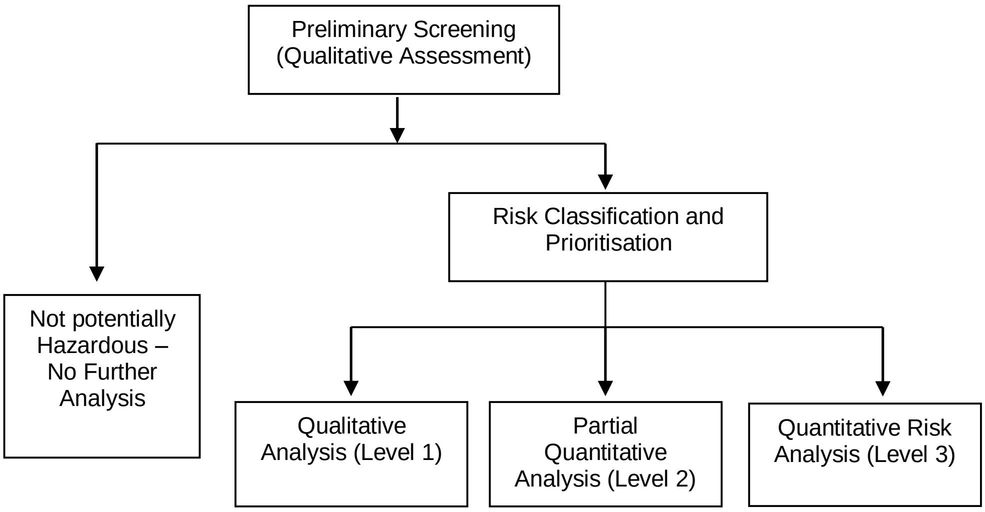


Figure 2-1: The Multi-Level Risk Assessment Approach

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

2.2 RISK ASSESSMENT STUDY APPROACH

The methodology used for the PHA is as follows;

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

Each postulated hazardous incident was assessed qualitatively in light of proposed safeguards (technical and management controls). Where a potential offsite impact was identified, the incident was carried into the main report for further analysis. Where the qualitative review in the main report determined that the safeguards were adequate to control the hazard, or that the consequence would obviously have no offsite impact, no further analysis was performed.

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. 2). The criteria selected for screening incidents is discussed in **Section 4.1**.

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. Where the criteria were exceeded, a review of the major risk contributors was performed and the risks reassessed incorporating the recommended risk reduction measures. Recommendations were then made regarding risk reduction measures.

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

3 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.

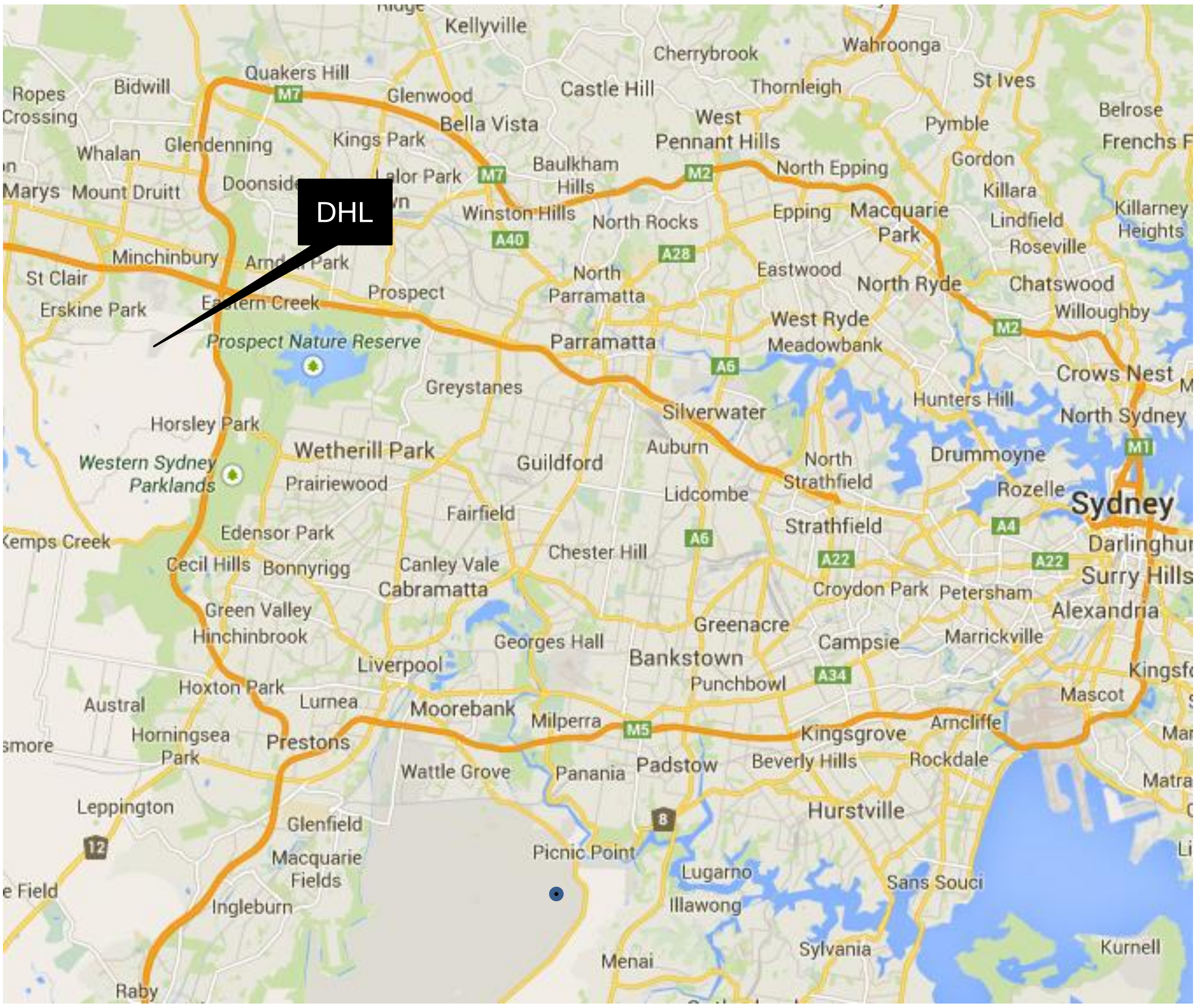


Figure 3-1: DHL Site Location

3.2 ADAJCENT 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 will consist of an office area, amenities and warehouse area including a Dangerous Goods (DG) storage area. The office area will house staff and general operations, and the warehouse will be 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 WAREHOUSE

The warehouse will have a floor area of approximately 29,500 m^2 including a DG store area of 1,495 m^2. The warehouse area will contain pallet racking capable of storing 6 pallets high. The DG will be constructed from 240/240/240 FRL panels which will penetrate through the roof by 0.5 m to provide a completely separate fire compartment. The bunker will be further separated by an internal wall (also penetrating 0.5 m through the roof) creating two fire compartments within the bunker (DGS1 & DGS2).

The larger store (DGS1) will contain Class 2.1 and Class 3 DGs and will be designed according to AS1940-2004 (Ref. 7). The store will be 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 will also be fitted with hose reels with foam making capabilities.

The storage will be bunded to be able to contain at least 125 m^3 which encompasses the requirements for a package store from AS9140 in addition to 20 minutes of fire water. The store will be ventilated to prevent the accumulation of vapours and ignitions sources within DGS1 will be controlled according to AS60079 series (Ref. 8).

DGS2 will contain Class 5.1, Class 8 and Class 9 DGs with the DGs within this location stored and handled according to AS3833-2007 (Ref. 4). The DGs 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 will be contained within the premises via isolation of the discharge valve.

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

It is currently proposed to operate the warehouse 24 hours a day 7 days a week. The site will occupied by 50 office staff during business hours and approximately 150 personnel working within the warehouse depending on shift rotation.

3.5 DANGEROUS GOODS STORAGE

As noted, several classes of DGs will be stored at the warehouse. A list of the classes, packing groups and quantities are shown in **Table 3-1**.

Table 3-1: Dangerous Goods Stored at DHL Site

CLASS	PACKING GROUP	QUANTITY (L OR KG)	DG LOCATION
2.1 (aerosols)	N/A	30,000 kg	DGS1
3	II	50,000 L	
3	III	250,000 L	
5.1	II & III	15,000 kg	DGS2
8	II & III	20,000 kg	
9	III	10,000 kg	

3.6 DANGEROUS GOODS LOCATIONS

Figure 3-2 shows the locations where the DGs are stored within the facility.

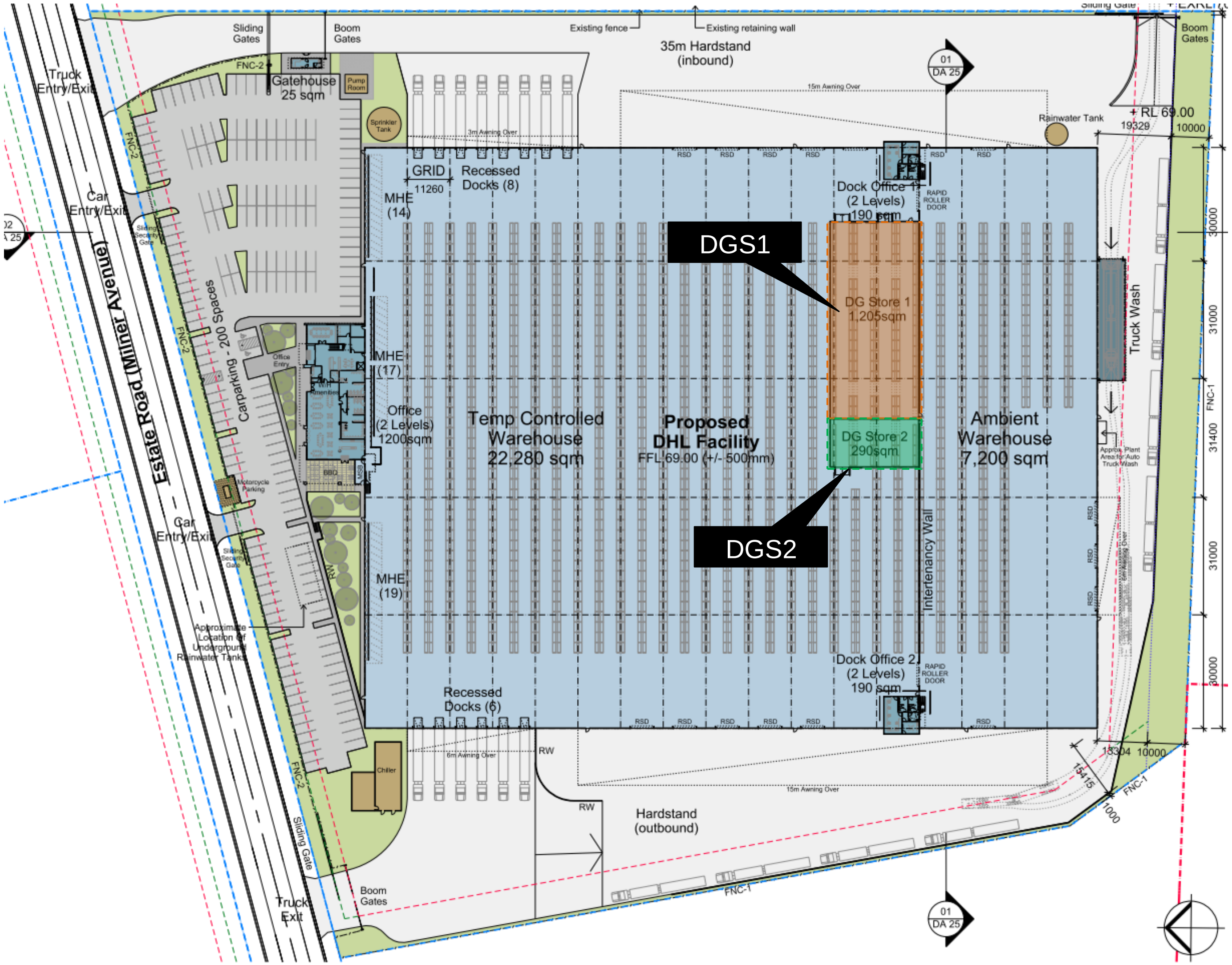


Figure 3-2: Building 2B at Oakdale Industrial Estate

4 HAZARD ANALYSIS

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. 2) 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. 2) that a criterion is provided for the maximum permissible explosion over pressure at the site boundary (7 kPa) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in an explosion overpressure less that 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* – It is noted that toxic materials are not planned for storage at the proposed facility. Hence, toxic impacts are not considered in this study.

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

- *Societal Risk* – HIPAP No. 4 (Ref. 2) discusses the application of societal risk to populations surrounding the proposed potentially hazardous facility. It is noted that HIPAP No. 4 indicates that where a development proposal involves a significant intensification of population, in the vicinity of such a facility, the change in societal risk needs to be taken into account. In the case of the 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.
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.
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.
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 –	Class 9 substances and articles (miscellaneous dangerous substances

CLASS	HAZARDOUS PROPERTIES
Miscellaneous DGs	and articles) are substances and articles which, during transport present a danger not covered by other classes. Materials included are: ▪ Environmentally hazardous substances which are not covered by other classes; or ▪ Elevated temperature substances; or ▪ Genetically modified micro-organisms and genetically modified organisms. 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. 6)

4.3 HAZARD IDENTIFICATION

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

- Flammable liquid or gas release, delayed ignition and flash fire or explosion;
- Flammable liquid 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; and
- Warehouse fire, sprinkler activation and potentially contaminated water release.

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

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

As noted in **Section 3.5**, flammable liquids will be held at the site for storage and distribution. There is potential that a flammable liquid 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 liquid spill occurred, the liquid 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 liquid 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 liquids). This is commensurate with the requirements of Table 3.1 of AS3833-2007 (Ref. 4) for a retail distribution centre (RDC). 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.

The general warehouse area contains a mixture of DGs (Class 2.1, 3, 5.1, 8 and 9); hence, has been designed according to AS3833-2007 (Ref. 4). The warehouse will be mechanically ventilated providing adequate ventilation according to AS3833-2007 with guidance from AS1940 (Ref. 7). The ventilation would extract any accumulation of flammable vapours, maintaining the vapour concentration well below the lower explosive limit (LEL).

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 AS60079.14 (Ref. 8).

It has been proposed to operate the site 24 hours a day 7 days a week; hence, if a spill occurred, it would be identified by personnel working in the warehouse 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 Liquid 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 liquid 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 liquid spill could occur.

If a flammable liquid 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, Early Suppression Fast Response (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 Packaged, 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 125 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 according to AS3833-2007 the site to be able to contain all DG spills and liquid effluent resulting from the management of an incident (i.e. fire) shall be confined 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. 14), hence, this incident has not been carried forward for further analysis.

5 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 packaged, flammable release, ignition and pallet fire; and
- Full warehouse fire and toxic smoke emission.

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	8.4
23	10.4
12.6	13.8
4.7	22.2
3.0	27.7
2.1	33.0

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	15.9
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 PACKAGED, 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	3.1
23	3.8
12.6	5.0
4.7	7.8
3.0	9.9
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	41.5
4.7	114.0
3.0	145.0
2.1	175.0

*Based on the research by Mudan & Croche reported in Lees (Ref. 9) & Cameron/Raman (Ref.10)

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.

5.6 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.

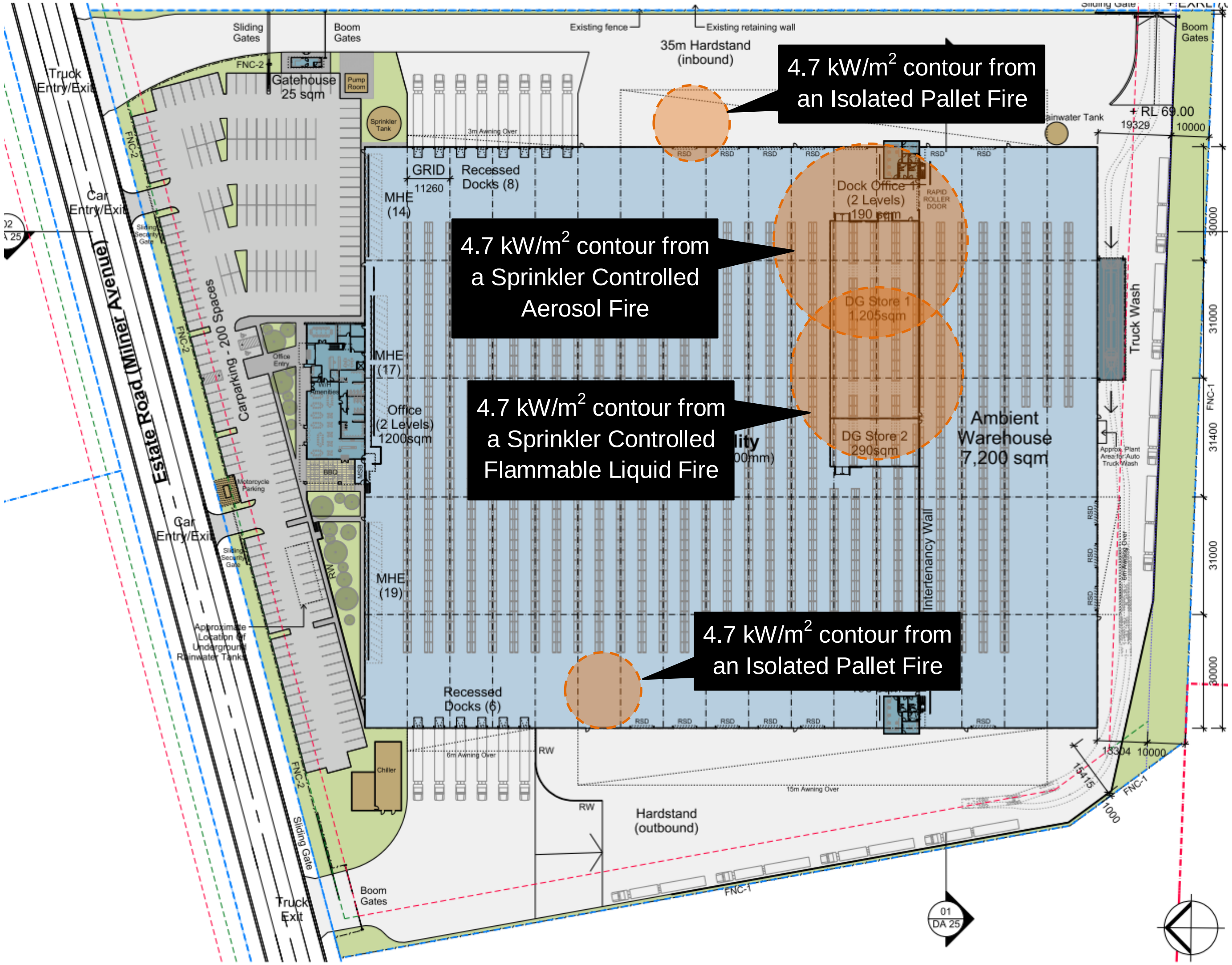


Figure 5-1: Radiant Heat Contours at 4.7 kW/m² from Sprinkler Controlled Fires

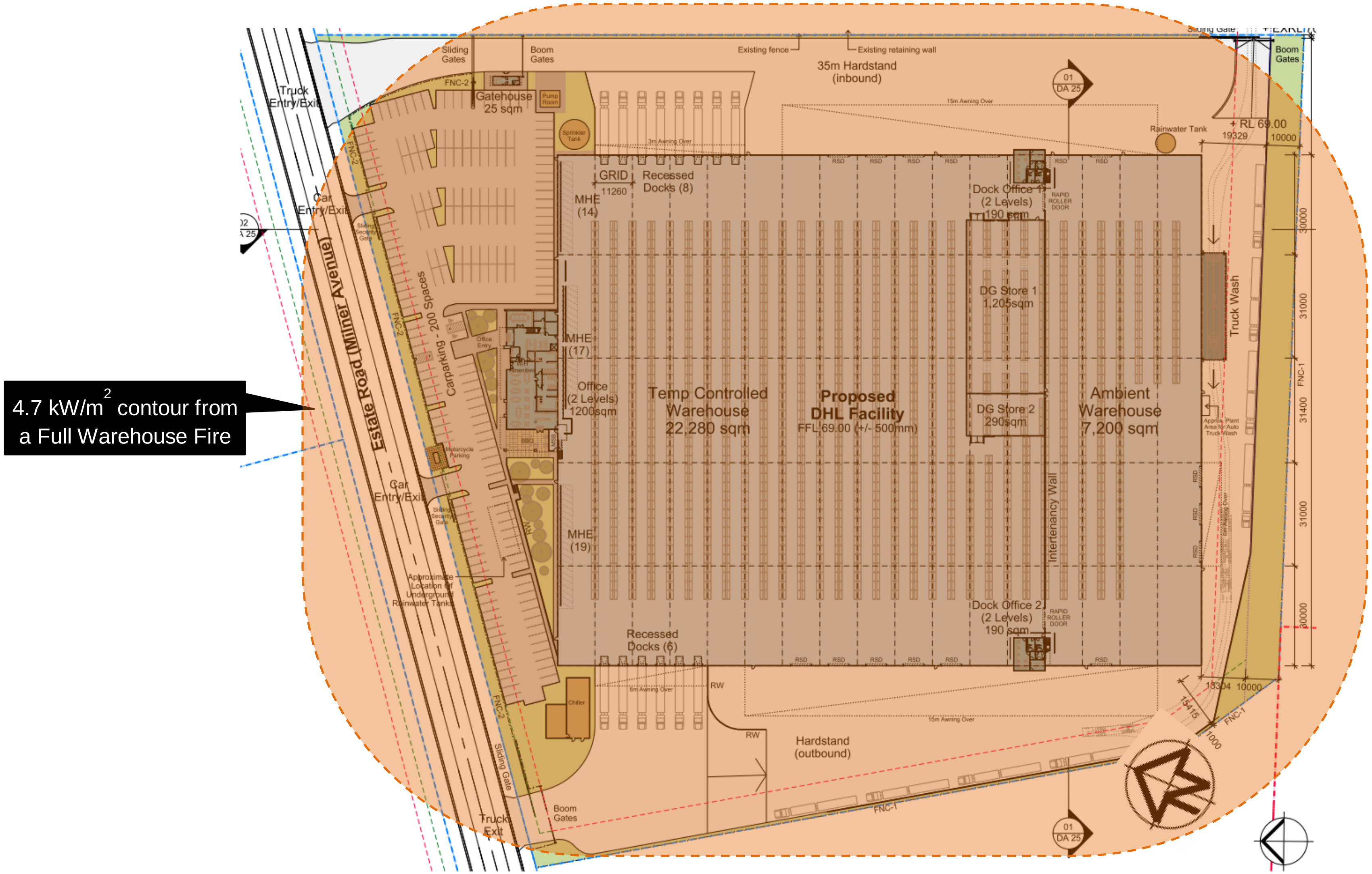


Figure 5-2: Radiant Heat Contours at 4.7 kW/m^2 from a Full Warehouse Fire

6 FREQUENCY ANALYSIS AND RISK ASSESSMENT

6.1 INCIDENTS CARRIED FORWARDS FOR FREQUENCY ANALYSIS

The following item has been carried forwards for frequency analysis;

- Full warehouse fire.

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 DHL site is fitted with an automatic sprinkler system 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. 11). 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.

Full Warehouse Fire Frequency = initiating fire frequency x PFD fire fighting system

Full Warehouse Fire Frequency = 0.001 x 0.00353 = $3.53x10^{-6}$ p.a.

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 COMPARISON AGAINST RISK CRITERIA

The NSW Department of Planning and Environment has issued a guideline on the acceptable risk criteria (Ref. 2). 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.

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

7 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.

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; and
- The site emergency plan should include response to spills and spill clean-up procedures.

8 REFERENCES

8.1 REFERENCES

1. "Applying SEPP 33", Hazardous and Offensive Industry Development Application Guidelines, NSW Department of Planning (2011)
2. Hazardous Industry Planning Advisory Paper No.4, "Risk Criteria for Land Use Planning", NSW Department of Planning (2011).
3. Hazardous Industry Planning Advisory Paper No.6, "Guidelines for Hazard Analysis", NSW Department of Planning (2011).
4. AS3833-2007, "Storage and Handling of Mixed Classes of Dangerous Goods, in Packages and Intermediate Bulk Containers", Standards Association of Australia, Sydney
5. FM Global Data Sheet 7-31, Storage of Aerosol Products, May 2003
6. "The Australian Code for the Transport of Dangerous Goods by Road and Rail", known as the Australian Dangerous Goods Code of AD), 7th ed., Road Safety Council, Canberra, ACT.
7. AS1940-2004, "Storage and Handling of Flammable and Combustible Liquids", Standards Association of Australia, Sydney
8. AS60079.14-2009, "Explosive Atmospheres Part 14: Electrical Installations, Design Selection and Erection", Standards Association of Australia, Sydney
9. Lees, F.P. (2005), Loss Prevention in the Process Industries, Butterworth-Heinemann, London
10. Cameron, I and Raman, R (2005), "Process Systems Risk Management", Elsevier, San Diego
11. Centre for Chemical Process Safety (1989), "Guidelines for Process Equipment Reliability Data with Data Tables"
12. Shell Safety and Environment (1997), "Fire Release Explosion Dispersion (FRED) User Manual Versions 2.3 – Hazard Consequence Analysis Package", Thornton, UK
13. "Fire Brigade Intervention Model V2.2", Australasian Fire Authorities Council, October 2004.
14. "Best Practice Guidelines for Contaminated Water Retention and Treatment Systems", Department of Planning, NSW

APPENDIX A HAZARD IDENTIFICATION TABLE

AREA/OPERATION	HAZARD CAUSE	HAZARD CONSEQUENCE	SAFEGUARD
General warehouse	▪ Dropped pallet ▪ Damaged packaging (receipt or during storage) ▪ Deterioration of packaging	▪ Release of Class 3, 5.1, 8 or 9 DGs to the environment	▪ Bunding exceeding the requirements of AS3833 (Ref. 4) ▪ Small retail sized packages (<20 L) ▪ Inspection of packages upon delivery to the site ▪ Trained forklift operators
	▪ 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	▪ Small retail sized packages (<20 L) ▪ Inspection of packages upon delivery to the site ▪ Ventilation provided according to AS3833 with guidance from AS1940 (Ref. 7) ▪ Control of ignition sources according to AS60079.14 (Ref. 8) ▪ Automatic fire protection system (ESFR) ▪ First attack fire-fighting equipment (e.g. hose reels & extinguishers) ▪ Fire detection systems
	Heating of Class 2.1 from a general warehouse fire	Rupture, ignition and explosion/rocketing of cylinder within warehouse spreading fire	▪ Aerosols stored in dedicated caged area ▪ In-rack sprinklers according to FM Global Data Sheet 7-31 (Ref. 5) ▪ Automatic fire protection system (ESFR) ▪ Stored according to AS3833

AREA/OPERATION	HAZARD CAUSE	HAZARD CONSEQUENCE	SAFEGUARD
ESFR activation	Fire activates ESFR resulting in fire water release and potential contaminated fire water offsite	Environmental impact to surrounding areas (e.g. stormwater drainage)	▪ Warehouse is bunded to contain in excess of the maximum required fire water in accordance with ▪ 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 ASSESSED IN DETAILED CONSEQUENCE ANALYSIS

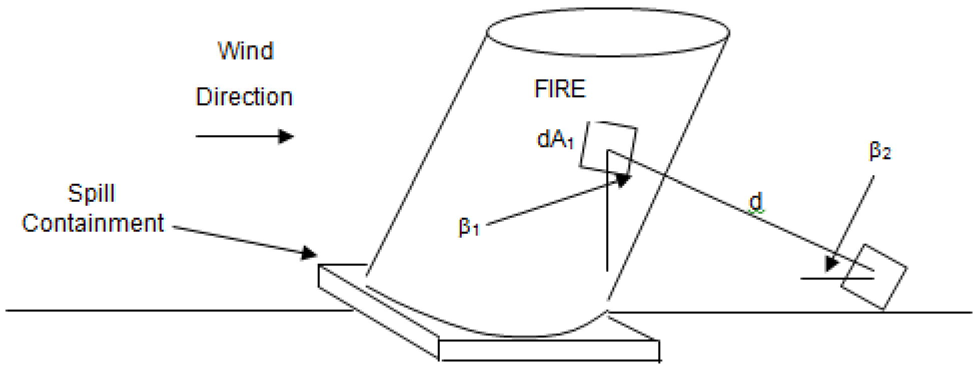
The following incidents are assessed for consequence impacts.

- Flammable liquid spill, ignition and racking fire;
- LPG release (from aerosol), ignition and racking fire;
- Forklift loading/unloading, damaged packaged, flammable release, ignition and pallet fire; and
- Full warehouse fire.

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**.

$Q = EF\tau$ **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:

$$F = \int\int_s \frac{\cos\beta_1 \cos\beta_2}{\pi d^2}$$ **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**:

$$VF = \Delta A \frac{\sin\gamma}{\pi \times X4 \times X4}$$ **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**:

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

The SCC now turns three dimensional. The vertical axis represents the variation in θ from 0 to 90^o 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-3**. Actually the sum is taken without the ΔA term. This sum is then multiplied by ΔA 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. 9 & Ref. 12) 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. 10) 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. 2).

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. 13).
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. 9)

The models provided the following information for the warehouse 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	8.4
23	10.4
12.6	13.8
4.7	22.2
3.0	27.7
2.1	33.0

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. 9)

The models provided the following information for the warehouse fire;

- SEP – 99.9 kW/m^2
- Flame Height – 21 m (from model without roof restriction)

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

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	15.9
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. 9);
- 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	3.1
23	3.8
12.6	5.0
4.7	7.8

HEAT RADIATION (KW/M^2)	DISTANCE (M)
3.0	9.9
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 has approximate dimensions of 177 m by 113 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 1.6 which is appropriate for use in the model.

The dimensions of the warehouse storage area have been used to estimate a circular diameter of a fire in the warehouse 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.

$$A = L \times W = 177 \times 113 = 669\ m^2$$

$$D = \sqrt{\frac{4 \times 20001}{\pi}} = 159.6\ m$$

The following information was input into the models;

- Equivalent fire diameter – 159.6 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. 9)

The models provided the following information for the warehouse fire;

- SEP – 20 kW/m^2
- Flame Height – 122 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	41.5
4.7	114.0
3.0	145.0
2.1	175.0

APPENDIX C WAREHOUSE FIRE FREQUENCY ESTIMATION

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.