Preliminary Hazard Analysis

585 – 649 Mamre Road, Orchard Hills

Linfox Logistics
Document No. Q16-065
Date 4/04/2017

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Quality Management

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A	24 Feb 2017		Renton Parker	Kevin Blackie
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Abbreviations

Abbreviation	Description
ADG	Australian Dangerous Goods Code
AS	Australian Standard
BMPL	Blackie Mendham Pty Ltd
CBD	Central Business District
CCPS	Centre for Chemical Process Safety
DA	Development Application
DGs	Dangerous Goods
DGS	Dangerous Goods Store
DPE	Department of Planning and Environment
FRNSW	Fire and Rescue New South Wales
HIPAP	Hazardous Industry Planning Advisory Paper
HSE	Health and Safety Executive
LPG	Liquefied Petroleum Gas
PFD	Probability of Failure on Demand
PHA	Preliminary Hazard Analysis
Pmpy	Per million per year
RDC	Retail Distribution Centre
SEP	Surface Emissive Power
SEPP	State Environmental Planning Policy
SMSS	Storage Mode Sprinkler System
SSC	Spread Sheet Calculator
VF	View Factor

Executive Summary

Background

Linfox proposes to develop a new warehouse at First Estate to be located at 585 – 649 Mamre Road 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 Dangerous Goods (DGs); including flammable gases and liquids.

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).

Hansen Yuncken, on behalf of Linfox, has commissioned Blackie Mendham Pty Ltd (BMPL) to prepare a PHA for the facility. This document represents the PHA study for the Linfox warehouse at Orchard Hills.

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 Linfox. A final report was then developed, incorporating the comments received by Linfox, 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 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 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; and
- Full warehouse fire and 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

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 (Ref. [2]) 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 only incident which may result in impacts to adjacent structures was a full warehouse fire. Due to the fire size there will be considerable smoke emitted which would obscure the flame surface reducing the average surface emissive power (SEP) and subsequently it would not exceed 23 kW/m^2. In addition, the distance to the closest buildings is 23 m which would allow attenuation of radiant heat from of luminous spots and would not result in sustained radiant heat such that propagation to adjacent facilities would occur.

Review of the estate proposal indicates this development is the only contributor to the risk profile; hence, cumulative risk is not a consideration at this stage. The cumulative risk at the site is therefore the reported 3.53 chances pmpy which is below the 50 chances pmpy limit. Therefore, the development of the Linfox warehouse does not increase the cumulative risk of the estate to an unacceptable level.

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

Recommendations

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

- multiple spill kits be provided around the DG store to ensure spills can be cleaned up immediately following identification.
- A drain with fire trap between DGS1 and DGS2 should be incorporated into the design to minimise the set down required to accommodate the bund volume.
- A rise of the main warehouse floor leading to the doors and entrances of 30 mm should be incorporated into the design to obtain the remaining volume of 595 m3.
- A storm water isolation point (i.e. penstock isolation valve) should be incorporated into the design. The penstock should automatically isolate the storm water system upon detection of a fire to prevent potentially contaminated liquids from entering the water course.
- A method for providing independency between these systems is investigated and incorporated into the design.

1.0 Introduction

1.1 Background

Linfox proposes to develop a new warehouse at First Estate to be located at 585 – 649 Mamre Road 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 Dangerous Goods (DGs); including flammable gases and liquids.

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).

Hansen Yuncken, on behalf of Linfox, has commissioned Blackie Mendham Pty Ltd (BMPL) to prepare a PHA for the facility. This document represents the PHA study for the Linfox warehouse at Orchard Hills.

1.2 Objectives

The objectives of the PHA project, for the proposed Linfox 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
- demonstrate compliance of the site with the relevant codes, standards and regulations (i.e. NSW Planning and Assessment Regulation 1979, WHS Regulation, 2011 Ref. [4])

1.3 Scope of Services

The scope of work is to complete a PHA study for the Linfox Warehouse located at 585 – 649 Mamre Road, Western Sydney, required by the Planning Regulations for the proposed Linfox Facility in Western Sydney, NSW. The scope does not include any other assessments at the site or any other Linfox facilities or third party owner facilities.

2.0 Methodology

2.1 Multi-Level Risk Assessment

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

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

Table 2-1: Level of Assessment PHA

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

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

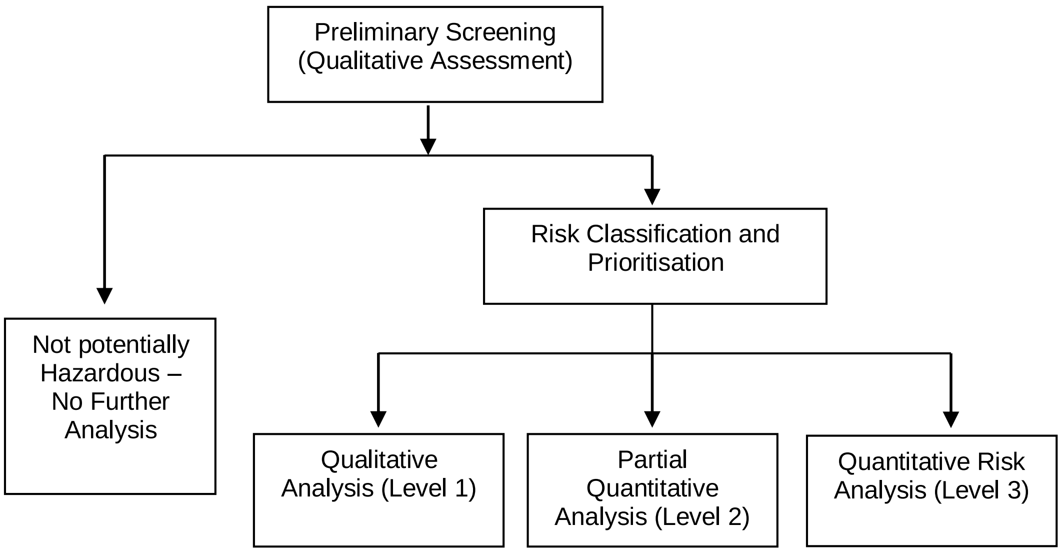

Figure 2-1: The Multi-Level Risk Assessment Approach

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

2.2 Risk Assessment Study Approach

The methodology used for the PHA is as follows;

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

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

Consequence Analysis – For those incidents qualitatively identified in the hazard analysis to have a potential offsite impact, a detailed consequence analysis was conducted. The analysis modelled the various postulated hazardous incidents and determined impact distances from the incident source. The results were compared to the consequence criteria listed in HIPAP No. 4 (Ref. [2]). 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. [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 Linfox. A final report was then developed, incorporating the comments received by Linfox, for submission to the regulatory authority.

3.0 Site Description

3.1 Site Location

The site is located at 585 – 649 Mamre Road in Orchard Hills which is approximately 46 km west of the Sydney Central Business District (CBD). **Figure 3-1** shows the regional location of the site in relation to the Sydney CBD. Provided in **Figure 3-2** is the layout of the site in Orchard Hills.

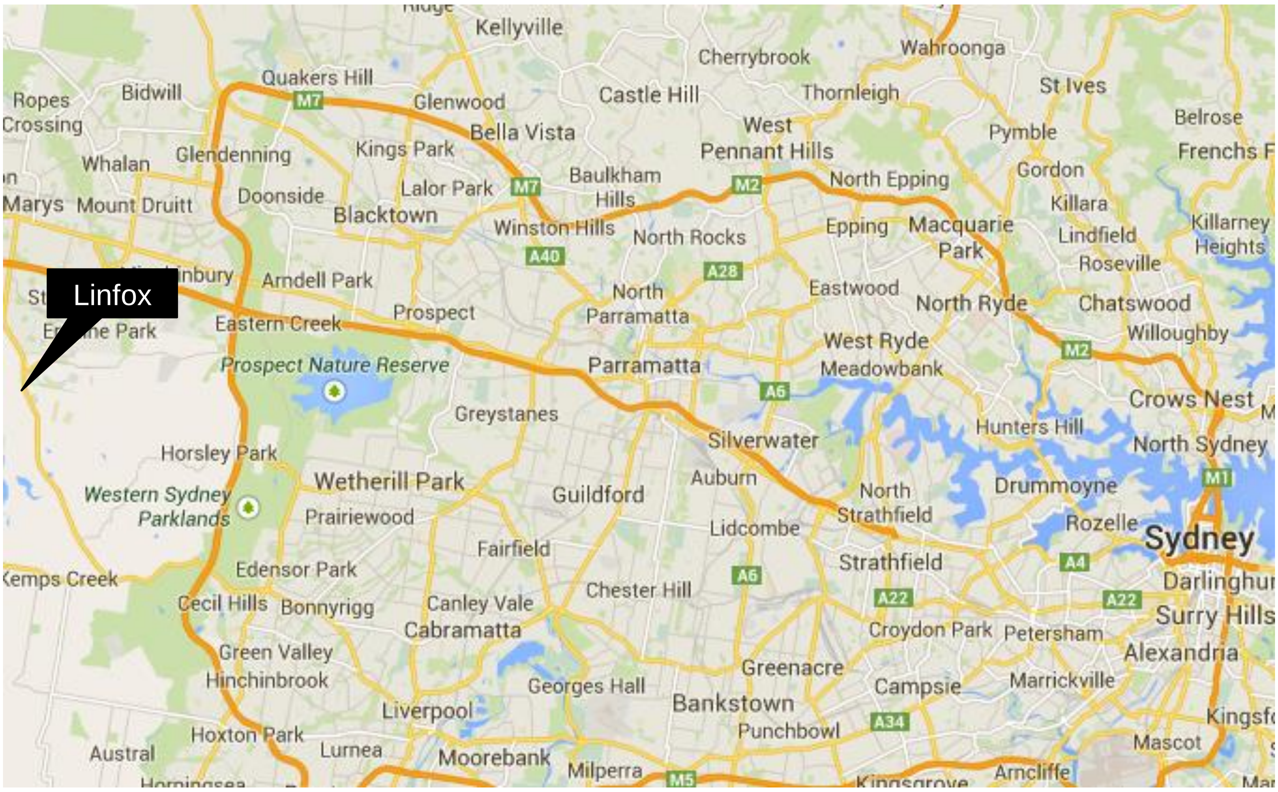

Figure 3-1: Linfox Site Location

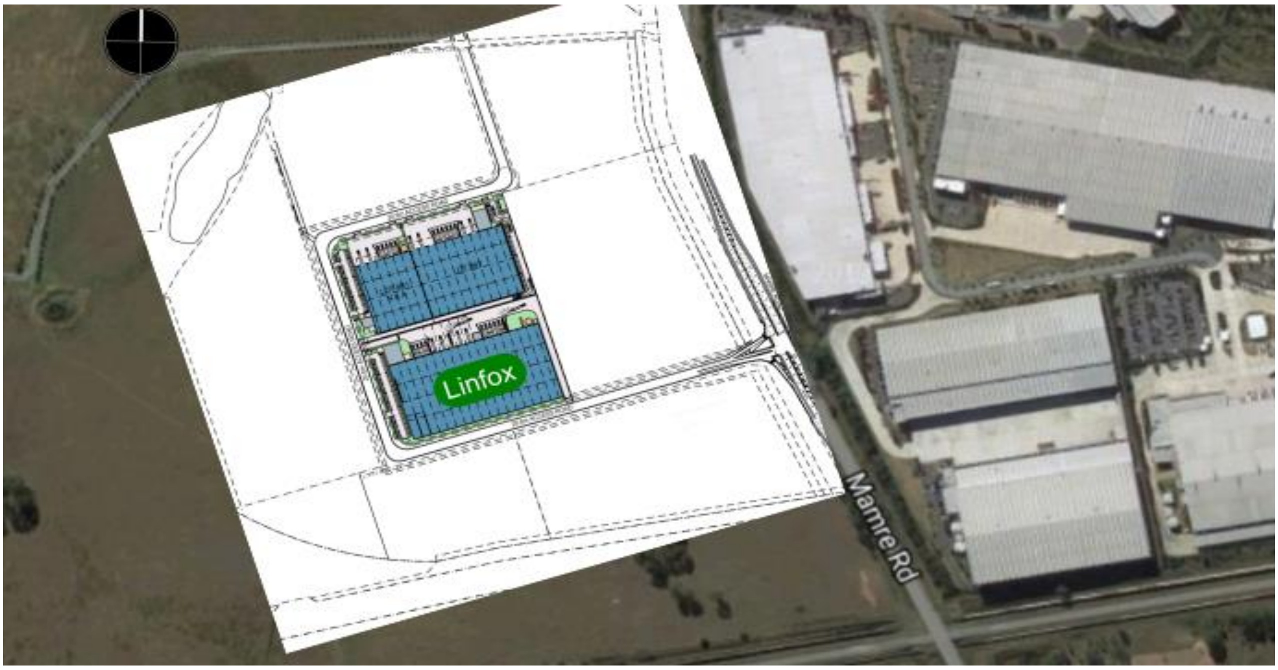

Figure 3-2: First Estate Master Plan

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 – Proposed warehousing facilities
- South – Vacant land
- East – Mamre Road and warehousing facilities
- West – Vacant land

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 stored in racking. The warehouse predominantly stores pharmaceutical products with approximately 3% of product stored classified as DGs. DG classes and volumes are discussed in **Section 3.4**. **Figure 3-3** can be used to assist in understanding the description provided below.

3.4 Warehouse Detailed Description

The warehouse will have a total floor area of approximately 21,000 m^2 including a DG store area of 750 m^2. The warehouse will store a range of DGs including Class 2.1 and 3. The main DG store area will be separated into two areas with one area containing Class 2s (DGS2) and the other Class 3 (DGS1). The DG stores will be stored in accordance with the Retail Distribution Centre (RDC) requirements of AS3833-2007 (Ref. [6]), although additional design considerations above and beyond the RDC specifications will be incorporated into the design.

The Class 3 DGs will be stored in a purpose build DG bunker constructed from concrete panel walls FRL 240/240/240, which will penetrate through the roof by 0.5 m to provide a completely separate fire compartment within the warehouse. Access to the bunkers will be through individual doors, both with a FRL -/120/30 which will automatically close upon fire detection and will be drencher protected on both sides to minimise radiant heat impacts to products external to the store and vice versa from a potential fire in the general warehouse impacting in toward the DG bunker.

All DG products will be protected by base building specified Storage Mode Sprinkler System (SMSS) sprinklers and in-rack sprinklers scheme A sprinkler systems designed according to FM Global Data Sheet 7-31 (Ref. [7]). The Class 3 store will also be fitted with hose reels, with foam generating capability.

The Class 3 storage will be bunded to contain at least 115 m^3 which includes the requirements for a package store and 20 minutes of fire water above the RDC requirements as specified in AS/NZS 3833:2007 (Ref. [6]). The whole site will be capable of containing a minimum of 90 minutes of potentially contaminated fire water which will be achieved via a penstock valve on the storm water system which will automatically isolate upon fire detection.

The Class 3 store will be ventilated to prevent the accumulation of vapours in accordance with AS/NZS 3833:2007 (Ref. [6]). The aerosol store will be naturally ventilated via the presence of louvres but will not have forced mechanical ventilation due infrequent, and short lived nature of aerosol releases. Ignition sources through the Class 2 and 3 stores will be controlled according to AS/NZS 60079.14:2009 of standards (Ref. [8]).

3.5 Site Staffing and Operational Hours

The site will have approval for 24 / 7 operation; however, during operation the site will be manned over 2 shifts of 8 hours resulting in an operational time of 16 hours a day, 7 days a week. The site will employ a total of 85 people working across the 2 shifts separated as follows:

- Distribution Centre: 55
- Processing Area: 10
- Office: 20

3.6 Quantities of Dangerous Goods Stored and Handled

The dangerous goods stored at the warehouse are predominantly for pharmaceutical use. As the individual chemical types are expected to list in the hundreds, within the warehouse, the materials have been represented as DG Classes for simplicity. A list of the classes, packing groups and expected quantities are shown in **Table 3-1**. The location of the DGs within the warehouse are shown in **Figure 3-3.**

Table 3-1: Dangerous Goods Stored at the Linfox Site

Class	Packing Group	Quantity (L or kg)	DG Location
2.1 (aerosols)	N/A	44,000 kg of LPG*	DGS2
3	II & III	125,000 L	DGS1

*175,000 L of total product is stored. Assuming a density of 1,000 kg/m^3 and 25% of the aerosol product is propellant (LPG) then 44,000 kg of LPG will be stored.

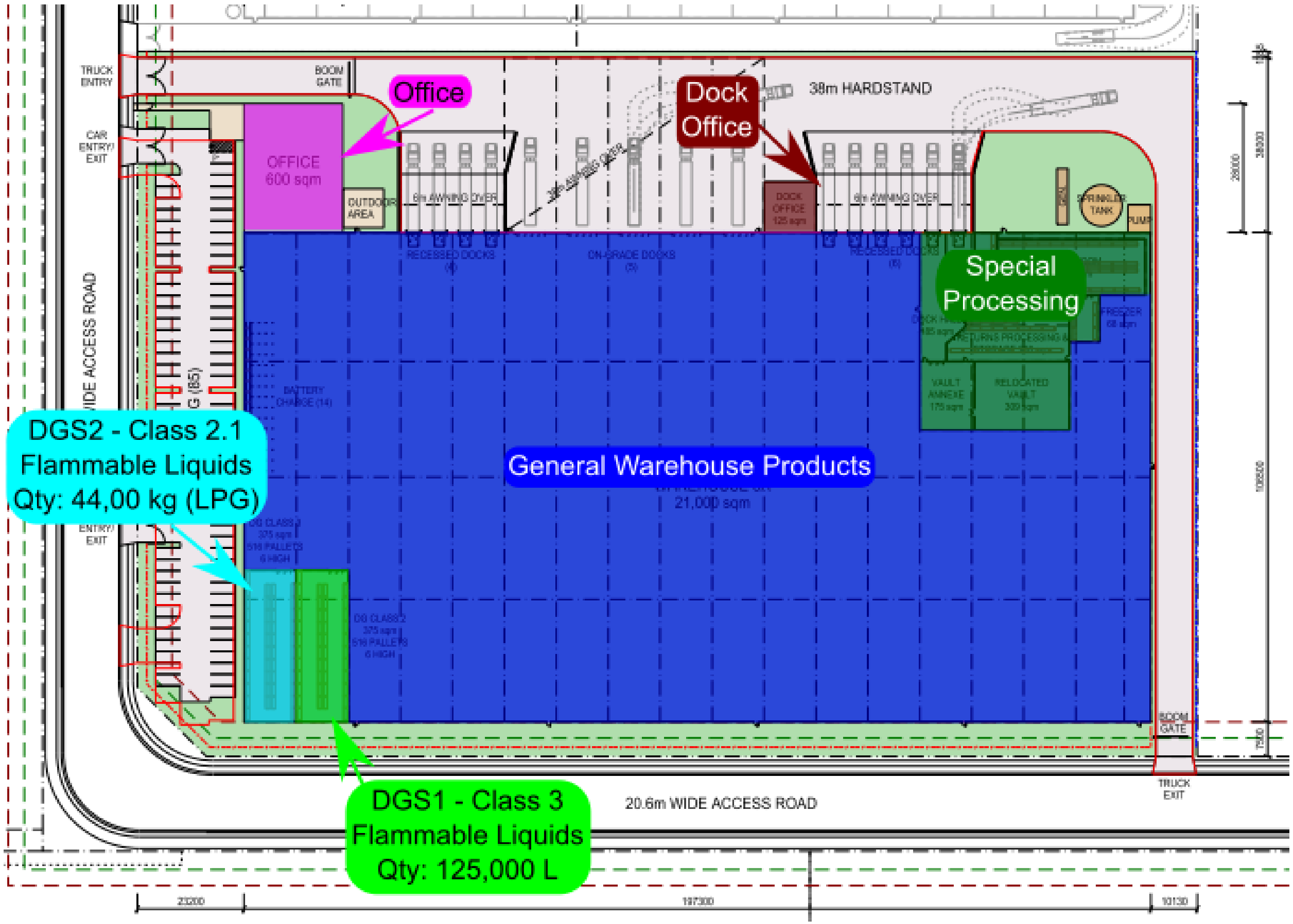

Figure 3-3: Linfox Site Layout

4.0 Hazard Identification

4.1 Introduction

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

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

- *Fire Impacts* - It is noted in Hazardous Industry Planning Advisory Paper (HIPAP) No. 4 (Ref. [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 (Ref. [2]) 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 300 m from the site, hence, by selecting 4.7 kW/m^2 as the consequence impact criteria (at the adjacent industrial site boundary) the assessment is considered conservative.

- *Explosion* - It is noted in HIPAP No. 4 (Ref. [2]) that a criterion is provided for the maximum permissible explosion over pressure at the site boundary (7 kPa) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in an explosion overpressure less than 7 kPa, at the site boundary, are screened from further assessment. Those incidents exceeding 7 kPa, at the site boundary, are carried forward for further assessment (i.e. frequency and risk). Similarly, to the heat radiation impact discussed above, this is conservative as the 7 kPa value listed in HIPAP No. 4 relates to residential areas, which are over 300 m from the site(noting that only industrial areas adjoin the proposed facility).

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

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

- *Societal Risk* – HIPAP No. 4 (Ref. [2]) discusses the application of societal risk to populations surrounding the proposed potentially hazardous facility. It is noted that HIPAP No. 4 indicates that where a development proposal involves a significant intensification of population, in the vicinity of such a facility, the change in societal risk needs to be taken into account. In the case of the Linfox 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 300 m from the site.

4.2 Properties of Dangerous Goods

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

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

Class	Hazardous Properties
2.1 – 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.

* The Australian Code for the Transport of Dangerous Goods by Road and Rail (Ref. [9])

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 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 sections.

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

As noted in **Section 3.0**, 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 if ignited, 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. Furthermore, the volume of gas release is the relative density of the gas to air.

A review of the product list to be stored at Linfox indicates that the majority of the products are small packages (< 175 g for aerosols and < 250 mL for flammable liquids). Therefore, the release from a single flammable liquid container would result in a release <250 mL. For aerosols, the quantity of LPG propellant used is approximately 25% of the weight of the product hence, for a 175 g product approximately 45 g 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. [8]).

It has been proposed to seek approval to operate the site 24 hours a day 7 days a week however the site will only be manned approximately 16 hours a day, 7 days a week. Therefore, 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.

4.5 Flammable Liquid Spill, Ignition and Racking Fire

As noted in **Section 4.4**, 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 pallet or package 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 <250 mL 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, a Storage Mode Sprinkler System (SMSS) 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 been carried forward for further analysis to demonstrate that the likely impact of an SMSS controlled fire is within the site boundary.

The Class 3 store will be fitted with in-rack sprinklers and SMSS; hence, it is recommended that a method for providing independency between these systems is investigated and incorporated into the design.

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

As noted in **Section 4.4**, 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 had not occurred prior to storage within the warehouse.

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 an 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 SMSS 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. [7]).

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.

The Class 2 store will be fitted with in-rack sprinklers and SMSS; hence, it is recommended that a method for providing independency between these systems is investigated and incorporated into the design.

4.7 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.

4.8 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.

4.9 Dangerous Goods Liquid Spill, Release and Environmental Incident

There is potential that a spill of the liquid DGs (Class 3) 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 bunker (DGS1) will be bunded to contain a portion of the package store according to the relevant standard. DGS1 will be able to contain a minimum of 125 m^3. The 125 m^3 required for DGS1 could be shared between DGS1 and DGS2. Therefore, it is recommended that a drain with fire trap between DGS1 and DGS2 should be incorporated into the design to minimise the set down required to accommodate the bund volume.

The site is required to hold 90 minutes of potentially contaminated water as required by the Department of Planning document "*Best Practice Guidelines for Potentially Contaminated Water Retention and Treatment Systems"* (Ref. [10]). Therefore, it is recommended that a storm water isolation point (i.e. penstock isolation valve) should be incorporated into the design. The penstock should automatically isolate the storm water system upon detection of a fire to prevent potentially contaminated liquids from entering the water course.

As noted, the volumes of the packages are small (< 250 mL) 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.

4.10 Warehouse Fire, Sprinkler Activation and Potentially Contaminated Water Release

In the event of a fire, the SMSS 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 SMSS 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. [10]) 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. In a DG fire scenario, the following protection systems are likely to be discharging:

- SMSS at 5 m^3/min
- In-rack sprinklers at 0.6 m^3/min
- 4 hydrant hoses at 2.4 m^3/min

The total water discharge would be 8 m^3/min. Therefore, operation for 90 minutes would result in a total discharge of 720 m^3.

DGS1 has been designed to contain a portion of the DGs stored in addition to 20 minutes of fire water resulting in containment of 125 m^3. It is recommended that a rise of the main warehouse floor leading to the doors and entrances of 30 mm should be incorporated into the design to obtain the remaining volume of 595 m^3.

As noted in **Section 4.9**, an automatic isolation valve was recommended to be incorporated into the design to prevent the release of potentially contaminated water. Therefore, this recommendation is reiterated, it is recommended that a storm water isolation point (i.e. penstock isolation valve) should be incorporated into the design. The penstock should automatically isolate the storm water system upon detection of a fire to prevent potentially contaminated liquids from entering the water course.

Based on the design and containment for the premises, there is adequate fire water retention to meet the '*Best Practice Guidelines for Contaminated Water Retention and Treatment Systems*" (Ref. [10]), hence, this incident has not been carried forward for further analysis.

5.0 Consequence Analysis

5.1 Incidents Carried Forward for Consequence Analysis

The following 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; and
- Full warehouse fire and 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 SMSS 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
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 SMSS 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**.

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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
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 SMSS 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
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	71.0
4.7	118.0
2.1	178.0

*Based on the research by Mudan & Croche reported in Lees (Ref. [11]) & Cameron/Raman (Ref. [12])

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.

It is noted that due to the fire size there will be considerable smoke emitted which would obscure the flame surface reducing the average surface emissive power (SEP) and subsequently it would not exceed 23 kW/m^2. In addition, the distance to the closest buildings is 23 m which would allow attenuation of radiant heat from of luminous spots and would not result in sustained radiant heat such that propagation to adjacent facilities would not occur.

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.

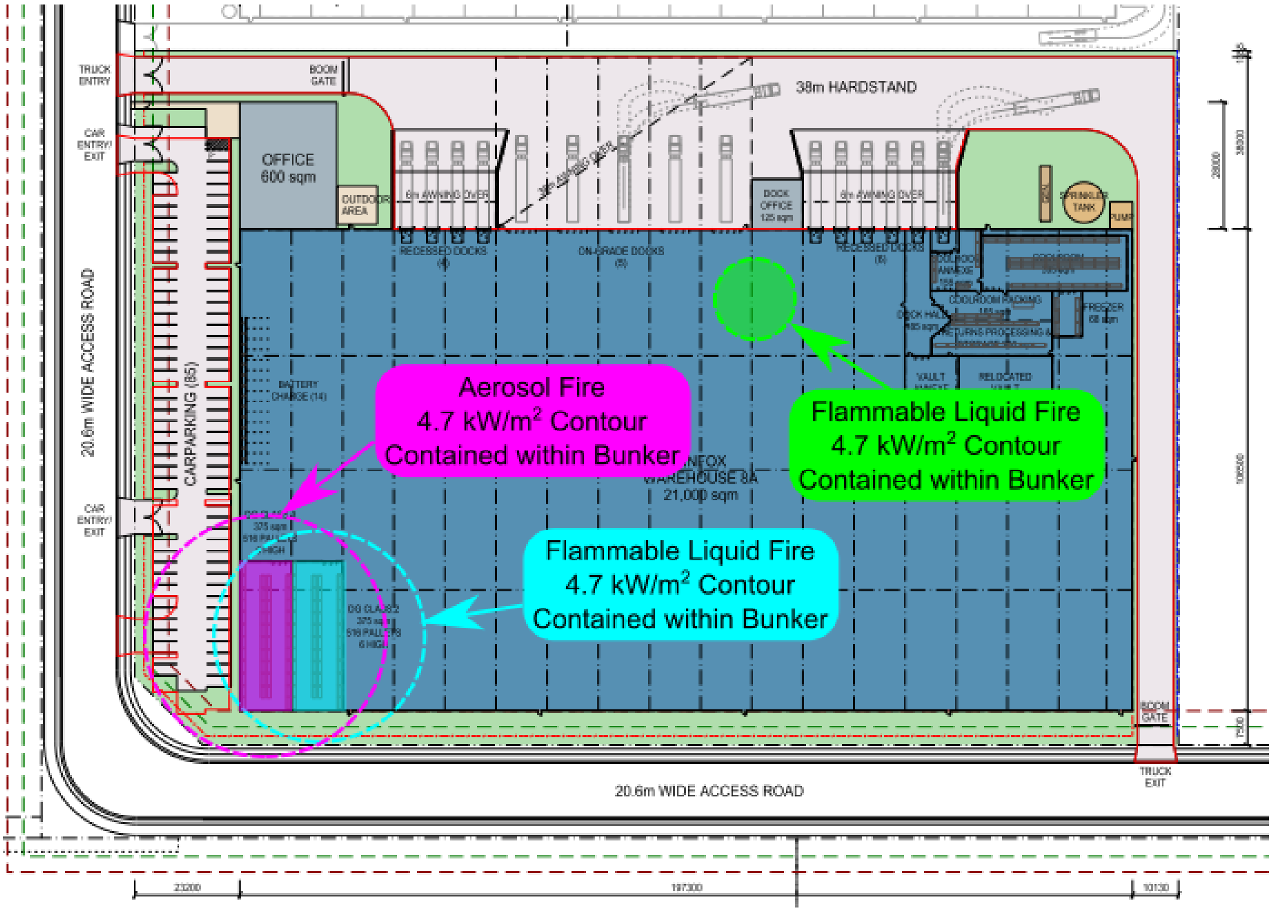


Figure 5-1: Small Fire Scenarios at 4.7 kW/m²

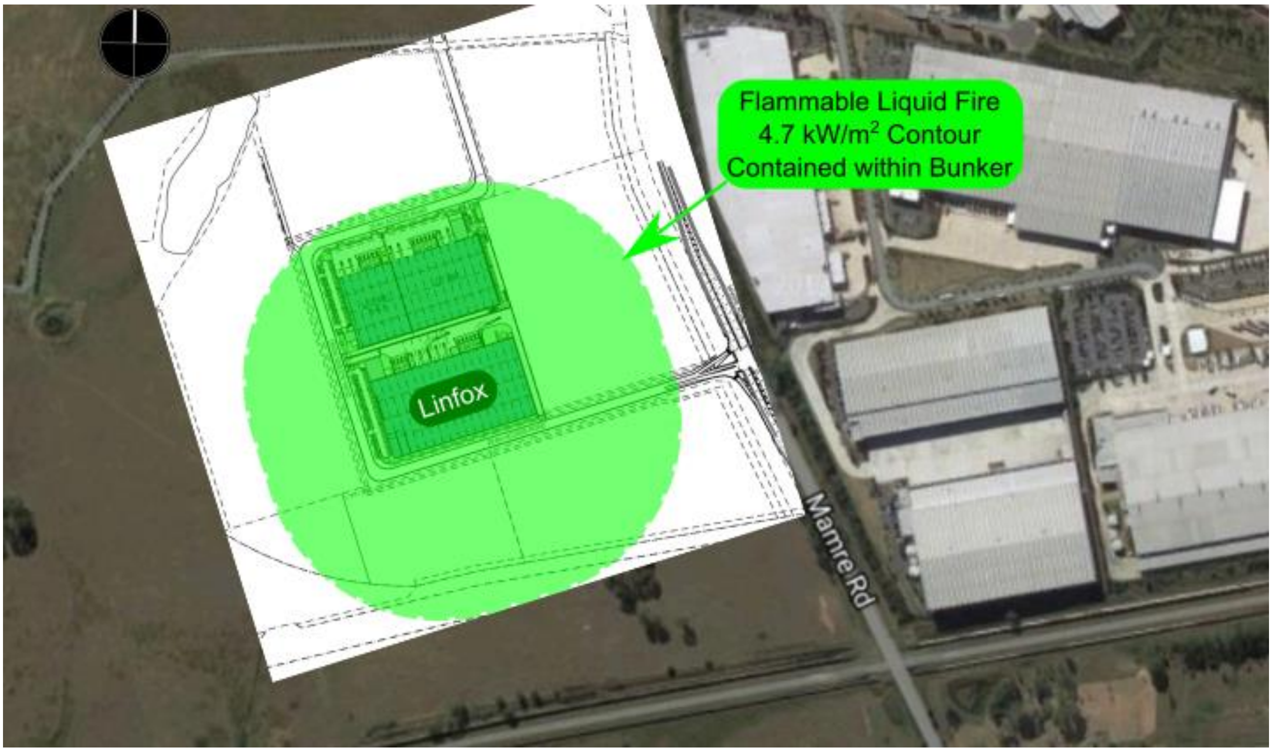


Figure 5-2: Full Warehouse Fire at 4.7 kW/m²

6.0 Frequency Analysis

6.1 Incidents Carried Forward 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 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. [13]). 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**.

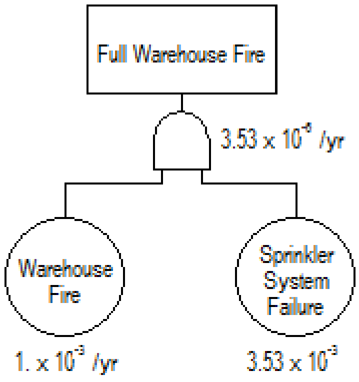


Figure 6-1: Full Warehouse Fire Fault Tree

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 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.

6.4 Cumulative Assessment

A review of the surrounding area indicates this would be the first development to occur at the estate. It is proposed to develop an adjacent warehouse which will not store any DGs. Due to the low level of development and the proposal of the adjacent uses, cumulative risks are not considered to be a risk at this stage.

7.0 Conclusion 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 (Ref. [2]) 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 only incident which may result in impacts to adjacent structures was a full warehouse fire. Due to the fire size there will be considerable smoke emitted which would obscure the flame surface reducing the average surface emissive power (SEP) and subsequently it would not exceed 23 kW/m^2. In addition, the distance to the closest buildings is 23 m which would allow attenuation of radiant heat from of luminous spots and would not result in sustained radiant heat such that propagation to adjacent facilities would occur.

Review of the estate proposal indicates this development is the only contributor to the risk profile; hence, cumulative risk is not a consideration at this stage. The cumulative risk at the site is therefore the reported 3.53 chances pmpy which is below the 50 chances pmpy limit. Therefore, the development of the Linfox warehouse does not increase the cumulative risk of the estate to an unacceptable level.

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

7.2 Recommendations

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

- multiple spill kits be provided around the DG store to ensure spills can be cleaned up immediately following identification.

- A drain with fire trap between DGS1 and DGS2 should be incorporated into the design to minimise the set down required to accommodate the bund volume.
- A rise of the main warehouse floor leading to the doors and entrances of 30 mm should be incorporated into the design to obtain the remaining volume of 595 m3.
- A storm water isolation point (i.e. penstock isolation valve) should be incorporated into the design. The penstock should automatically isolate the storm water system upon detection of a fire to prevent potentially contaminated liquids from entering the water course.
- A method for providing independency between these systems is investigated and incorporated into the design.

8.0 References

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

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

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

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

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

[6] Standards Australia, “AS/NZS 3833:2007 - Storage and Handling of Mixed Classes of Dangerous Goods, in Packages and Intermediate Bulk Containers,” Standards Australia, Sydney, 2007.

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

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

[9] Road Safety Council, The Australian Code for the Transport of Dangerous Goods by Road and Rail Edition 7.4, Canberra: Road Safety Council, 2016.

[10] NSW Department of Planning, “Best Practice Guidelines for Contaminated Water Retention and Treatment Systems,” NSW Department of Planning, Sydney, 1994.

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

[12] I. Cameron and R. Raman, Process Systems Risk Management, San Diego: Elsevier, 2005.

[13] Centre for Chemical Process Safety, “Guidelines for Process Equipment Reliability Data with Data Tables,” Centre for Chemical Process Safety, 1989.

Appendix A

Hazard Identification Table

A1. Hazard Identification

Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
Warehouse	• Dropped pallet • Damaged packaging (receipt or during storage) • Deterioration of packaging	• Release of Class 2.1 or 3 DGs to the environment	• Small retail sized packages (< 250 mL) • Inspection of packages upon delivery to the site. • Trained forklift operators (including spill response training). • Storage of DGs within AS/NZS 3833:2007 compliant store (Ref. [6])
	• 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 (< 250 mL) • Inspection of packages upon delivery to the site • Control of ignition sources according to AS/NZS 60079.14:2009 (Ref. [8]) • Automatic fire protection system (in-rack and SMSS) • First attack fire-fighting equipment (e.g. hose reels & extinguishers) • Fire detection systems • Storage of DGs within AS/NZS 3833:2007 compliant store (Ref. [6])
	• Heating of Class 2.1 from a general warehouse fire	• Rupture, ignition and explosion/rocketing of cylinder within warehouse spreading fire	• Aerosols stored in 240/240/240 FRL bunker • In-rack sprinklers according to FM Global Data Sheet 7-31 (Ref. [7]) • Automatic fire protection system
Sprinkler activation	• Fire activates SMSS 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/NZS 3833:2007 (Ref. [6])

Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
			• Site drainage to comply with the Best Practice Guide for Potentially Contaminated Water Retention and Treatment Systems (Ref. [10])
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) • SMSS 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.

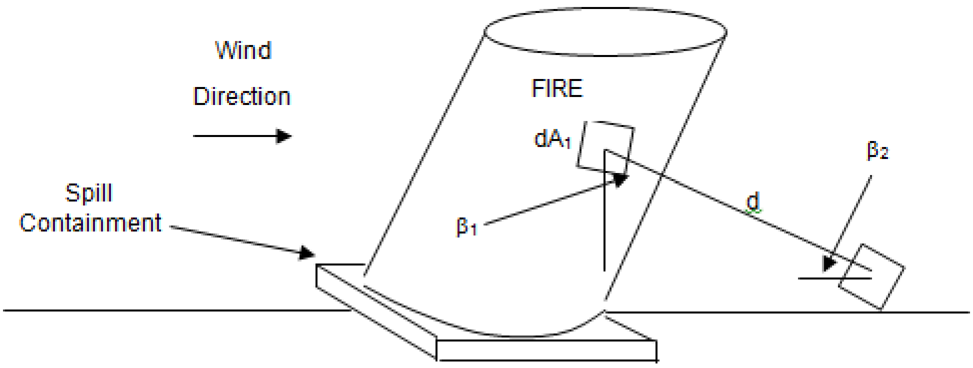
- Flammable liquid spill, ignition and racking fire;
- LPG release (from aerosol), ignition and racking fire;
- Forklift loading/unloading, damaged package, flammable release, ignition and pallet fire; and
- Full warehouse fire and smoke emission.

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. [12]).

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

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 B-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 (Ref. [12]). 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** (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-3**. 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. [11] & 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. [12]) 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)
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 in-rack sprinklers and the SMSS 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. [11])

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
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 SMSS and in-rack sprinklers to suppress the fire and cool adjacent packages to minimise the potential for rocketing.

As mentioned in **Section B3**, the SMSS 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. [11])

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
4.7	25.5
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. [11]);
- 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
2.1	11.4

B6. Full Warehouse Fire

If the fire protection system fails (SMSS and in-racks), there is the potential that a fire could develop into a full warehouse fire. The warehouse has an area of 21,000 m^2; however, the dimensions of the warehouse area where product is approximately 100 m x 50 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 2 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.

$$D = \sqrt{\frac{4 \times 21000}{\pi}} = 163\ m$$

The following information was input into the models;

- Equivalent fire diameter – 163 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. [11])

The models provided the following information for the warehouse fire;

- SEP – 20 kW/m^2
- Flame Height – 124 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	71.0
4.7	118.0
2.1	178.0

* Research conducted in relation to large fires (Ref. [12]) indicates that where a large fire occurs, it is difficult for complete combustion to occur towards the centre of the fire due to the lack of air being unable to reach the centre of the flames. Hence, combustion tends to occur effectively at the fire surface, but poorly towards the centre of the fire. This generates large quantities of black smoke, which shields the flame surface as the smoke from the centre of the fire escapes towards the outer fire surface. The research presented in Lees (Ref. [11]) indicates that fires will generate a SEP within a range of between 20 kW/m^2 for larger fires and 130 kW/m^2 for smaller fires. Hence, a full warehouse fire would be of significant dimensions, generating large quantities of black smoke, shielding the flames at the fire surface. Hence, for the analysis of a full warehouse fire in this study, an SEP value of 20 kW/m^2 has been used.

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 $2.5x10^{-3}$ p.a.;
- Baldwin, Accident Analysis and Prevention (Vol.6) – indicates a serious fire frequency in warehouses to be in the order of $1x10^{-3}$ 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 $4.6x10^{-3}$ per warehouse year; and
- VROM 2005, Guidelines for quantitative risk assessment CPR 18E (Purple Book), Publication Series on Dangerous Substances (PGS 3), The Netherlands. – $4x10^{-4}$ 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 $1x10^{-3}$ to $4x10^{-4}$. 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 $1x10^{-3}$ p.a. (i.e. the upper end of the range).

Selected Initiating Fire Frequency = $1x10^{-3}$ p.a.