

RiskCon Engineering

Preliminary Hazard Analysis
Oakdale South 1D, Kemps Creek

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Linfox Australia Pty Ltd

Prepared by

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Quality Management

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A	16 April 2019	Draft issue for comment	Renton Parker	Steve Sylvester
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Executive Summary

Background

Linfox proposes to develop a new warehouse within the Oakdale Industrial Estate to be located at Oakdale South 1D in Kemps Creek, 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.) 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).

Linfox has commissioned Riskcon Engineering Pty Ltd (Riskcon) to prepare a PHA for the facility. This document represents the PHA study for the Linfox warehouse at Kemps Creek.

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 7.06 chances per million per year (pmpy) at the site boundary, with lesser risk at further distances from the boundary. HIPAP No. 4 (Ref. [1]) 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 7.06 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:

1. The site shall be designed to contain any spills or contaminated water from a fire incident within the boundaries of the site.
2. Multiple spill kits be provided around the DG storage areas to ensure spills can be cleaned up immediately following identification.
3. Aerosols shall be stored in a dedicated storage area which prevents rocketing cans from escalating the incident (i.e. storage in an aerosol cage, separate storage area, or in palletised aerosol cages).
4. The warehouse and/or site boundaries shall be capable of containing 612 m³ which may be contained within the warehouse footprint, site stormwater pipework and any recessed docks or other containment areas that may be present as part of the site design.
5. The civil engineers designing the site containment shall demonstrate the design is capable of containing at least 612 m³.
6. A storm water isolation point (i.e. penstock isolation valve) shall be incorporated into the design. The penstock shall automatically isolate the storm water system upon detection of a fire (smoke or sprinkler activation) to prevent potentially contaminated liquids from entering the water course.

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Abbreviations

Abbreviation	Description
ADG	Australian Dangerous Goods Code
AS	Australian Standard
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

1.0 Introduction

1.1 Background

Linfox proposes to develop a new warehouse within the Oakdale Industrial Estate to be located at Oakdale South 1D in Kemps Creek, 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).

Linfox has commissioned Riskcon Engineering Pty Ltd (Riskcon) to prepare a PHA for the facility. This document represents the PHA study for the Linfox warehouse at Kemps Creek.

1.2 Objectives

The objectives of the PHA project, for the proposed Linfox facility at Oakdale South 1D, Kemps Creek, NSW, include:

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

1.3 Scope of Services

The scope of work is to complete a PHA study for the Linfox Warehouse located at Oakdale South 1D, Kemps Creek, required by the Planning Regulations for the proposed development. The scope does not include any other assessments at the site or any other Linfox facilities.

2.0 Methodology

2.1 Multi-Level Risk Assessment

The Multi-Level Risk Assessment approach (Ref. [3]), although published by the NSW Department of Planning and Environment, has been used as the basis for the study to determine the level of risk assessment required. The approach considered the development in context of its location, the quantity and type (i.e. hazardous nature) Dangerous Goods stored and used, and the facility's technical and safety management control. The Multi-Level Risk Assessment Guidelines are intended to assist industry, consultants and the consent authorities to carry out and evaluate risk assessments at an appropriate level for the facility being studied.

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

Table 2-1: Level of Assessment PHA

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

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

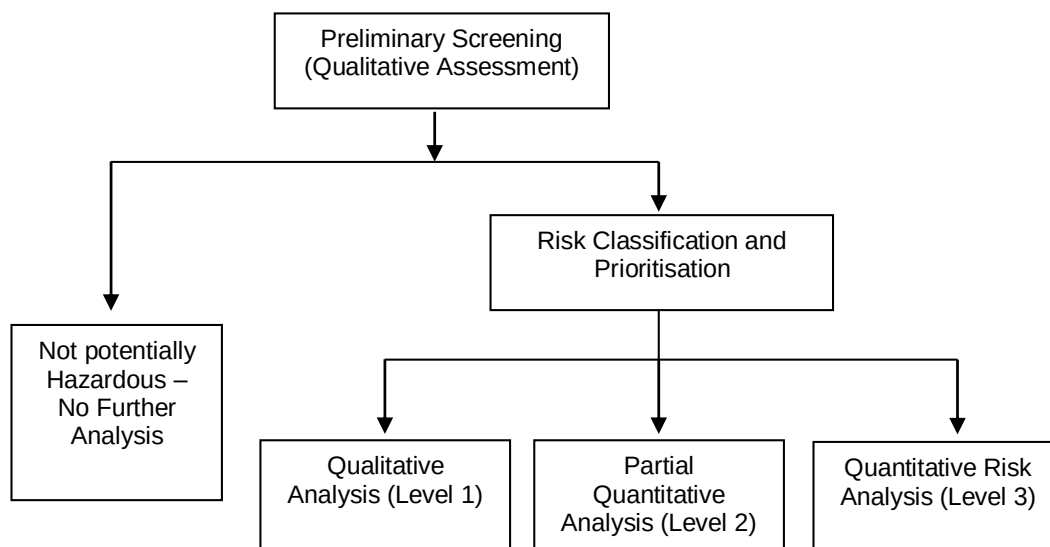


Figure 2-1: The Multi-Level Risk Assessment Approach

Based on the type of DGs to be 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. [4]).

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 3.1** of this report provides details of values used to assist in selecting incidents required to be carried forward for further analysis.

Consequence Analysis – For those incidents qualitatively identified in the hazard analysis to have a potential offsite impact, a detailed consequence analysis was conducted. The analysis modelled the various postulated hazardous incidents and determined impact distances from the incident source. The results were compared to the consequence criteria listed in HIPAP No. 4 (Ref. [2]). The criteria selected for screening incidents is discussed in **Section 3.1**.

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 (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 Oakdale South 1D in Kemps Creek which is approximately 44 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 Kemps Creek.

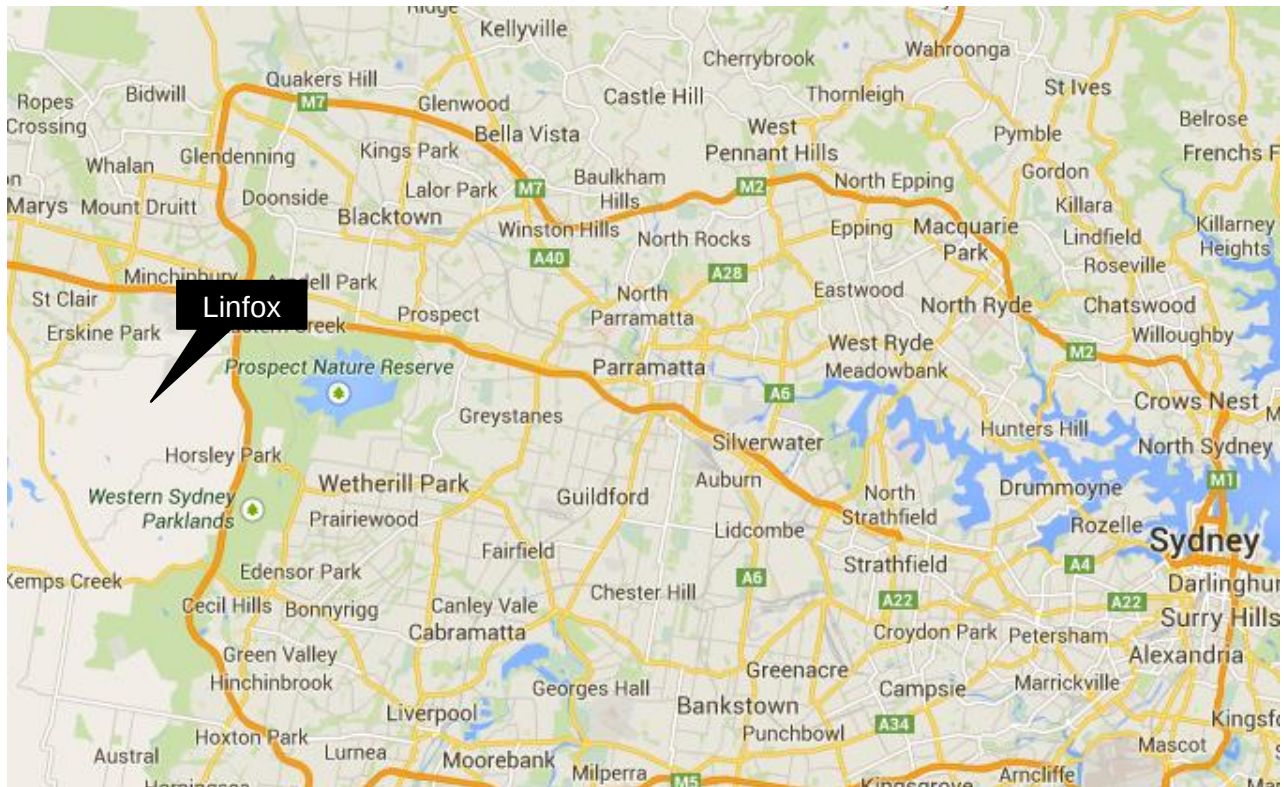


Figure 3-1: Linfox Site Location

3.2 Adjacent Land Uses

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

- North – Industrial warehousing
- South – Industrial warehousing
- East – Industrial warehousing
- West – Industrial warehousing

3.3 General Description

The building will consist of an office area, amenities and warehouse area including a Dangerous Goods (DG) storage area and automated packing / picking store (The Autostore). 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. DG classes and volumes are discussed in **Section 3.4**.

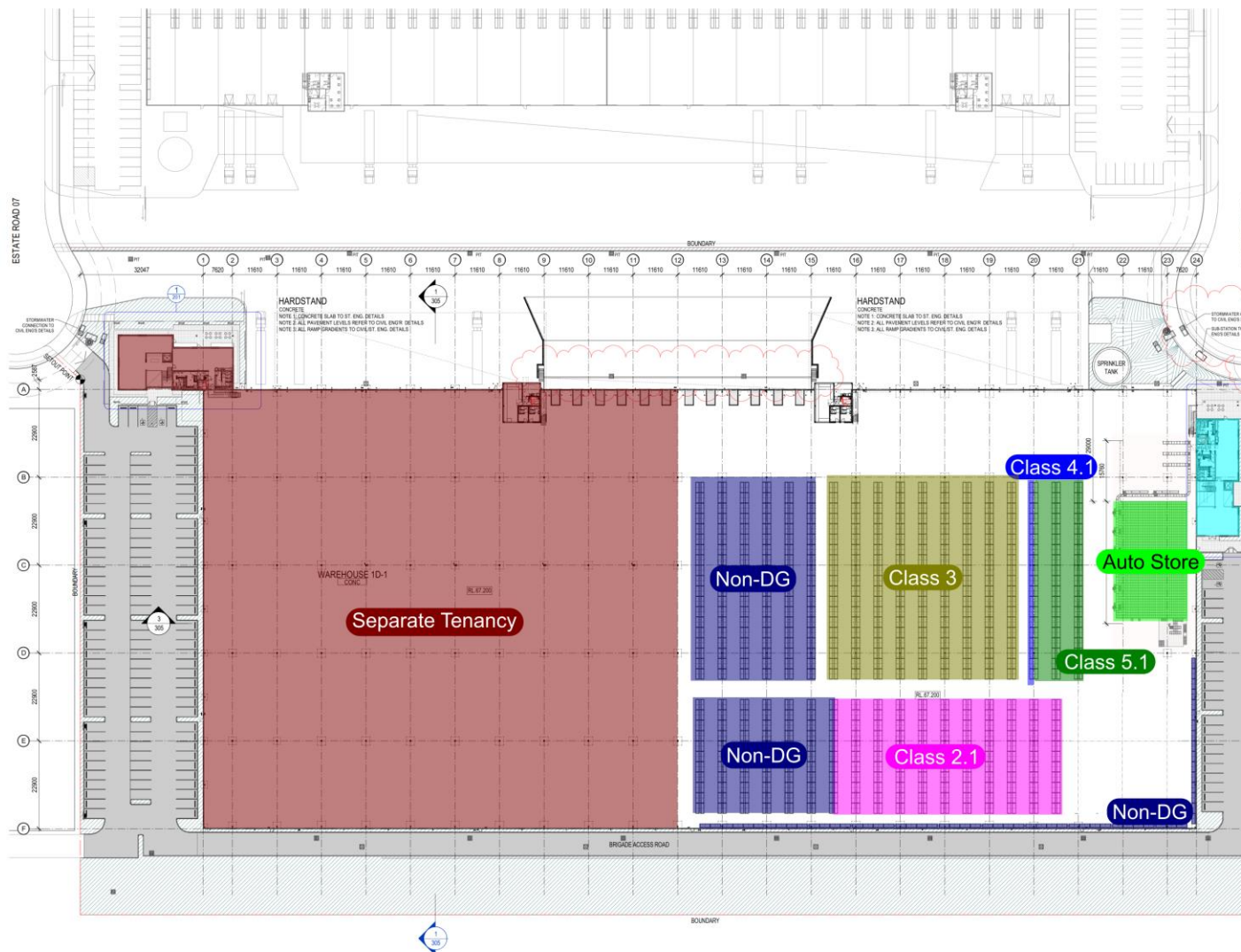


Figure 3-2 can be used to assist in understanding the description provided below.

3.4 Warehouse Detailed Description

The warehouse will have a total floor area of approximately 15,369 m² which will house general racking, racking dedicated to DG storage and the Autostore. The warehouse layout also includes additional space for offices, amenities, lunch rooms, etc. The DG component of the warehouse will be designed and operated in accordance with the Retail Distribution Centre (RDC) requirements of AS/NZS 3833:2007 (Ref. [5]).

DG classes will be stored in designated areas within the warehouse as shown in **Figure 3-2** with the Class 2.1 (aerosols) being stored within in a caged area to prevent rocketing of cans throughout the facility in the event of a fire which can rapidly accelerate fire spread throughout the warehouse.

All DG products will be protected by base building specified Storage Mode Sprinkler System (SMSS) sprinklers and the aerosols will be protected by in-rack sprinklers scheme A sprinkler systems designed according to FM Global Data Sheet 7-31 (Ref. [6]). All DG areas will be protected by hose reel coverage in addition to hydrant coverage.

The whole site will be capable of containing at least 90 minutes of potentially contaminated fire water as required by AS/NZS 3833:2007 (Ref. [5]) and the NSW “*Best Practice Guidelines for Contaminated Water and Retention Systems*” (Ref. [7]). The water will be contained via isolation of the stormwater system which is performed by the actuation of a penstock valve upon fire detection.

The warehouse areas will be naturally ventilated via the presence of louvres but will not have forced mechanical ventilation which is permissible under AS/NZS 3833:2007 (Ref. [5]) due to the reduced risk of spill posed by retail products. Ignition sources through the Class 2 and 3 storage areas will be controlled according to AS/NZS 60079.14:2009 of standards (Ref. [8]).

The Autostore will house a range of mixed products of goods including DG and non-DG products. The Autostore operates by storing products in purpose built totes which come in either full, half or quartered totes allowing for separation of products within the tote. The totes are full enclosed on all sides except the top which is open to air. The totes are stacked within the Autostore via robots which traverse along the top of the store rearranging the totes within the store as required.

The structure of the Autostore is essentially close compact vertical shafts which contain the totes with minimal separation between one vertical shaft and another shaft. The shafts are capable of containing up to sixteen (16) totes stacked vertically. Restriction on the packing of the Autostore are included in the programming of the robots which allows for products with low turnover to be stored at the base of a store with high frequency products stored close to the top to minimise item movements. Included within the programming is designation of DG storage locations within the Autostore to allow for adequate separation between DG products within the store. The maximum quantities that can be stored in each zone are summarised in **Table 3-1**.

While separation between the DG classes and other products has been provided, the potential for a spill within the totes and within the store is low as products are only moved in one direction at a time (i.e. vertically followed by horizontal movements) and that the totes themselves act as a bund as they are enclosed. Therefore, any spills that may occur within a tote are contained and would not impact adjacent totes. In addition, products within the totes are separated from each other further minimising the potential for cross contamination of DG with non-DG products.

3.5 Site Staffing and Operational Hours

The site will have approval for 24 / 7 operation; however, during operation the warehouse 2 site will be manned over 2 shifts of 8 hours resulting in an operational time of 16 hours a day, 6 days a week. The site will employ a total of 116 people working across the 2 shifts separated as follows:

- Distribution Centre: 40
- Office: 20

3.6 Quantities of Dangerous Goods Stored and Handled

The dangerous goods stored at the warehouse are retail products store prior to distribution to retail stores. 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 3-2**.

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

Area	Class	Packing Group	Quantity (L or kg)
General Warehouse	2.1 (aerosols)	N/A	556,554 L / 139,139 kg*
	3	II & III	494,678 L
	4.1	II & III	7,051
	5.1	III	58,724
Autostore	2.1 (aerosols)	N/A	~290* kg
	3	II & III	16,750 L
	4	II & III	70 L
	8	II & III	5 L
	5.1	II & III	450 L
	9	III	72 L

*Assuming a density of 1,000 kg/m³ and 25% of the aerosol product is propellant (LPG)

3.7 Aggregate Quantity Ratio

Where more than one class of dangerous goods are stored and handled at the site an AQR exists. This ratio is calculated using **Equation 3-1**:

$$AQR = \frac{q_x}{Q_x} + \frac{q_y}{Q_y} + [...] + \frac{q_n}{Q_n} \quad \text{Equation 3-1}$$

Where:

x,y [...] and n are the dangerous goods present

q_x, q_y, [...] and q_n is the total quantity of dangerous goods x, y, [...] and n present.

Q_x, Q_y, [...] and Q_n is the individual threshold quantity for each dangerous good of x, y, [...] and n

Where the ratio AQR exceeds a value of 1, the site would be considered a Major Hazard Facility (MHF). The threshold quantities for each class is taken from Schedule 15 of the Work Health and Safety (WHS) Regulation 2017 (Ref. [9]). These are summarised in **Table 3-2** noting Class 2.2, 4.1(II & III), 5.1 (III) 8, and 9 are not subject to MHF legislation.

Table 3-2: Major Hazard Facility Thresholds

Class	Packing Group	Threshold (tonnes)	Storage (tonnes)
2.1	n/a	200	139.43
3	II & III	50,000	511.43

A review of the thresholds and the commodities and packing groups listed in **Table 3-1** indicates only Class 2.1, and 3 are assessable against the MHF thresholds. Therefore, substituting the storage masses into **Equation 3-1** the AQR is calculated as follows:

$$AQR = \frac{139.14}{200} + \frac{511.43}{50000} = 0.706$$

The AQR is less than 1; hence, the facility would not be classified as an MHF.

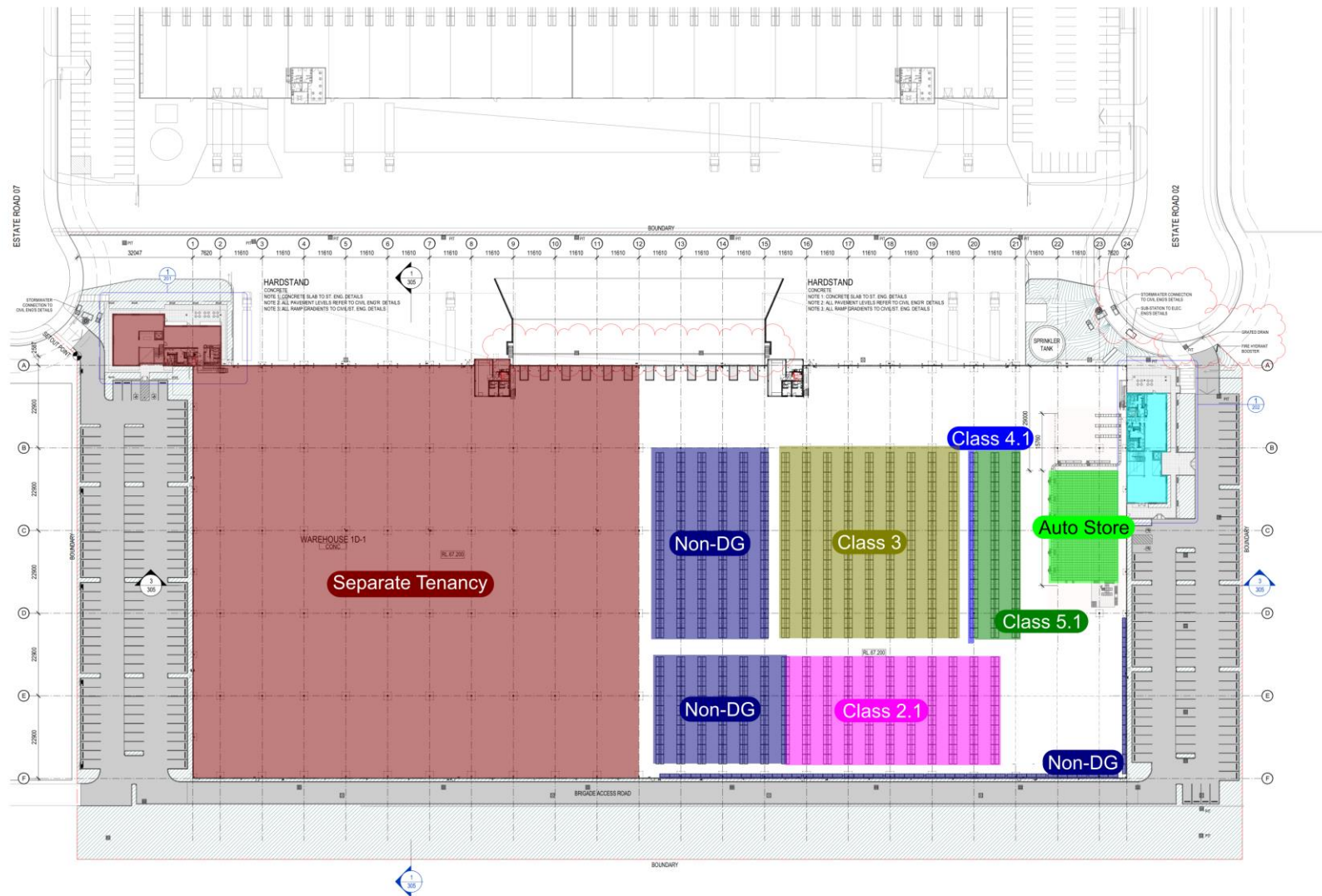


Figure 3-2: Linfox Site Layout

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. [4]). 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 than 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 more than several hundred meters 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 more than several hundred meters from the site.
- Toxicity – No toxic gases have been proposed to be stored at the site; hence, toxicity has not been assessed 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 ($23 \text{ kW/m}^2/14 \text{ kPa}$) 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 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/m² 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 facility, there is currently no significant intensification of population around the proposed site; however, the adjacent land has been rezoned residential; hence, there will be housing located approximately more than several hundred meters from the site. Therefore, societal risk has been considered in the assessment.

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 Gas	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. Where gas released under pressure from a hole in a pressurised component is ignited, a jet fire may occur.
2.2 – Non-Flammable, Non-Toxic Gases	Class 2.2 includes non-flammable and non-toxic gases which are asphyxiant (dilute or replace the oxygen normally in the atmosphere).
3 – Flammable Liquids	Class 3 includes flammable liquids which are liquids, or mixtures of liquids, or liquids containing solids in solution or suspension (for example, paints, varnishes, lacquers, etc.) which give off a flammable vapour at temperatures of not more than 60°C closed-cup test or not more than 65.6°C open-cup test. Vapours released may mix with air and if ignited, at the right, concentration will burn resulting in pool fires at the liquid surface.
4.1 – Flammable Solids	Flammable solid materials are materials that may burn when exposed to an ignition source, examples of flammable solids include matches and some waxes.
5.1 -Oxidising Agents	Class 5.1 materials will not 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.
6.1 – Toxic Substances	Substances liable either to cause death or serious injury or to harm human health if swallowed or inhaled or by skin contact.
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.

Class	Hazardous Properties
9 – Miscellaneous DGs	Class 9 substances and articles (miscellaneous dangerous substances and articles) are substances and articles which, during transport present a danger not covered by other classes. Releases to the environment may cause damage to sensitive receptors within the environment.

* The Australian Code for the Transport of Dangerous Goods by Road and Rail (Ref. [10])

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 material spill, ignition and racking fire.
- LPG release (from aerosol), ignition and racking fire.
- Full warehouse fire and radiant heat.
- Full warehouse fire and toxic smoke emission.
- Fire within the autostore.
- Dangerous goods liquid spill, release and environmental incident.
- 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 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.

A review of the product list to be stored indicates the products are small retail packages as defined by AS/NZS 3833:2007 (Ref. [5]). Therefore, the release from a single flammable liquid container would result in a release <20 L. For flammable gas canisters, the quantity of flammable gas

released would be <1 L in the worst-case release. 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 a damaged package is incorrectly stored. Once stored inside the warehouse, deterioration or damage are unlikely to occur.

To minimise the likelihood 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 be unlikely to be used for these proposed hours of operation. 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, the following recommendation has been made:

- Multiple spill kits be provided around the DG storage areas to ensure spills can be cleaned up immediately following identification.

Based on the warehouse design (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 Material 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 material spill and there are several controls in place to minimise the likelihood of a damaged container entering the warehouse and additional controls to minimise the potential that ignition of a flammable material spill could occur.

If a flammable material spill was to occur (e.g. dropped 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 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 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.

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 is expected to 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.

A sprinkler controlled 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.

Notwithstanding the above, the following recommendation has been made:

- Aerosols shall be stored in a dedicated storage area which prevents rocketing cans from escalating the incident (i.e. storage in an aerosol cage, separate storage area, or in palletised aerosol cages).

4.7 Full Warehouse Fire and Radiant Heat

There is potential that if a fire occurred and the fire protection systems failed to activate, a small fire may escalate as radiant heat impacts adjacent packages resulting in deterioration and release of additional fuel. While it is considered unlikely for a fire to occur simultaneously with the sprinkler system failing to operate there is the potential for this scenario to occur. Therefore, this incident has been carried forward for further analysis.

4.8 Full Warehouse Fire and Toxic Smoke Emission

As discussed in **Section 4.7** there is the potential for a full warehouse fire to occur in the event of sprinkler failure. During combustion toxic products of combustion may be generated which will be dispersed in the smoke plume which may impact downwind from the site. Depending on the toxicity of the bi-products, this may result in injury or fatality. Therefore, this incident has been carried forward for further analysis.

4.9 Fire Within the Autostore

The Autostore will contain a range of mixed products including DG products which are stored in totes and shuffled through the Autostore via overhead robotic units. The totes are composed of plastic PPE and are fully enclosed on all sides except for the top. The enclosed nature of the totes will prevent any spills within a tote from impacting packages in adjacent totes. The DG products are segregated within the Autostore to prevent interaction in the unlikely event that a spill does occur and is somehow released from the enclosed tote.

Notwithstanding this, there is always the potential that a release could occur and could be ignited (i.e. static). If this were to occur the fire would initially be small and would likely smoulder for some time as oxygen availability is restricted due to the tight spacing between totes both laterally and

vertically. However, as heat accumulates it will impact adjacent totes which will begin to heat up transferring heat into the plastic totes which may heat up and begin to melt, smoulder, or ignite.

As the spacing is tight within the Autostore the fire will likely take a substantial time to develop which will also prevent activation of the overhead sprinkler system. However, as the fire will likely progress slowly in a low oxygen environment black smoke will be generated which will alert operators to the presence of a fire who can alert Fire & Rescue NSW (FRNSW) to attend the site to control fire growth.

While it is anticipated the fire will progress slowly based on a smouldering fire growth it could progress quickly given the fire risks associated with these types of store are relatively unknown as these products are only entering the market. Therefore, for the purposes of modelling the risk, it must be assumed that the fire can grow throughout the Autostore as the close packed nature of the store will prevent the overhead sprinklers from extinguishing fire in the base. Therefore, this incident has been carried forward for further analysis.

4.10 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 site per the requirements of AS/NZS 3833:2007 (Ref. [5]) the following recommendation has been made:

- The site shall be designed to contain any spills or contaminated water from a fire incident within the boundaries of the site.

The site will also be designed to prevent the release of any spills from the site, including potentially contaminated water. Therefore, the potential for a release is considered unlikely as this is expected to be contained within the footprint of the warehouse. Nonetheless, in the event of a catastrophic scenario and spills are released from the footprint of the warehouse, it will be necessary to prevent this from being released into the public water course. Therefore, the following recommendation has been made:

- A storm water isolation point (i.e. penstock isolation valve) shall be incorporated into the design. The penstock shall automatically isolate the storm water system upon detection of a fire (smoke or sprinkler activation) to prevent potentially contaminated liquids from entering the water course.

As noted, the volumes of the packages are small (< 20 L) and the site will be designed with a 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.

4.11 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

m³/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 site will hold 60 minutes of water storage on site as required by FM Global standards; hence, to allow for additional conservatism, following a risk assessment methodology as outlined by the Department of Planning document “*Best Practice Guidelines for Potentially Contaminated Water Retention and Treatment Systems*” (Ref. [7]), an allowance of 90 minutes of potentially contaminated water has been selected noting this includes all sources of application (i.e. onsite storage and towns mains) thus far exceeding the 60 minute on site storage. In a DG fire scenario, the following protection systems are likely to be discharging:

- SMSS at 5 m³/min.
- 3 hydrant hoses at 1.8 m³/min.

The total water discharge would be 6.8 m³/min. Therefore, operation for 90 minutes would result in a total discharge of 612 m³. The following recommendation has been made:

- The warehouse and/or site boundaries shall be capable of containing 612 m³ which may be contained within the warehouse footprint, site stormwater pipework and any recessed docks or other containment areas that may be present as part of the site design.
- The civil engineers designing the site containment shall demonstrate the design is capable of containing at least 612 m³.

As noted in **Section 4.10**, an automatic isolation valve has been recommended to be incorporated into the design to prevent the release of potentially contaminated water. Therefore, the volume within the stormwater system can also be used in calculation total volume contained.

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. [7]), hence, this incident has not been carried forward for further analysis.

5.0 Consequence Analysis

The following incidents were identified to have potential to impact off site:

5.1 Incidents Carried Forward for Consequence Analysis

The following incidents were identified to have potential to impact off site:

- Flammable material spill, ignition and racking fire.
- LPG release (from aerosol), ignition and racking fire.
- Full warehouse fire and radiant heat.
- Full warehouse fire and toxic smoke emission.
- Fire within the autostore.

Each incident has been assessed in the following sections.

5.2 Flammable Material Spill, Ignition and Racking Fire

There is the potential for a fire to develop involving flammable material stored within the warehouse 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)	
	Base Case	Sensitivity
35	4.6	8.5
23	5.6	10.3
12.6	7.5	13.7
4.7	12.0	22.2

The closest site boundary to the warehouse is to the west and is located 21.7 m from the warehouse structure. A review of the Class 3 or 4.1 DG storage locations indicates the distance to the site boundary would be in excess of 30 m in all directions. Therefore, a fire originating in this area of the warehouse would not result in offsite impacts at 4.7 kW/m² in both the base case and

the sensitivity case scenarios as illustrated in

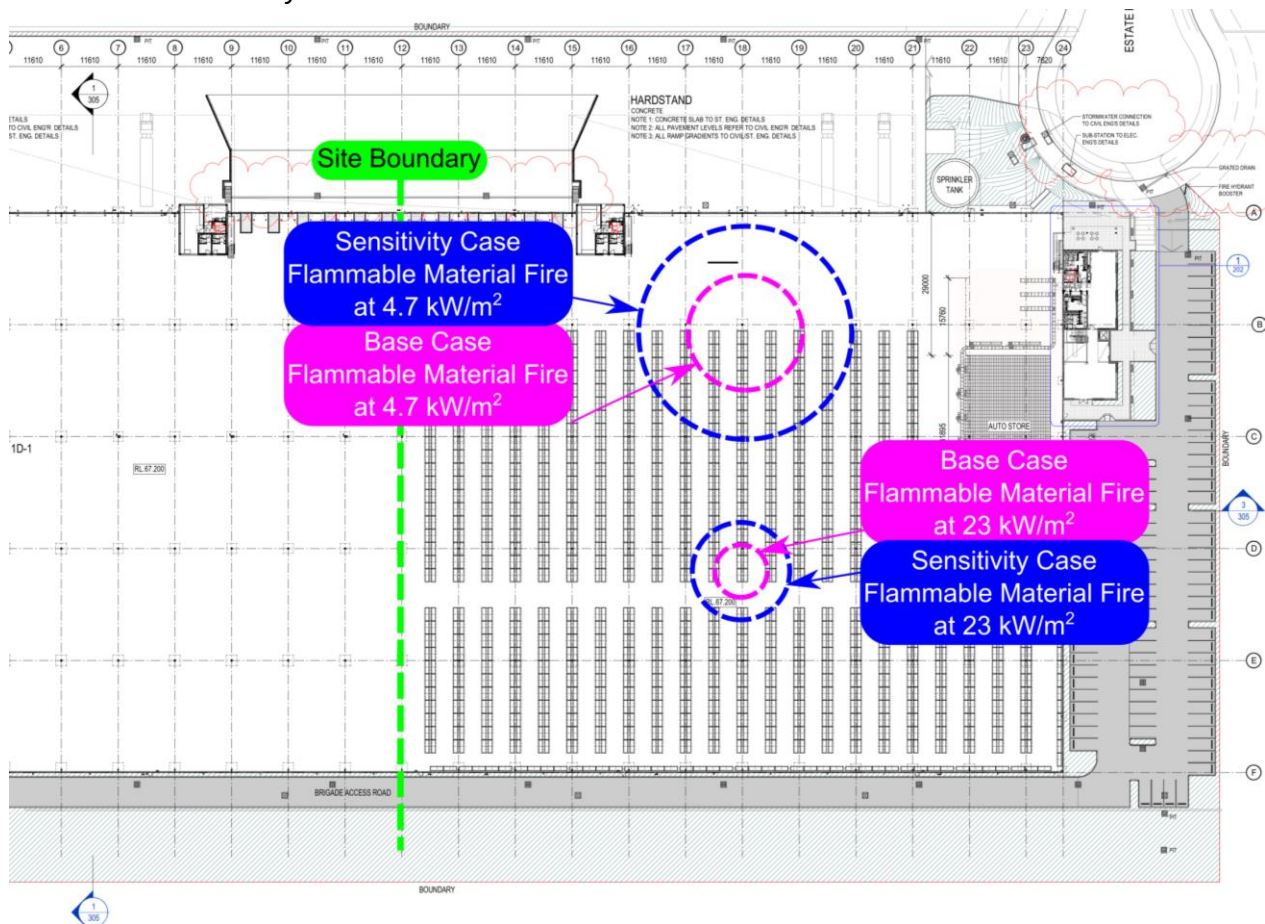


Figure 5-1.

A review of the 23 kW/m² impact distance indicates an offsite impact would not occur as neither contour for base case nor sensitivity case impact over the site boundary. Therefore, it is not considered that a propagation risk is present based on the radiant heat levels observed for this fire scenario.

As no offsite impacts for the scenario at 4.7 kW/m² nor 23 kW/m² were identified, this incident has not been carried forward for further analysis.

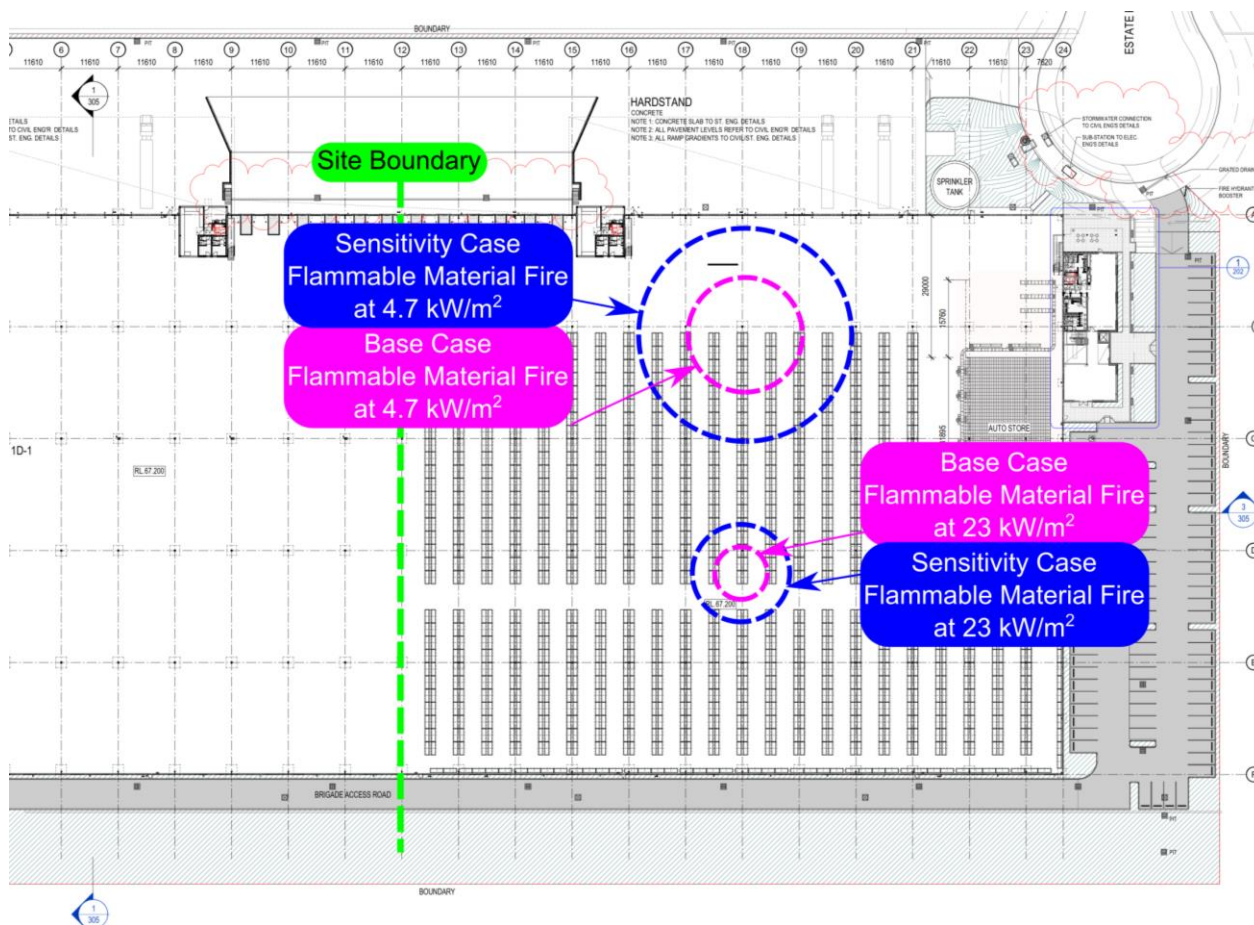


Figure 5-1: Sprinkler Controlled Flammable Material Fire Radiant Heat Contours

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 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)	
	Base Case	Sensitivity
35	5.4	10.1
23	6.5	12.1
12.6	8.6	15.9
4.7	13.7	25.5

The closest site boundary to the warehouse is to the west and is located 21.7 m from the warehouse structure. A review of the Class 2.1 DG storage location indicates the distance to the site boundary

would be approximately 21.7 m (located on the eastern side of the warehouse). Therefore, a fire originating in this area of the warehouse would not result in offsite impacts at 4.7 kW/m^2 in both the base case and the sensitivity case scenarios as illustrated in **Figure 5-2**.

A review of the 23 kW/m^2 impact distance indicates an offsite impact would not occur as neither contour for base case nor sensitivity case impact over the site boundary. Therefore, it is not considered that a propagation risk is present based on the radiant heat levels observed for this fire scenario.

As no offsite impacts for the scenario at 4.7 kW/m^2 nor 23 kW/m^2 were identified, this incident has not been carried forward for further analysis.

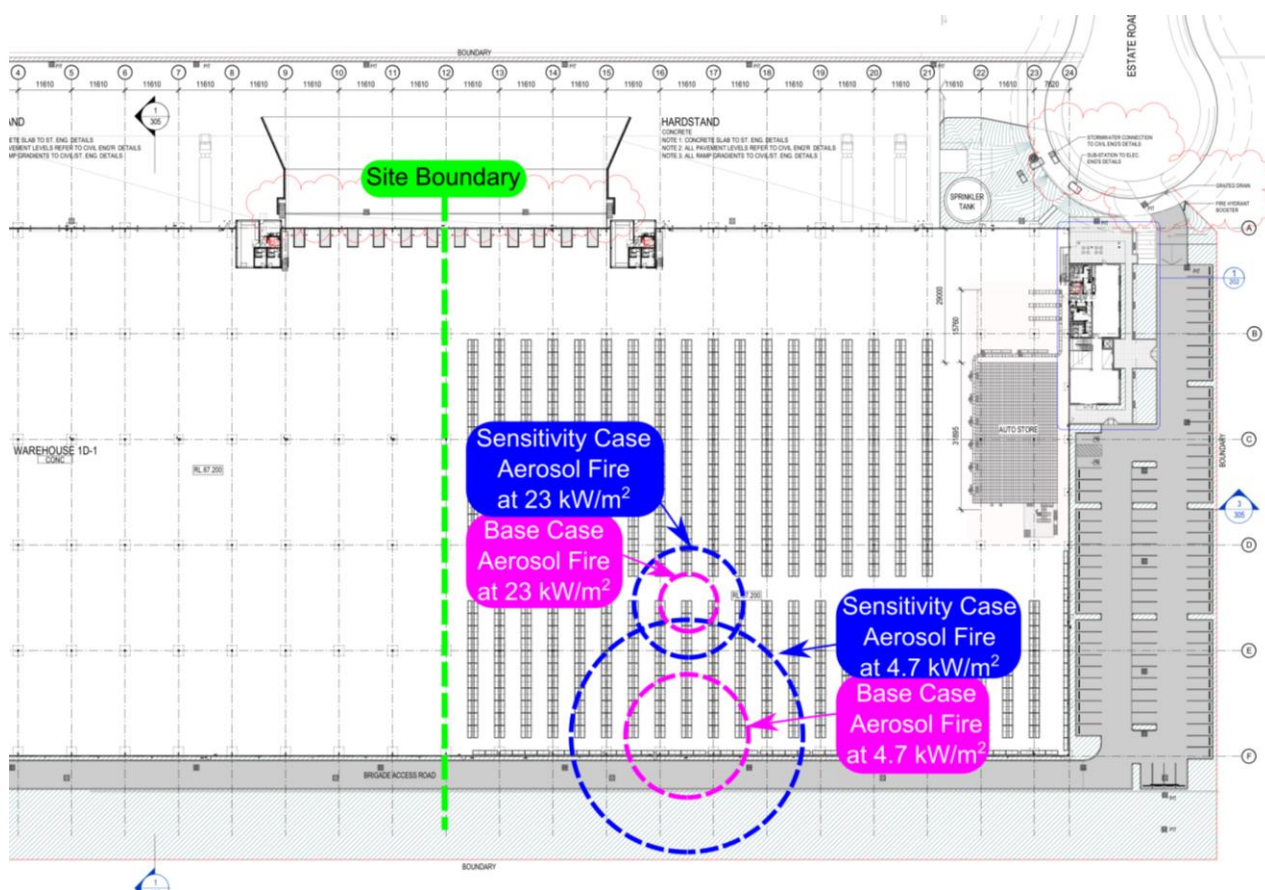


Figure 5-2: Sprinkler Controlled Aerosol Fire Radiant Heat Contours

5.4 Full Warehouse Fire and Radiant Heat

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 5-3**.

Table 5-3: 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	32.0
4.7	72.0

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

As shown in **Figure 5-3**, the radiant heat impacts at 4.7 kW/m² 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/m². 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.

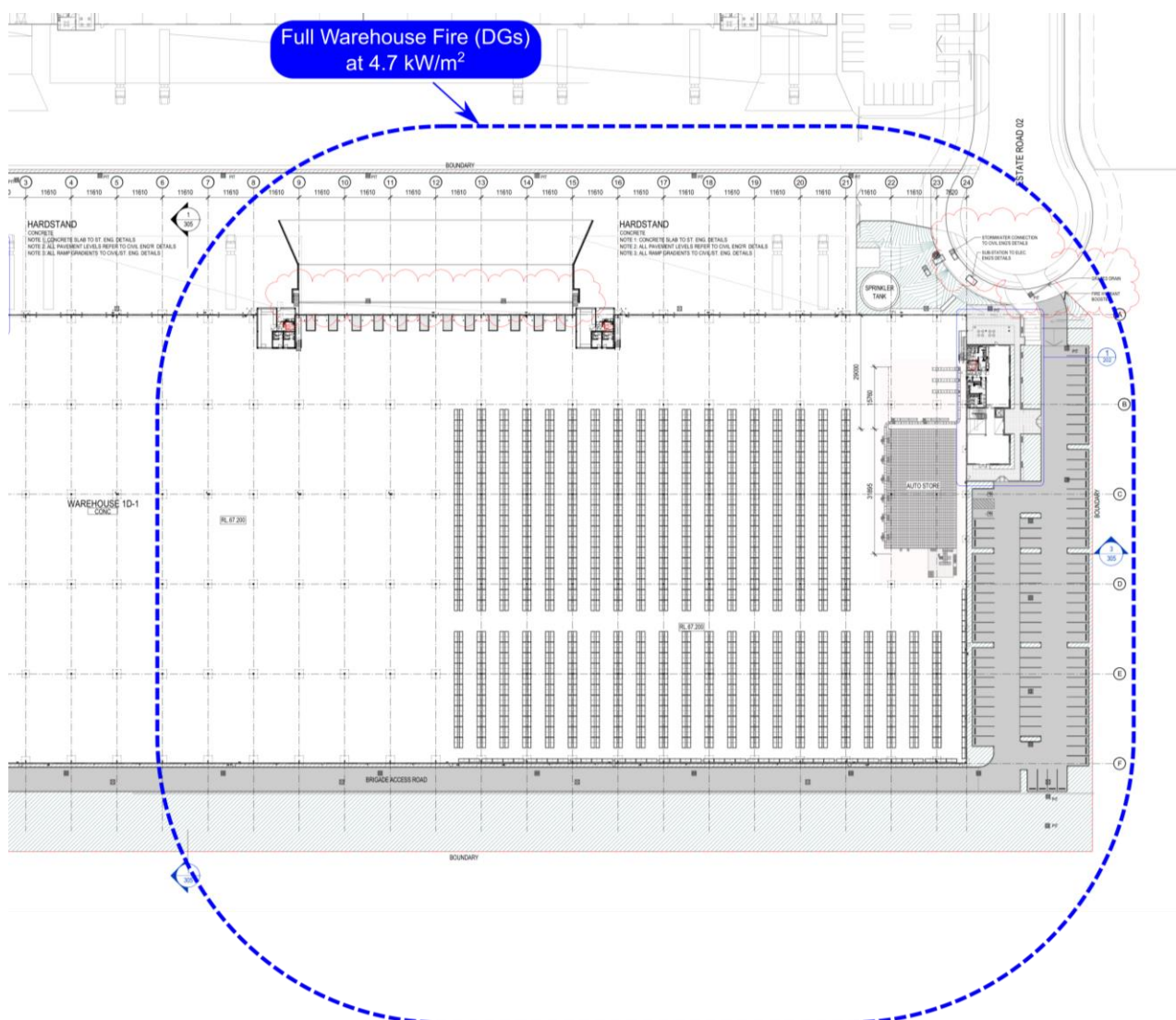


Figure 5-3: Full Warehouse Fire Radiant Heat Contours

5.5 Full Warehouse Fire and Toxic Smoke Emission

A detailed analysis has been performed in **Section B6** of **Appendix B** to estimate the impact of toxic products of combustion on the surrounding area. In addition, it was concluded that due to the relatively low quantity of toxic products that may be stored in the warehouse, and a substantial portion of toxic products involved in a fire will actually be combusted, the results generated from the assessment of toxic bi-products would provide a conservative analysis when applied to uncombusted toxic products.

Provided in **Table 5-4** is a summary of several toxic products of combustion which may be present in the smoke plume and their acceptable concentration of exposure for the Acute Exposure Guideline Levels (AEGL). These levels provide guidance on exposure concentrations for general populations, including susceptible populations over a range of exposure times to assist in the assessment of releases which may result in a toxic exposure.

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

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

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

Table 5-4: Concentrations of Toxic Products of Combustion from a Smoke Plume

Pollutant	Fatality or Serious Injury (ppm)	Injury (ppm)	Concentration (ppm)
Carbon monoxide	600	150	13.1
Nitric Dioxide	25	15	12.2
Hydrogen cyanide	21	10	13.6
Hydrogen chloride	210	43	10.1
Sulphur dioxide	30	0.75	5.7

The analysis indicates all quantities are below the AEGL-3 values. It is noted the analysis conducted is based on the primary toxic bi-product (carbon monoxide) which forms at rates higher than other toxic bi-products. Therefore, application of this result to other components is considered conservative. As these concentrations are taken at the point of release, they will disperse downwind resulting in substantially lower concentrations at the residential areas.

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

Based on the analysis conducted, it is considered that the concentrations at the residential area are likely to be lower than the fatality and injury concentration levels based on the comparison to the fatality and injury targets at the point of release. Therefore, it is considered that fatality and injury are unlikely to occur as a result of this incident. Notwithstanding this, this incident has been carried forward for conservatism.

5.6 Fire Within the Autostore

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 5-3**.

Table 5-5: Radiant Heat Impact Distances from an Autostore Fire

Heat Radiation (kW/m ²)	Distance (m)
35	Maximum heat flux is 25.6*
23	6.9
12.6	12.2
4.7	25.7

A review of site boundaries with reference to the Autostore DG storage location indicates the closest boundary is 34.5 m away (located on the northern side of the warehouse). Therefore, a fire originating in the Autostore would not result in offsite impacts at 4.7 kW/m² as illustrated in **Figure 5-4**.

A review of the 23 kW/m² impact distance indicates an offsite impact would not occur this contour has a smaller impact distance than the 4.7 kW/m² contour which was shown to not impact offsite. Therefore, it is not considered that a propagation risk is present based on the radiant heat levels observed for this fire scenario.

As no offsite impacts for the scenario at 4.7 kW/m² nor 23 kW/m² were identified, this incident has not been carried forward for further analysis.

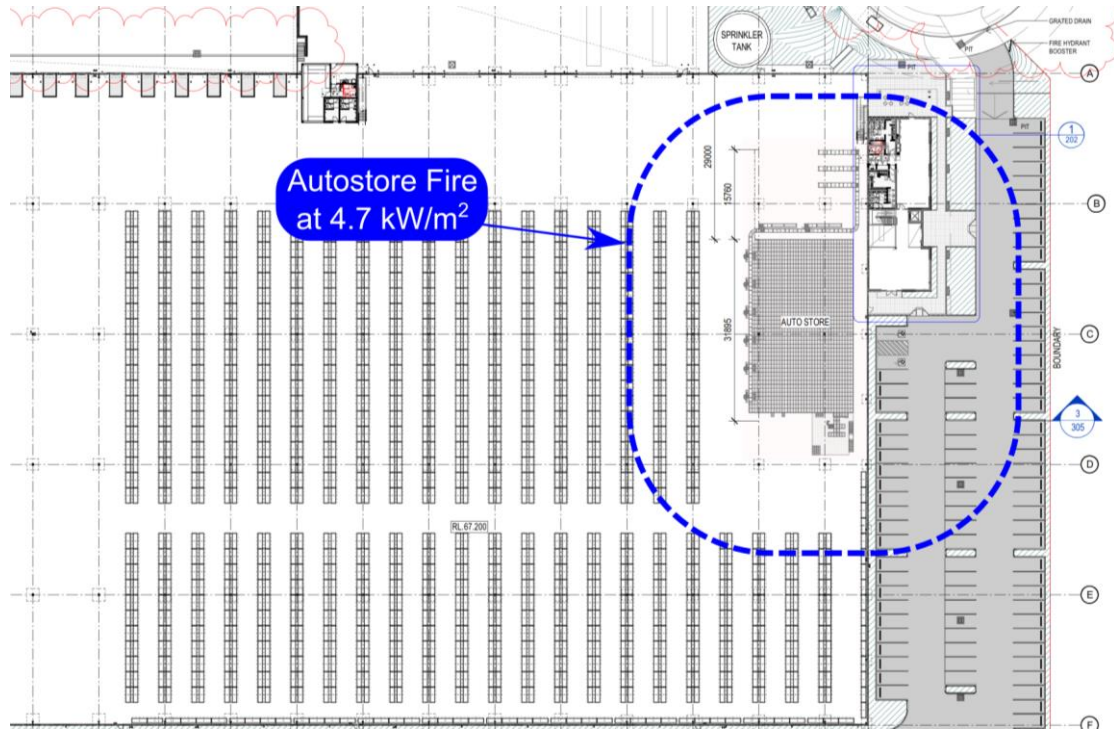


Figure 5-4: Autostore Fire Radiant Heat Contours

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.
- Full warehouse fire and toxic smoke emission.

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 1×10^{-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:

$$\text{Failures per Annum} = \text{Failures per hour} \times 8760 \text{ hours per year}$$

$$\text{Failures per Annum} = 9.66 \times 10^{-6} \times 8760 = 0.085$$

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**.

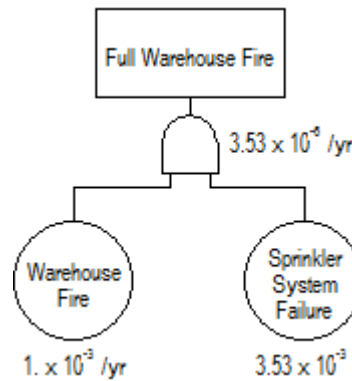


Figure 6-1: Full Warehouse Fire Fault Tree

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 $3.53 \times 10^{-6} \times 1 = 3.53 \times 10^{-6}$ chances of fatality per year or 3.53 chances of a fatality in a million per year (pmpp).

6.3 Full Warehouse Fire and Toxic Smoke Emission Frequency and Risk Assessment

The toxic smoke emission (or toxic bi-products of combustion) is based on the initiating event which is the formation of a full warehouse fire. Therefore, the frequency of the toxic smoke emission is the same as that of the full warehouse which was identified to be 3.53×10^{-6} p.a.

For conservatism, it has been assumed exposure to the smoke will result in an fatality at the site boundary; therefore, the fatality risk of exposure to the toxic smoke becomes $3.53 \times 10^{-6} \times 1 = 3.53$ chances pmpp.

6.4 Total Fatality Risk

The total fatality risk in the most conservative location becomes the sum of all incidents which may result in a fatality at the site boundary. Therefore, the total fatality risk becomes $3.53 + 3.53 = 7.06$ chances pmpp.

6.5 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 pmpp. The assessed highest fatality risk is 7.06 pmpp 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.

6.6 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 7.06 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/m². 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 7.06 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:

- The site shall be designed to contain any spills or contaminated water from a fire incident within the boundaries of the site.
- Multiple spill kits be provided around the DG storage areas to ensure spills can be cleaned up immediately following identification.

- The warehouse and/or site boundaries shall be capable of containing 612 m³ which may be contained within the warehouse footprint, site stormwater pipework and any recessed docks or other containment areas that may be present as part of the site design.
- The civil engineers designing the site containment shall demonstrate the design is capable of containing at least 612 m³.
- A storm water isolation point (i.e. penstock isolation valve) shall be incorporated into the design. The penstock shall automatically isolate the storm water system upon detection of a fire (smoke or sprinkler activation) to prevent potentially contaminated liquids from entering the water course.

1.

8.0 References

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Appendix A

Hazard Identification Table

A1. Hazard Identification Table

Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
Warehouse / Autostore	- Dropped pallet - Damaged packaging (receipt or during storage) - Deterioration of packaging	Release of Class 2.1, 3, 4.1, 5.1, and other 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. [5])
	- 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. [5])
	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. [6]) - 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 banded to contain in excess of the maximum required fire water, per AS/NZS 3833:2007 (Ref. [5])

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. [7])
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.

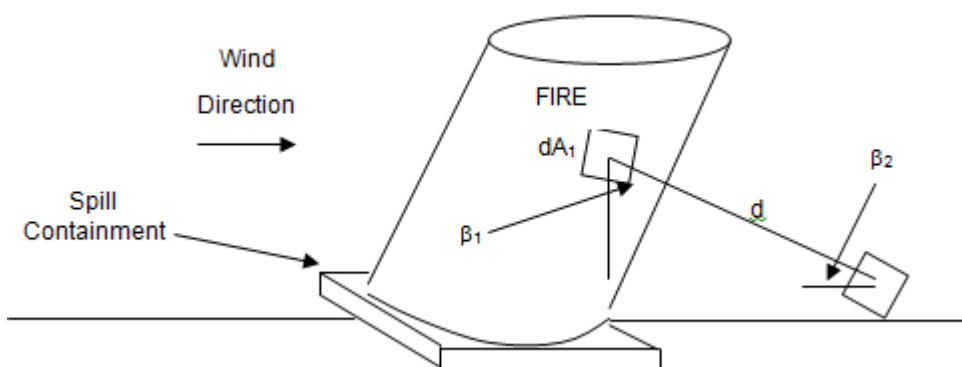
- Flammable material spill, ignition and racking fire.
- LPG release (from aerosol), ignition and racking fire.
- Full warehouse fire and radiant heat.
- Full warehouse fire and toxic smoke emission.
- Fire within the autostore.

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]).

$$Q = EF\tau$$

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:

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

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 SCC 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 SCC 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° in intervals of 2.5 degrees. Zero degrees represents the straight line joining the centre of the cylinder to the target (x_0, x_1, x_2) while 90° 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 (x_4). This angle varies from 90° at the closest distance between the liquid flame (circle) and the target (x_0) and gets progressively smaller as θ increases. As θ increases, the line x_4 subtends an angle phi Φ with x_0 . By similar triangles we see that the angle gamma γ is equal to $90 - \theta - \Phi$. 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° , $\sin(\gamma)$ is 1.0, meaning that the projected area is 100% of the actual area.

Before the value of θ reaches 90° the line x_4 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 SCC 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**):

$$VF = \Delta A \frac{\sin \gamma}{\pi \times X_4 \times X_4} \quad \text{Equation B-3}$$

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

Note: the denominator ($\pi \cdot x_4 \cdot x_4$) 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 x_4 increase as θ increase, and the value of $\sin(\gamma)$ 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 SCC adds up the separate contributions of **Equation B-3** for values of θ between zero until x_4 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 x_4 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 X_4'). The angle of elevation to the element of the fire (alpha α) is the arctangent of the height over the ground distance. From the $\cos(\alpha)$ 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**):

$$VF = \Delta A \frac{\sin \gamma \times \cos \alpha}{\pi \times X_4 \times X_4'} \quad \text{Equation B-4}$$

The SCC now turns three dimensional. The vertical axis represents the variation in θ from 0 to 90° 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. [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**.

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

Where;

$$E_{max} = 140$$

$$S = 0.12$$

$$E_s = 20$$

$$D = \text{pool diameter}$$

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/m³ at 20°C)

$\dot{m}$ = burning rate (kg/m².s)

g = 9.81 m/s²

The transmissivity is estimated using **Equation B-7** (Ref. [12]).

$$\tau = 1.006 - 0.01171(\log_{10} X(H_2O) - 0.02368(\log_{10} X(H_2O))^2 - 0.03188(\log_{10} X(CO_2) + 0.001164(\log_{10} X(CO_2))^2)$$

Equation B-7

Where:

- τ = Transmissivity (%)

- $X(H_2O) = \frac{R_H \times L \times S_{mm} \times 2.88651 \times 10^2}{T}$

- $X(CO_2) = \frac{L \times 273}{T}$

and

- R_H = Relative humidity (%) expressed as a decimal)

- L = Distance to target (m)

- S_{mm} = saturated water vapour pressure in mm of mercury at temperature (at 25°C $S_{mm} = 23.756$)

- T = Atmospheric temperature (K)

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

Heat Radiation (kW/m ²)	Impact
	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 Material 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. Two sprinkler activation scenarios have been assessed:

- A worst credible (WC) scenario whereby the first row of the SMSS activates and controls the spread of a fire.
- A sensitivity scenario whereby the first row of sprinklers fails to activate and the fire is instead controlled by the second row of the SMSS.

The first row of sprinklers has an approximate diameter of 3 m with the second row having an approximate diameter of 9 m. These diameters are used to estimate the flame height and SEP for the fire scenarios. To estimate the flame height and SEP the following information was substituted into the models:

- Equivalent fire diameter: WC – 3 m, Sensitivity - 9 m
- Burning rate – 0.0667 kg/m².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 selection of a flammable liquid burning rate is considered appropriate and conservative as a the fire will be composed of burning flammable liquids and packaging. The packaging is a solid material that will yield a lower burning rate than selected as it requires an additional phase change prior to combustion reducing the rate at which the product burns.

Furthermore, the analysis is considered incredibly conservative as it assumes a 100% burning area; however, as the subject areas will encompass aisle spaces, which will have no combustible material stored these locations. Therefore, it is considered the results generated from this analysis would substantially overestimate the radiant heat impacts from the identified scenarios.

The results for flame height and SEP for each scenario are summarised in **Appendix Table B-2**.

Appendix Table B-2: Flame Height and SEP for a Flammable Material Sprinkler Controlled Fire

Output	Base Case	Sensitivity
Flame Height (m)	7.7	16.5
SEP (kW/m ²)	103.7	60.8

The inputs summarised in **Appendix Table B-2** were input in to the SSC with the results for each scenario shown in **Appendix Table B-3**.

Appendix Table B-3: Heat Radiation from a Flammable Material Sprinkler Controlled Fire

Heat Radiation (kW/m ²)	Distance (m)	
	Base Case	Sensitivity
35	4.6	8.5
23	5.6	10.3
12.6	7.5	13.7
4.7	12.0	22.2

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 heat and smoke is generated from the fire, the in-rack sprinklers and the SMSS will activate. Two sprinkler activation scenarios have been assessed:

- A worst credible (WC) scenario whereby the first row of the SMSS activates and controls the spread of a fire.
- A sensitivity scenario whereby the first row of sprinklers fails to activate and the fire is instead controlled by the second row of the SMSS.

The first row of sprinkler has an approximate diameter of 3 m with the second row having an approximate diameter of 9 m. These diameters are used to estimate the flame height and SEP for the fire scenarios. To estimate the flame height and SEP the following information was substituted into the models:

- Equivalent fire diameter: WC – 3 m, Sensitivity - 9 m
- Burning rate – 0.099 kg/m².s (the burning rate for LPG, Ref. [11]).

The selection of a LPG burning rate is considered appropriate and conservative as a fire involving aerosols will be composed predominantly of packaging (i.e. plastic wrapping and cardboard) which will be punctuated by rupturing of cans and combustion of the released LPG. The packaging is a solid material that will yield a lower burning rate than selected as it requires an additional phase change prior to combustion reducing the rate at which the product burns.

Furthermore, the analysis is considered incredibly conservative as it assumes a 100% burning area; however, as the subject areas will encompass aisle spaces, there will be no combustible material stored in these locations. Therefore, it is considered the results generated from this analysis would substantially overestimate the radiant heat impacts from the identified scenarios.

The results for flame height and SEP for each scenario are summarised in **Appendix Table B-4**.

Appendix Table B-4: Flame Height and SEP for Class 2.1 Sprinkler Controlled Scenarios

Output	Base Case	Sensitivity
Flame Height (m)	7.7	21.0
SEP (kW/m ²)	103.7	60.8

The inputs summarised in **Appendix Table B-4** were input in to the SSC with the results for each scenario shown in **Appendix Table B-5**.

Appendix Table B-5: Heat Radiation from Class 2.1 Sprinkler Controlled Scenarios

Heat Radiation (kW/m ²)	Distance (m)	
	Base Case	Sensitivity
35	5.4	10.1
23	6.5	12.1
12.6	8.6	15.9
4.7	13.7	25.5

B5. Full Warehouse Fire

The main storage area has an approximate floor area of 9,500 m² which is the area that is assumed to participate in the fire. The equivalent diameter for the fire can be calculated by:

$$D = \sqrt{\frac{4 \times 9500}{\pi}} = 110 \text{ m}$$

Provided in **Appendix Table B-6** is a summary of the classes of materials stored within the facility, the applicable burning rates based on commodities stored and the contribution of each product to the total burning rate

Appendix Table B-6: Estimation of Average Burning Rate

Class	Quantity (L)*	% of Total Quantity	Burning Rate (kg/m ² .s)	Burning Rate Based on %
2.1	556,554	49.8	0.099	0.0493
3	494,678	44.3	0.0667	0.0295
4.1	7,051	0.60	0.022	0.0001
5.1	58,724	5.30	0.022	0.0012
Total	1,117,007	100	-	0.0802

*Assumed density of 1,000 kg/m³

The following information was input into the models;

- Equivalent fire diameter – 110 m
- Burning rate – 0.0802 kg/m².s
- Fire wall height: no fire wall

The models provided the following information for the warehouse fire;

- SEP – 20 kW/m²
- Flame Height – 105 m (from model without roof restriction)

Provided in **Appendix Table B-7** are the results generated by the SSC.

Appendix Table B-7: 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	32.0
4.7	72.0

* 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/m² for larger fires and 130 kW/m² 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/m² has been used.

B6. Full Warehouse Fire and Smoke Emission

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

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

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

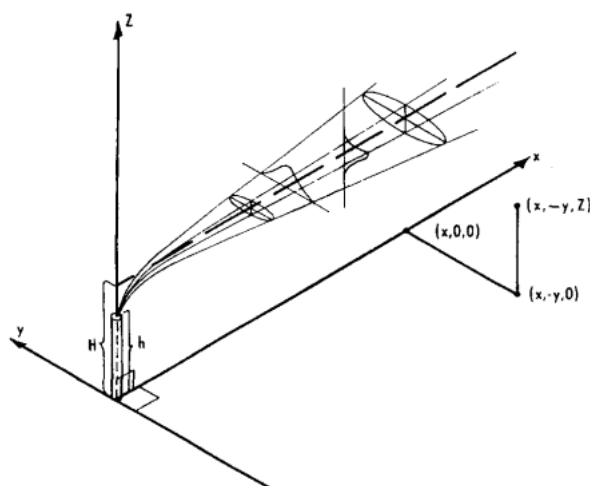
The atmospheric conditions are classified as Pasquill Guifford's Stability categories which are summarised in **Appendix Table B-8** (Ref. [12]).

Appendix Table B-8: Pasquill's Stability Categories

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

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

A smoke plume is buoyant, and will disperse laterally and vertically as it rises essentially following a Gaussian dispersion as shown in **Appendix Figure B-2** (Ref. [12]).



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

Ian Cameron, professor of Risk Engineering at the University of Queensland, has developed a risk assessment tool known as Risk Assessor produced by DAESIM Technologies. The tool has numerous risk engineering applications; however, the component of interest for this assessment is the smoke plume modelling from fire scenarios. The model has been developed based on a Gaussian dispersion model accounting for modifications to the plume drag coefficients required to model a plume dispersion from a warehouse fire (Ref. [12]).

The model requires several inputs which have been summarised in **Appendix Table B-9** with the associated value input as part of this modelling exercise. As noted, the more onerous conditions

occur during stable air conditions which allow far reaching effects with reduced dispersion due to low air velocities and vertical mixing. The industry standard for modelling this scenario is selection of F1.5 (F stability at 1.5 m/s wind velocity) which has been adopted for this assessment.

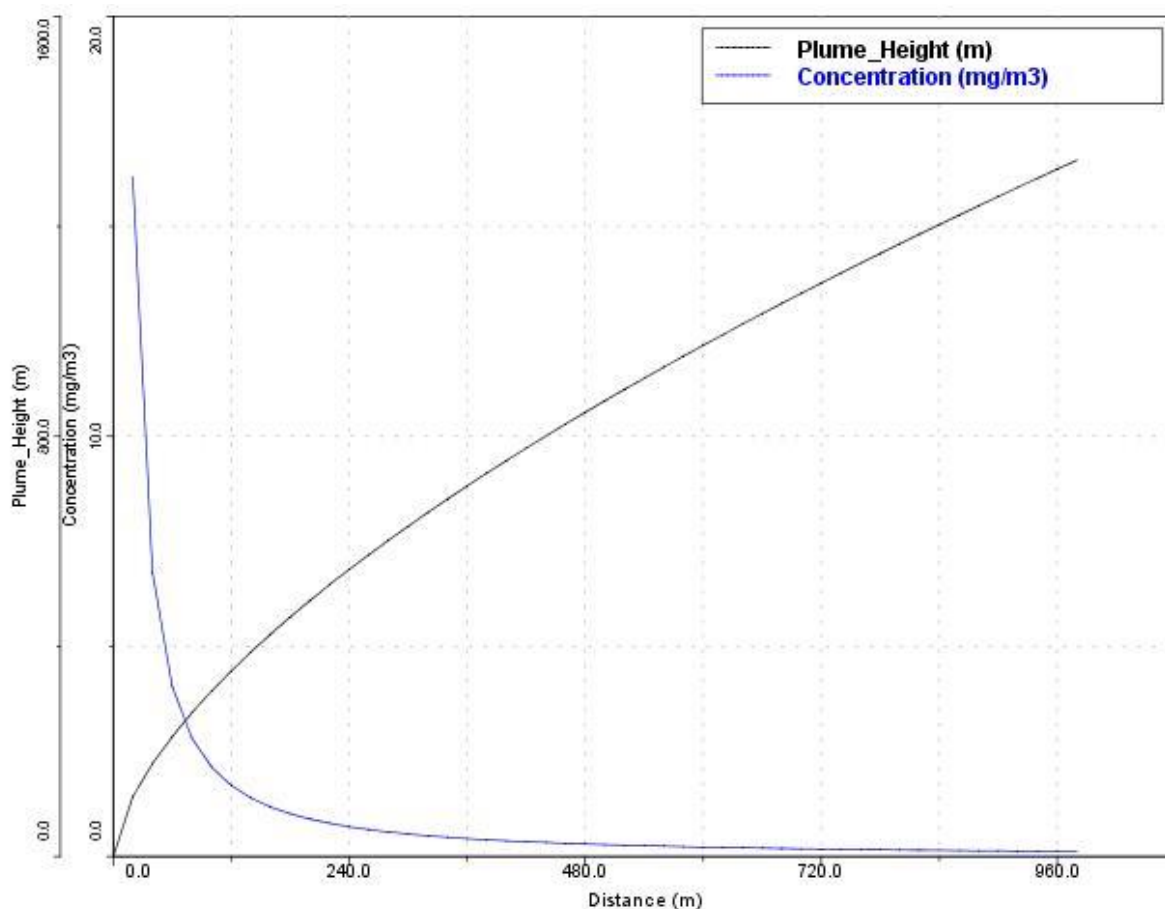
Appendix Table B-9: Input Data for Plume Gaussian Dispersion

Input	Selected Values	Justification
Max burning rate (kg/m ² .s)	0.0802	Taken from full warehouse fire above
Fire equivalent Diameter (m)	110	Equivalent diameter of the warehouse
Heat of combustion (kJ/kg)	45,000	Heat of combustion for combustible liquid (diesel) Ref. [14]
Fraction energy radiated	0.5	Conservative assumption based on high radiant heat blocking which occurs from dense smoke
Pollutant Rate (kg/s)	32,000	Burning rate multiplied by area multiplied by 7 (number of racks) multiplied by 6 (number of surfaces on a pallet that can burn)
Wind speed (m/s)	1.5	Industry standard
Stability	F	Industry standard

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

The worst-case concentration occurs in the initial phases of the fire and rapidly decrease with distance from the fire. It has been assumed that an inversion occurs at low level and the plume has insufficient heat to 'punch through' the inversion and remains trapped relatively close to the ground. A maximum value of 15 mg/m³ has been selected per **Appendix Figure B-3** that may impact the surrounding area with regards to potential toxic bi-products of combustion.

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



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

Provided in **Appendix Table B-10** is a summary of several toxic products of combustion which may be present in the smoke plume and their acceptable concentration of exposure for the Acute Exposure Guideline Levels (AEGL). These levels provide guidance on exposure concentrations for general populations, including susceptible populations over a range of exposure times to assist in the assessment of releases which may result in a toxic exposure.

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

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

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

Appendix Table B-10: Concentration of Toxic Products of Combustion in Smoke Plume

Pollutant	Fatality or Serious Injury (ppm)	Injury (ppm)	Concentration (ppm)
Carbon monoxide	600	150	13.1
Nitric Dioxide	25	15	12.2
Hydrogen cyanide	21	10	13.6
Hydrogen chloride	210	43	10.1
Sulphur dioxide	30	0.75	5.7

B7. Fire Within the Autostore

The Autostore has approximate dimensions of 17 m x 30 m which is assumed to participate in a fire should one occur within the Autostore. The equivalent diameter for the fire can be calculated by:

$$D = \sqrt{\frac{4 \times 17 \times 30}{\pi}} = 25.5 \text{ m}$$

Provided in **Appendix Table B-9** is a summary of the classes of materials stored within the facility, the applicable burning rates based on commodities stored and the contribution of each product to the total burning rate

Appendix Table B-11: Estimation of Average Burning Rate

Class	Quantity (L)*	% of Total Quantity	Burning Rate (kg/m ² .s)	Burning Rate Based on %
2.1	1,160	6.300	0.099	0.0062
3	16,750	90.50	0.0667	0.0604
4.1	70	0.004	0.0667	0.0003
5.1	450	0.024	0.022	0.0005
8	5	0.000	0.022	0.0000
9	72	0.004	0.022	0.0001
Total	18,507	100	-	0.0675

*Assumed density of 1,000 kg/m³

The following information was input into the models;

- Equivalent fire diameter – 25.5 m
- Burning rate – 0.0675 kg/m².s
- Fire wall height: no fire wall

The models provided the following information for the warehouse fire;

- SEP – 25.6 kW/m²

- Flame Height – 34.3 m (from model without roof restriction)

Provided in **Appendix Table B-7** are the results generated by the SSC.

Appendix Table B-12: Heat Radiation Impacts from an Autostore Fire

Heat Radiation (kW/m ²)	Distance (m)
35	Maximum heat flux is 25.6*
23	6.9
12.6	12.2
4.7	25.7

- * 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/m² for larger fires and 130 kW/m² 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/m² 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 2.5×10^{-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.

