Riskcon engineering

Final Hazard Analysis

Moorebank Intermodal Precinct (JN)

Woolworths Limited
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Date 14/07/2025

Final Hazard Analysis

Moorebank Intermodal Precinct (JN)

Woolworths Limited

Prepared by

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Quality Management

Rev	Date	Remarks	Prepared By	Reviewed By
A	3 February 2025	Draft issue for comment	Ezra Bagaskara	Jason Costa
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1	14 July 2025	Updated per DPHI comments		

Executive Summary

Background

Woolworths Limited (Woolworths), has developed a distribution centre within the Moorebank Intermodal Precinct, NSW. The project will comprise two warehouses (JN & JR) which will be connected by two link bridges. Each warehouse will store and handling materials classified as Dangerous Goods (DGs) which were identified to exceed the thresholds detailed within the State Environmental Planning Policy No. 33 (SEPP 33, Ref. [1]); hence, a Preliminary Hazard Analysis (PHA) was prepared as part of the Development Application (DA).

Following approval of the DA, Conditions of Consent (CoC) were issued requiring the preparation of several studies prior to issuance of a Construction Certificate for the facilities. Specifically, Condition B176B states:

"*Unless otherwise agreed with the Planning Secretary, at least one month prior to the commencement of the storage of dangerous goods at the Warehouse JR and JN Distribution Precinct, the studies set out below must be submitted to the Planning Secretary:*

b) A Final Hazards Analysis for the Warehouse JR and JN Distribution Precinct, consistent with the Department's Hazardous Industry Planning Advisory Paper No. 6, 'Hazard Analysis', and addressing the storage of dangerous goods quantities listed in Table 3-8 of the Preliminary Hazard Analysis prepared by Riskcon Rev 1 (Document No. RCE-21050) dated 13 March 2023.

Storage of dangerous goods at the Warehouse JR and JN Distribution Precinct must not commence until study recommendations have been considered and, where appropriate, acted upon."

Woolworths has commissioned Riskcon Engineering Pty Ltd (Riskcon) to prepare an FHA for the facility. This document represents the FHA study of the Woolworths JN Warehouse.

Conclusions

A hazard identification table was developed for the 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 worst-case incident in terms of fatality risk would be an JN full warehouse fire with a fatality risk of 3.53 chances per million per year (pmpy) at the site boundary, with lesser risk at further distances from the boundary. HIPAP No. 4 (Ref. [2]) publishes acceptable risk criteria at the site boundary of 50 pmpy (for industrial sites). Therefore, the probability of a fatality from a full warehouse fire at the site boundary is within the acceptable risk criteria.

In addition, no incidents were identified to result in offsite impact which could propagate incidents into adjacent sites (i.e. the 23 kW/m^2 contours did not impact offsite). Therefore, the risk of incident propagation would be below the acceptable criteria.

The two assessed warehouses, JN & JR, were the only contributors to the risk profile of the site; hence, cumulative risk was not a considered at this stage. Notwithstanding this, the cumulative risk of all incidents would be 10.6 pmpy assuming they could overlap which would still be below the acceptable criteria of 50 pmpy. Therefore, the development of the JN & JR warehouses do not increase the cumulative risk of the site to an unacceptable level.

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

Recommendations

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

- Multiple spill kits be provided around the DG storage areas to ensure spills can be cleaned up immediately following identification.
- The LPG tanks shall be protected from impacts by bollards, railings or similar physical barriers.

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Abbreviations

Abbreviation	Description
ADG	Australian Dangerous Goods Code
AEGL	Acute Exposure Guideline Levels
AS	Australian Standard
CBD	Central Business District
CCPS	Centre for Chemical Process Safety
CIP	Commercial & Industrial Property
DA	Development Application
DGs	Dangerous Goods
DGS	Dangerous Goods Store
DPE	Department of Planning and Environment
FHA	Final Hazard Analysis
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

Abbreviation	Description
SSC	Spread Sheet Calculator
VF	View Factor

1.0 Introduction

1.1 Background

Woolworths Limited (Woolworths), has developed a distribution centre within the Moorebank Intermodal Precinct, NSW. The project will comprise two warehouses (JN & JR) which will be connected by two link bridges. Each warehouse will store and handling materials classified as Dangerous Goods (DGs) which were identified to exceed the thresholds detailed within the State Environmental Planning Policy No. 33 (SEPP 33, Ref. [1]); hence, a Preliminary Hazard Analysis (PHA) was prepared as part of the Development Application (DA).

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Storage of dangerous goods at the Warehouse JR and JN Distribution Precinct must not commence until study recommendations have been considered and, where appropriate, acted upon."

Woolworths has commissioned Riskcon Engineering Pty Ltd (Riskcon) to prepare an FHA for the facility. This document represents the FHA study of the Woolworths JN Warehouse.

1.2 Objectives

The objectives of the FHA are to:

- Review the findings of the revised Preliminary Hazard Analysis (PHA) prepared for the site to determine if any changes have been made since the preparation of the report.
- Review the findings of the submitted Fire Safety Study (FSS, RCE-23263_WoolworthsJN_FSS_30Jun25_Rev(4)) to determine if any changes have been made since the preparation of the report.
- Prepare a report in accordance with HIPAP No. 6 (Ref. [3]) using criteria from HIPAP No. 4 (Ref. [2]) assessing and changes which may have occurred to determine whether the risk profile of the site has been altered compared to the findings in the PHA.
- Prepare a report detailing the assessment of the Woolworths JN Warehouse.

1.3 Scope of Work

The scope of work is for the preparation of a revised FHA for the Woolworths facility to reassess the risk profile of the site in accordance with HIPAP No. 4 (Ref. [2]) and No. 6 (Ref. [3]) to determine whether it has been altered by any changes which may have occurred with the facility design since submission of the Development Application (DA).

2.0 Methodology

2.1 Multi-Level Risk Assessment

The Multi-Level Risk Assessment approach (Ref. [4]) 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**.

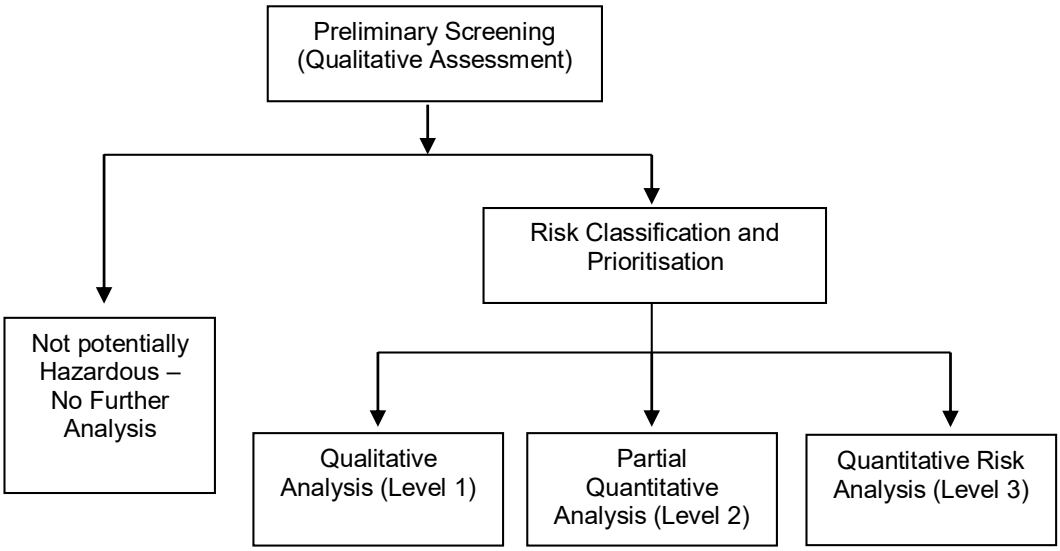


Figure 2-1: The Multi-Level Risk Assessment Approach

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. [3]).

Each postulated hazardous incident was assessed qualitatively in light of proposed safeguards (technical and management controls). Where a potential offsite impact was identified, the incident was carried into the main report for further analysis. Where the qualitative review in the main report determined that the safeguards were adequate to control the hazard, or that the consequence would obviously have no offsite impact, no further analysis was performed. **Section 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 Woolworths. A final report was then developed, incorporating the comments received by Woolworths, for submission to the regulatory authority.

3.0 Site Description

3.1 Site Location

The Woolworths JN Warehouse is situated in the Moorebank Intermodal Precinct which is located approximately 35 km south west of 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 Moorebank.

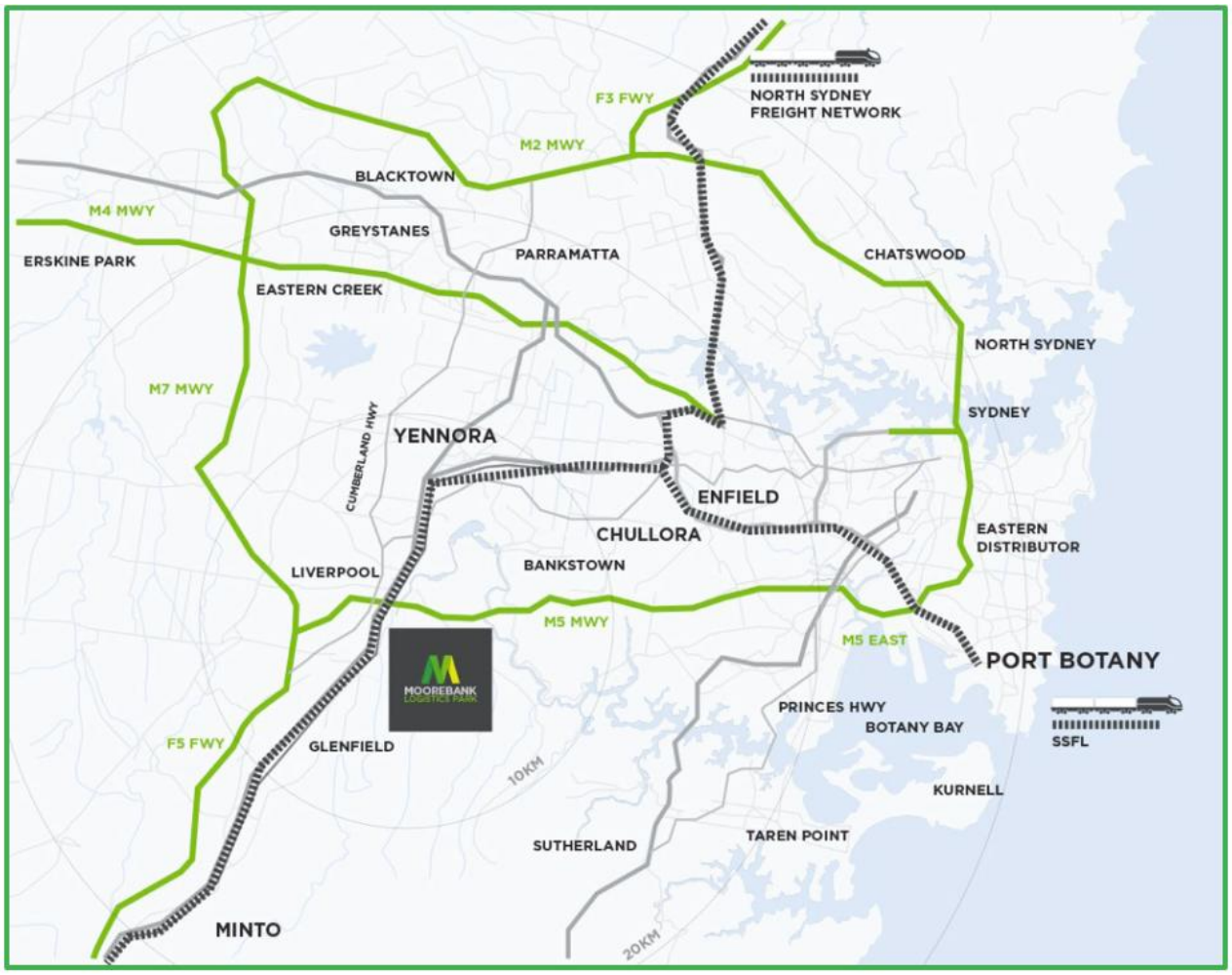


Figure 3-1: Site Location

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 – JR Warehouse
- South – Industrial warehousing
- East – Industrial warehousing
- West – Designated reserve area / George's River

3.3 Site Staffing and Operational Hours

The site will have approval for 24-hour operation; however, during operation the warehouse site will be manned over three (3) shifts of 8 hours resulting in an operational time of 24 hours a day, 6 days a week. The site staffing for the JN warehouse has been summarised in **Table 3-1** across the three shifts.

Table 3-1: Shift Hours and Staffing

Shift	JN
Day Shift (06:00 – 14:00	260
Evening Shift (14:00 – 20:00)	240
Night Shift (20:00 – 06:00)	Nil
Total	500

3.4 General Description

The site will consist of the following:

- JN Warehouse
- Carparking (adjacent to JN warehouse)
- LPG tank
- Office areas
- Gate houses
- Weigh bridges

Each item relating to the storage and handling of DGs have been discussed in further detail in the following subsections. An overall site layout of the dual warehouses is shown in **Figure 3-2**. A summary of the floor areas for JN has been provided in **Table 3-2**.

Table 3-2: JN Warehouse Floor Areas

Items	Area (m^2)
Total Site areas	115,064
Heavy duty paving	37,944
Light duty paving	1,741
Car park	
Ground including permeable paving	37,944
Mid-level	6,349
Level 1	4,927

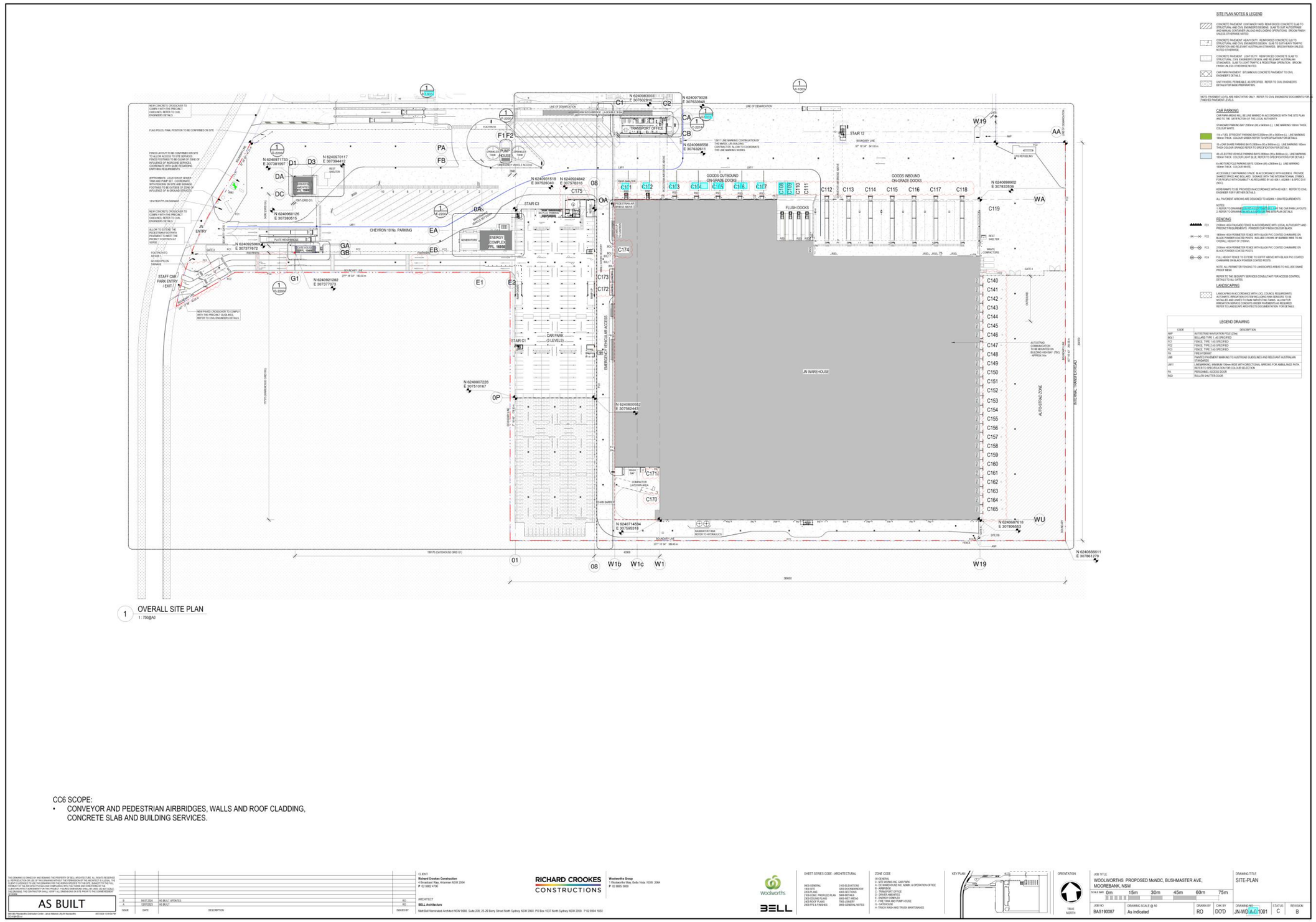


Figure 3-2: Site Layout (JN Warehouse)

3.5 JN Warehouse

3.5.1 JN Description

The JANUS National (JN) warehouse will have a height of 43.25 m and will be utilised for the distribution of products nationally from the precinct. The warehouse has an approximate footprint area of 45,000 m^2 and comprises a DG store, high bay automated racking system, workshops, receival despatch areas and associated docks, office space, amenities, etc.

The DG store, named the Special Goods Store (SGS), has an area of 1,500 m^2 and is designed to cater for DGs which may not be stored within the automated systems as they cannot be adequately protected within the automated systems.

3.5.2 ErgoPal

The ErgoPal is an automated storage system which stores product within totes which are transported vertically and horizontally through the system to the assigned storage area. Vertical movement occurs at one end of the ErgoPal locating the tote on the correct row where it is then conveyed horizontally on a shuttle before being moved 90^o into the allocated location. The totes have dimensions of 600 mm x 400 mm x 200 mm with system reaching approximately 16 m high.

The ErgoPal is a relatively open storage system which looks similar to normal racked storage in that it has space for in-rack sprinklers as shown in **Figure 3-3**. The system has been designed according to FM Global Data Sheet 8-34 (Ref. [5]) which includes in-rack sprinklers along with SMSS located at ceiling height complying with FM Global Data Sheet 8-9 (Ref. [6]). The sprinklers are spaced every three (3) metres vertically with two (2) runs per double row rack.

It is noted that there are no DGs stored within the ErgoPal which reduces the potential for a spill of flammable or combustible liquids which may ignite resulting in a fire.

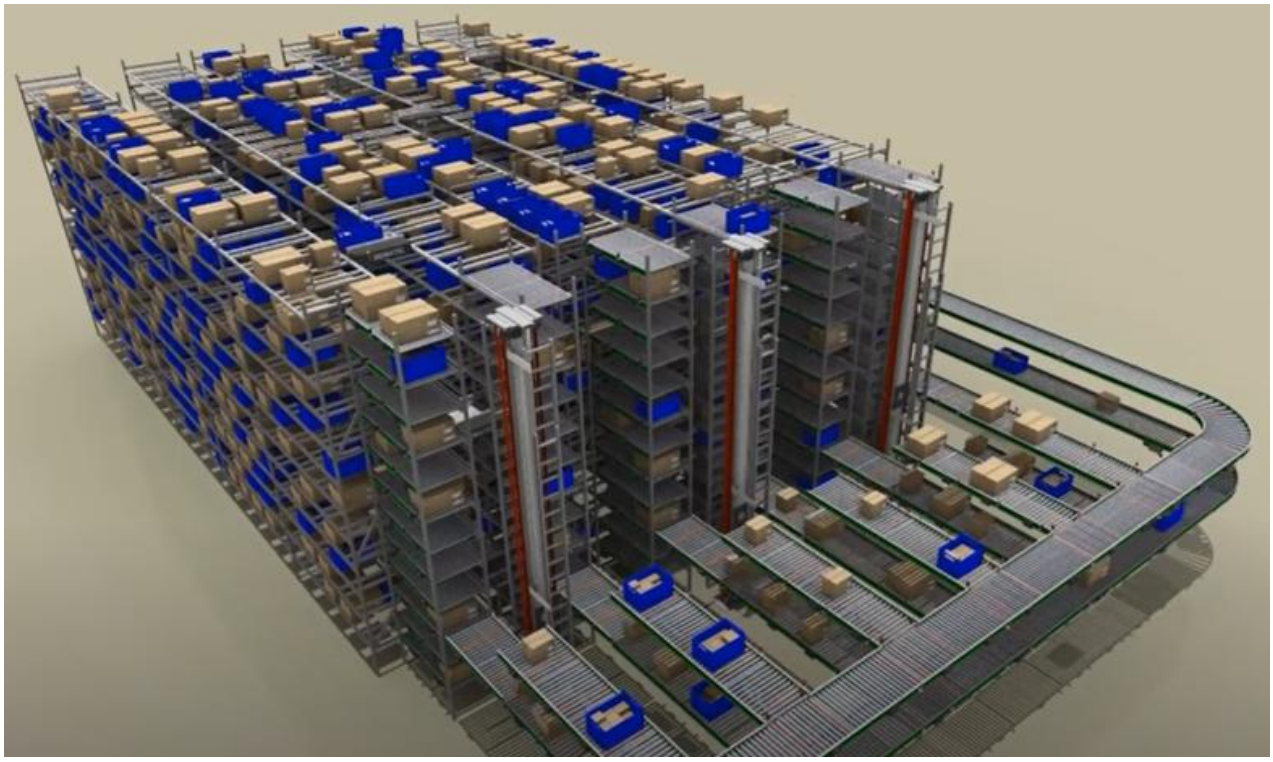


Figure 3-3: ErgoPal Structure

3.5.3 High Bay

The High Bay racking area is an automated system where pallets are transported via cranes through the system and stored per the storage logic. The high bay is approximately 40 m in height and is fitted with in-rack Early Suppression Fast Response (ESFR) sprinklers complying with FM Global Data Sheet 8-9 (Ref. [6]). The in-rack sprinklers are located at heights of 9 – 12 m depending upon the racking spacing. No DG products are proposed to be stored within the High Bay area.

3.5.4 Special Goods Store

The Special Goods Store (SGS) contains the DGs anticipated to be stored within the warehouse. The SGS is a purpose-built DG store which is constructed of walls with an FRL of 240/240/240 which compartmentalises the DGs from the main warehouse. The store has been designed to comply with AS/NZS 3833:2007 (Ref. [7]) including ventilation, bunding, ignition source control, etc. The commodities will be protected by a SMSS complying with FM Global Data Sheet 8-9 (Ref. [6]) and includes environmentally friendly foam making capabilities.

3.5.5 JN DG Quantities

Provided in **Table 3-3** is a summary of the DGs stored within the JN warehouse. **Figure 3-4** shows the location of the DGs listed in **Table 3-3**.

Table 3-3: DG Classes and Quantities Stored in JN

Location	Description	Class	PG	Total (kg)
SGS	Explosives (party poppers)	1.4s	n/a	500
	Flammable Liquids (paint, hand sanitiser, nail polish, etc.)	3	II	32,700
			III	47,000

	Flammable Solids (fire lighters, ethanol wipes)	4.1	II	1,000
			III	4,500
	Corrosive substances (cleaning products)	8	II	38,000
			III	114,500
	Miscellaneous DGs	9	III	27,000
Aerosols	Aerosols	2.1	n/a	100,000 / 25,000*
		2.2	n/a	24,500

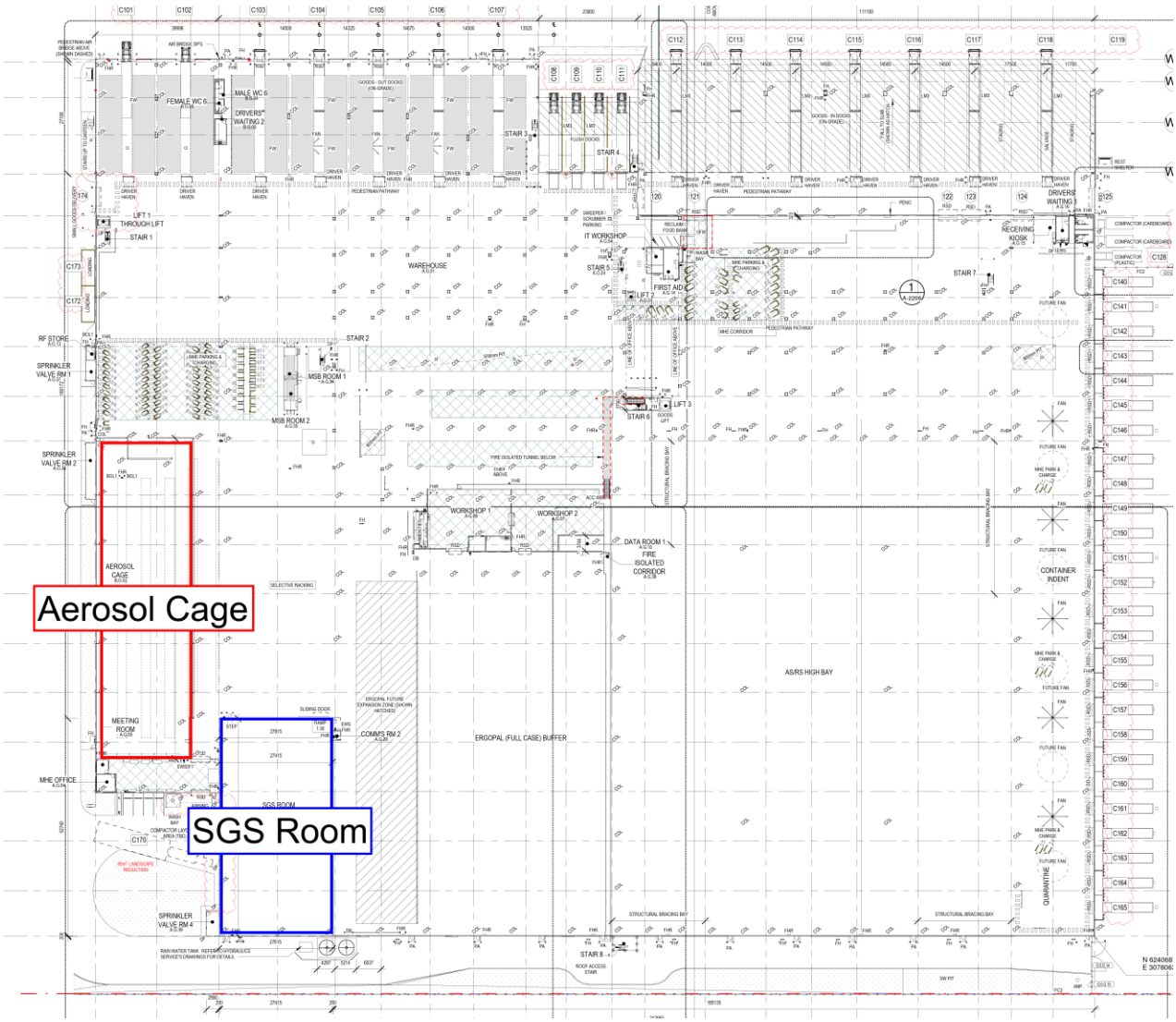


Figure 3-4: JN DG Storage Locations

3.6 LPG Tank

3.6.1 LPG Description

There is an Liquefied Petroleum tank (LPG) located in the north eastern corner of the site which will supply LPG for forklift refuelling. The tank has a volume of 5,880 L resulting in a mass of LPG of 3,234 kg.

3.6.2 LPG DG Quantities

The quantities of LPG proposed to be stored are provided in **Table 3-4**. The location of the LPG storage is shown in **Figure 3-5**.

Table 3-4: LPG Storage Tank Volumes

Location	Description	Class	PG	Total (kg)
LPG Tank 1	Liquefied Petroleum Gas	2.1	n/a	5,880 L / 3,234 kg

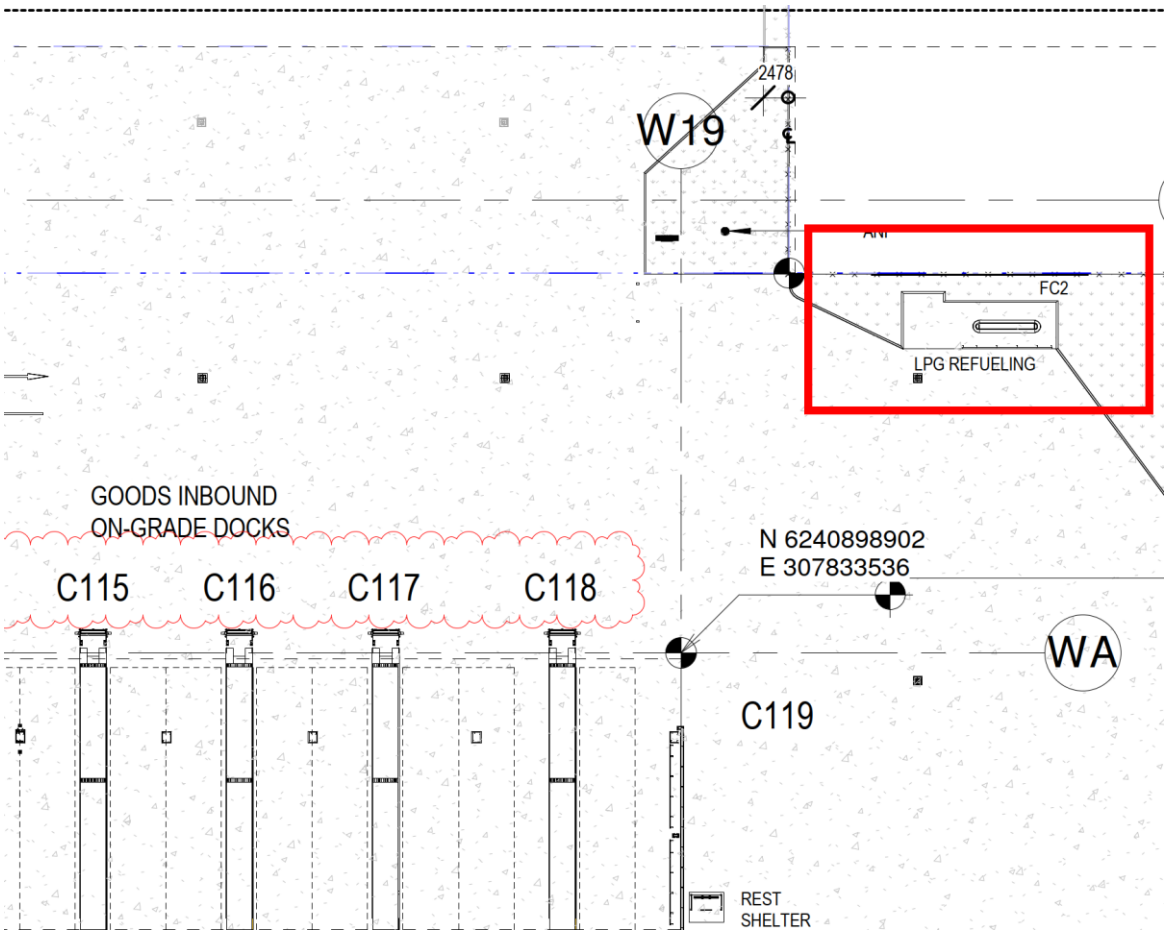


Figure 3-5: Forklift LPG Storage Locations

3.7 Quantities of Dangerous Goods Stored and Handled

Provided in **Table 3-5** is a summary all the DGs proposed to be stored across the whole JN site.

Table 3-5: Dangerous Goods Stored at the Woolworths Distribution Precinct

Area	Description	Class	PG	Total (kg^)
JN	Explosives	1.4s	n/a	500
	Aerosols	2.1	n/a	100,000 / 25,000*
		2.2	n/a	24,500
	Flammable Liquids	3	II	32,700
			III	47,000

Area	Description	Class	PG	Total (kg^)
	Flammable Solids	4.1	II	1,000
			III	4,500
	Corrosive substances	8	II	38,000
			III	114,500
	Miscellaneous DGs	9	III	27,000
LPG Tank 1	Liquefied Petroleum Gas	2.1	n/a	5,880 L / 3,234 kg

^kg unless noted otherwise

3.8 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:**

$$AQR = \frac{q_x}{Q_x} + \frac{q_y}{Q_y} + [\ldots] + \frac{q_n}{Q_n}$$ **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 have been taken from Schedule 15 of the Work Health and Safety (WHS) Regulation 2017 (Ref. [8]). These are summarised in **Table 3-6** and designated whether the class is subject to MHF assessment.

Table 3-6: Major Hazard Facility Thresholds

Class	Packing Group	Threshold (tonnes)	Storage (tonnes)
1.4s	n/a	Not subject to MHF	n/a
2.1	n/a	200	49.5
3	II & III	50,000	79.7
4.1	II & III	Not subject to MHF	n/a
5.1	III	Not subject to MHF	n/a
8	II & III	Not subject to MHF	n/a
C1	n/a	Not subject to MHF	n/a

A review of the thresholds and the commodities and packing groups listed in **Table 3-6** 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:

$$AQR = \frac{49.5}{200} + \frac{79.7}{50000} = 0.249$$

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

4.0 Hazard Identification

4.1 Introduction

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

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

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

  Those incidents exceeding 4.7 kW/m^2 at the site boundary are carried forward for further assessment (i.e. frequency and risk). This is a conservative approach, as HIPAP No. 4 (Ref. [2]) indicates that values of heat radiation of 4.7 kW/m^2 should not exceed 50 chances per million per year at sensitive land uses (e.g. residential). It is noted that the closest residential area is 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 kW/m^2/14 kPa) above which the risk of property damage and accident propagation to neighbouring sites must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk to incident propagation, for this study, incidents that result in a heat radiation heat radiation less than 23 kW/m^2 and explosion over pressure less than 14 kPa, at the site boundary, are screened from further assessment. Those incidents

exceeding 23 kW/m^2 at the site boundary are carried forward for further assessment with respect to incident propagation (i.e. frequency and risk).

- *Societal Risk* – HIPAP No. 4 (Ref. [2]) discusses the application of societal risk to populations surrounding the proposed potentially hazardous facility. It is noted that HIPAP No. 4 indicates that where a development proposal involves a significant intensification of population, in the vicinity of such a facility, the change in societal risk needs to be taken into account. In the case of the 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 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
1.4s – Explosives	Class 1.4s are a sub-designation of explosives which covers explosive products which include blasting caps, small arms, ammunition. Essentially, Class 1.4s contains explosives with relatively low risk (compared to other explosives) they are not shock sensitive and are contained within enclosed products. Products likely to be stored at CA include party poppers, sparklers, etc.
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^{o}C closed-cup test or not more than 65.6^{o}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.
8 – Corrosive Substances	Class 8 substances (corrosive substances) are substances which, by chemical action, could cause damage when in contact with living tissue (i.e. necrosis), or, in case of leakage, may materially damage, or even destroy, other goods which come into contact with the leaked corrosive material. Releases to the environment may cause damage to sensitive receptors within the environment.
9 – Miscellaneous DGs	Class 9 substances and articles (miscellaneous dangerous substances and articles) are substances and articles which, during transport present a danger not

Class	Hazardous Properties
	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. [9]

4.3 Hazard Identification

A hazard identification was prepared as part of the original PHA which has been included in **Appendix A** of this report. To determine whether additional assessment is required, the original hazards identified in the PHA have been listed below with each hazard reviewed in turn to confirm whether any changes have occurred that would require reassessment.

- JN flammable liquid release, delayed ignition and flash fire or explosion.
- JN flammable material spill, ignition and racking fire.
- JN LPG release (from aerosol), ignition and racking fire.
- JN full warehouse fire and radiant heat.
- JN full warehouse fire and toxic smoke emission.
- JN dangerous goods liquid spill, release and environmental incident.
- JN dangerous goods liquid spill, release, incompatible mixing and reaction.
- JN warehouse fire, sprinkler activation and potentially contaminated water release.
- LPG release, ignition and pool fire.
- LPG unloading incident, hose rupture, LPG release, ignition and jet fire.
- LPG release and ignition causing flash fire or explosion.
- LPG unloading incident, hose rupture, LPG release, ignition and jet fire and impact on LPG delivery tanker and Boiling Liquid Expanding Vapour Explosion (BLEVE).
- LPG unloading incident, hose rupture, LPG release, ignition and jet fire and impact on LPG tank and BLEVE.
- Fire in ErgoPal or High Bay and propagation between storage areas.

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

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

As noted in **Section 3.0**, flammable liquids will be stored at JN. 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 review of the product list to be stored indicates the products are small retail packages as defined by AS/NZS 3833:2007 (Ref. [7]). Therefore, the release from a single flammable liquid container would result in a release <20 L. The associated vapour cloud formed by the release of 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 60079.14:2017 (Ref. [10]).

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.

Explosives may be stored at the site which will be Class 1.4S which is a subclassification of explosives covering ammunition, blasting caps, etc. These products are finished products that contain small quantities of explosives. In the case of Woolworths, if these are stored they will consist of sparklers and party popper type products. As the products contain only small quantities of explosives a large explosion would not occur. Rather, if exposed to heat (i.e. from a fire) the packaging will burn exposing the explosives which will then ignite resulting in a more aggressive fire. The combustion profile of these products would be similar to ignition of aerosols (i.e. constant flames from combustion of packaging punctuated by the increase burning rate of the LPG when the can ruptures). Nonetheless, combustion of such products would not be expected to result in a pressure wave as there is insufficient explosive mass in a dense form.

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 JN 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.

The original PHA has recommended the following measure to further mitigate risks:

- 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).

A review of the as-built design has indicated that an aerosol cage compliant with the relevant requirements of AS3833 will be implemented; hence, it is considered that the recommendation is met.

4.6 JN LPG Release (from Aerosol), Ignition and Flash Fire or Explosion

As discussed prior, there is potential that LPG may be released from an aerosol if the packages are damaged or dislodged from racking. If a flammable gas release occurred, it would instantly form a gas cloud as the LPG would flash to gas following release from the canister. If the source of release 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 gas cloud may explode if ignited, or, if it is unconfined, it may result in a flash fire.

It is noted that the potential for a release of LPG is low as aerosol canisters are pressure tested after filling in a hot water bath to identify faulty products; 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. Therefore, the release from a single flammable gas canister would result in a release <1 L in the worst-case scenario. This release would be readily dispersed by the air conditioning system within the warehouse and therefore likely be below the LEL of the gas. However, even if the release were to ignite, the flash fire from the small release volume would be insufficient to result in a significant fire event.

Furthermore, to minimise the likelihood that any flammable gas cloud may contact an ignition source, the electrical equipment within the aerosol store will be installed according to the requirements of AS/NZS 60079.14:2022 to exclude ignition sources.

Therefore, based on the warehouse design (controlled ignition sources, etc.), operation practices and the storage of small packages, the risk of a gas cloud being generated that is large enough to ignite and impact throughout the warehouse, by way of an explosion or a flash fire, is considered to be low (if not negligible). Notwithstanding the above, this scenario has been carried forward for further analysis to identify the risk associated with an exploding aerosol can.

4.7 JN 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.

4.8 JN 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.

4.9 JN Full Warehouse Fire and Toxic Smoke Emission

As discussed in **Section 4.8** 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.

4.10 JN Dangerous Goods Liquid Spill, Release and Environmental Incident

There is potential that a spill of the liquid DGs (Class 3, 4.1, 5.1, 8) could occur at the site which if not contained could be released into the public water course resulting in a potential environmental incident.

The original PHA has recommended the following two (2) measures to address the risks associated with release and the eventual environmental incident, which are as follows:

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

It has been noted in the as-built design that potential firewater and stormwater runoff has been accounted for. **Table 4-2** has been provided to summarise the total containment volume provided for the JN warehouse and **Figure 4-1** has the location/calculation of such containment areas/vessels.

Table 4-2: Containment Volume Provided for the JN Warehouse Site

Area	Containment Volume (m^3)
Sunken Docks	490
SGS Room	139
Storage Tank	30
Total	659
Minimum Required (Section 4.12)	653.4

The site contains more than sufficient containment for firewater runoff; 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.

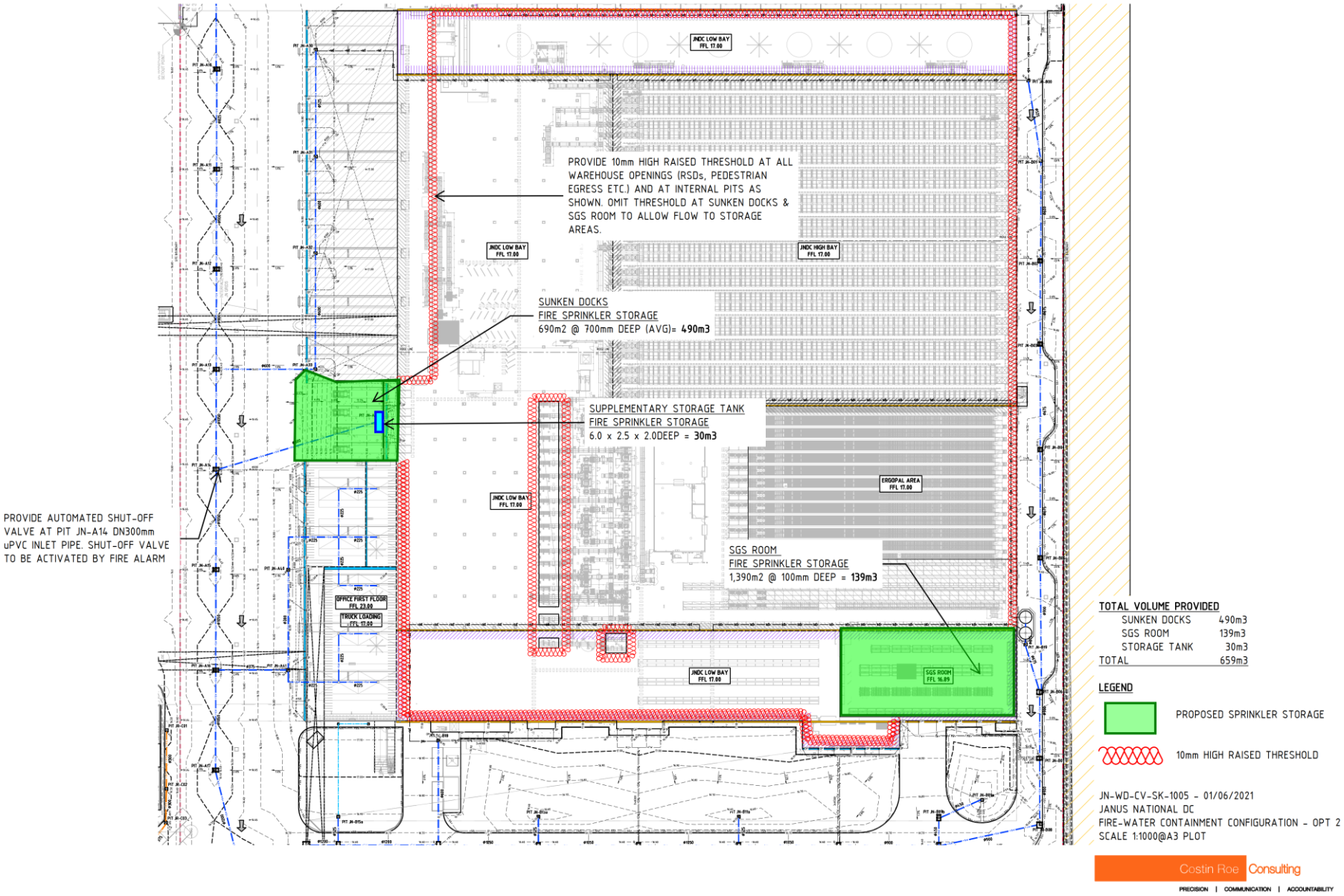


Figure 4-1: Water Containment Design of the JN Warehouse

4.11 JN Dangerous Goods Liquid Spill, Release, Incompatible Mixing and Reaction

As described in **Section 4.10**, there is potential that a spill of the liquid DGs (Class 3, 4.1, 5.1, 8) could occur which could lead to incompatible mixing and thus an exothermic reaction. Sodium hypochlorite and hydrogen peroxide will react to form oxygen. In the event of a fire this may exacerbate a fire; however, it is noted that Class 8 and 5.1 DGs are not flammable themselves hence the risk for fire initiation in these storage areas is not increased relative to other non-DG areas.

However, it is highly unlikely that packages will consecutively fail given that these are in retail sizes (<20 L), stored on different pallets and wrapped in plastic. Additionally, the cardboard packaging will absorb spill liquid thus further reducing the potential volume that may mix. Note that the retail volumes of the classes would limit available reactants if multiple containers were to fail. Furthermore, the warehouse will be protected by an automatic sprinkler system; hence, if there were a fire in this area the dilution from the sprinkler system would be expected to dramatically reduce the rate of reaction and subsequent formation of oxygen.

Based on the analysis conducted, it is considered that the risks of incompatible mixing would be low in the event of a fire due to the retail nature of the commodities stored and the presence of sprinkler systems which will provide substantial dilution of any releases noting the system aims to prevent propagation and ultimate package failure.

4.12 JN Warehouse Fire, Sprinkler Activation and Potentially Contaminated Water Release

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

The 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. [11]), 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 with 12 heads operating at 0.455 m^3/min or 5.46 m^3/min.
- 3 hydrant hoses at 1.8 m^3/min.

The total water discharge would be 7.26 m^3/min. Therefore, operation for 90 minutes would result in a total discharge of 653.4 m^3.

As noted in **Section 4.10**, the containment system of the site is able to contain 659 m^3 of firewater output which is in excess of the calculated requirement.

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

4.13 LPG Release, Ignition and Pool Fire

In the event of a leak from a vessel or pipework, a pool of LPG may form when the rate of evaporation of LPG is less than the flow rate of LPG from the leak. If the pool were to ignite, an LPG pool fire would occur which may impact over the site boundary.

A leak sufficient to cause a release that exceeds the evaporation rate to develop a pool large enough to ignite (noting the area is zoned per the requirements of AS/NZS 60079.10.1:2009 (Ref. [12])) and the subsequent fire to impact over the site boundary is very low. This is substantiated by numerous similar sized LPG tanks installed throughout Australia with very low incidences of leaks and fires occurring from such installations.

It is noted that the primary cause of a leak would be physical damage to the LPG tank or fittings from vehicular collision. Hence, the following recommendation has been made to minimise the potential for a major release and pool fire:

- The LPG tanks shall be protected from impacts by bollards, railings or similar physical barriers.

Based on the incorporation of the above recommendation, the potential for a leak and LPG pool and subsequent ignition to occur is incredibly low. Hence, this incident has not been carried forward for further analysis.

4.14 LPG Unloading Incident, Hose Rupture, LPG Release, Ignition and Jet Fire

As the site LPG is depleted, it will be refilled by a delivery tanker at the site. During loading of the tank there is the potential for the hose to rupture which may be the result of a puncture of the hosing or deterioration through general wear and tear. It has been assumed the hoses are inspected monthly and pressure tested annually in accordance with the Australian Dangerous Goods Code (ADG, Ref. [13]).

Notwithstanding this, there is the potential for a hose to become damaged between inspection and test periods which may lead to sufficient deterioration resulting in a hose rupture when transferring pressurised LPG. Excess flow and non-return valves will isolate the flow of LPG; however, if these fail in addition to a hose rupture, LPG will be released resulting in an LPG vapour cloud. The operator may be able to respond and isolate the LPG transfer by activating an emergency stop button located on the tanker.

If the operator is incapacitated or unable to stop the transfer, the LPG will continue to flow developing a substantial cloud which may contact an ignition source and ignite which would result in a flash fire or explosion which would burn back to the release point and subsequent jet fire. It is noted the area is unconfined; hence, an explosion is unlikely to occur and would likely result in a flash fire.

The potential for a fatality to occur as a result of a flash fire is not considered credible as the mechanism for a fatality to occur from a flash fire is via combustion of flammable vapours at head height which results in oxygen within the lungs being consumed as the fuel burns. The impacted person will involuntarily inhale, as low oxygen is detected, resulting in inhalation of hot combustion products which burn the sensitive lining of the lungs. As LPG is a dense gas, any release will spread

along at ground level and due to the open nature of the site it will not accumulate to a level where a person offsite will be fully engulfed; hence, a fatality is unlikely to occur.

While a flash fire may not be expected to cause significant harm, the impacts from a jet fire are likely to be substantial and would impact over the site boundary; hence, this incident has been carried forward for further analysis.

4.15 LPG Release and Ignition Causing Flash Fire or Explosion

In the event of an LPG release, LPG will vapourise forming a flammable atmosphere which may ignite. A review of the area indicates the tank will not be stored in an area where confinement will occur; hence, the atmosphere would not ignite as an explosion but would rather result in a flash fire.

As noted in **Section 0**, the mechanism for a fatality to occur from a flash fire is inhalation of hot combustion products when a person is fully engulfed in a vapour cloud when ignition occurs. As LPG is a dense gas it will spread out at ground level as there is no confinement to allow the gas to accumulate at height; therefore, it is unlikely that a vapour cloud would form to allow a person to be fully engulfed; hence, a fatality would be unlikely to occur.

Furthermore, AS/NZS 1596:2014 (Ref. [14]) has been developed with reference to the likely impact scenarios from storage of LPG in various tank sizes. Review of Table 6.1 of AS/NZS 1596:2014 (Ref. [14]) indicates for a 5.9 kL tank the separation distance to a protected place is approximately 5.5 m. Therefore, the standard would consider that in open air, events resulting from a release from the tank would be unlikely to significantly impact >5.5 m.

A catastrophic failure of an LPG tank (i.e. rupture and full release of LPG) is considered incredible due to the manufacturing and regular testing of pressure vessels according to AS 1210:2010 (Ref. [15]).

As the area is unconfined and the location of the tank provides adequate separation to the site boundary and protected places it is considered that a fatality would not result from this incident; hence, this incident has not been carried forward for further analysis.

4.16 LPG Unloading Incident, Hose Rupture, LPG Release, Ignition and Jet Fire and Impact on LPG Delivery Tanker and BLEVE

Similarly, to the scenario described in **Section 4.15** the hose may rupture resulting in a jet fire. If this jet fire were aimed at the delivery tanker, the tanker shell would begin to heat, transferring the heat into the LPG within the tank which would begin to vaporise and increase the pressure within the tanker. At the design pressure of the tank, the pressure relief valve will begin to lift to relieve pressure within the tanker.

As the liquid level within the tanker drops, the impact zone of the jet fire may impact the vapour space in the tanker. The vapour will absorb less energy than the liquid which will result in localised heating of the tanker shell at the point of the jet fire impact. This may compromise the structural integrity of the tanker shell which may rupture resulting in a blast overpressure as the vessel fails and formation of an LPG vapour cloud which may also ignite resulting in a vapour cloud explosion known as a Boiling Liquid Expanding Vapour Explosion (BLEVE). This incident has been carried forward to assess the potential impact zone.

4.17 LPG Unloading Incident, Hose Rupture, LPG Release, Ignition and Jet Fire and Impact on LPG Tank and BLEVE

Similarly, to the scenario described in **Section 4.15** the hose may rupture resulting in a jet fire. If this jet fire were aimed at the tank, the tank shell would begin to heat, transferring the heat into the LPG within the tank which would begin to vaporise and increase the pressure within the tank which may result in a BLEVE as described in **Section 4.16**. Hence this incident has been carried forward for further analysis.

4.18 Fire in ErgoPal or High Bay and Propagation Between Storage Areas

Discussion with FRNSW indicates there is the concern that a fire within the ErgoPal (or the High Bay racking) may result in incident propagation between the storage areas. A review of the protection systems indicates that both systems are fitted with in-rack sprinklers sized for the commodities stored. The ErgoPal contains in-rack sprinklers as required by FM Global Data Sheet 8-34 (Ref. [5]) and is also protected by SMSS located at ceiling height in accordance with FM Global Data Sheet 8-9 (Ref. [6]). Similarly, the High Bay area is protected by in-rack sprinklers complying with FM Global Data Sheet 8-9 (Ref. [6]) which are located at heights between 9-12 m within the High Bay system.

It is noted that there are no DGs stored within these systems; hence, the fire risk posed by these storage areas is commensurate with other warehouses storing non-DG products. DGs pose an increased potential for ignition as some classes of DGs are flammable gases or liquids which can create flammable atmospheres which can migrate to an ignition source (i.e. light switch) and ignite flashing back to the point for release and resulting in a fire. As none of the products present within the ErgoPal or High Bay are flammable gases or liquids there potential for migrating flammable atmospheres is eliminated which drastically reduces the potential for ignition. In addition, the products stored, while combustible, are not readily ignited (i.e. by a spark, or static) and required sustained exposure to heat to ignite. Therefore, it is considered that ignition would be unlikely to occur in normal operation and would likely only occur from malicious activities, faulty equipment, or mismanaged hot work.

In addition, the FM Global Standards have been developed based upon empirical testing of sprinkler systems for various configuration of commodities and material types to demonstrate that the sprinkler system can suppress and control a fire adequately. Part of this testing involves the potential for lateral spread from one racked storage area across and aisle into an adjacent storage area. If a fire is able to laterally spread via radiant heat propagation then the system would fail the test and subsequently would not be recommended within the data sheets. Therefore, it would be expected that the potential for incident propagation from the ErgoPal to the High Bay or vice versa would be a low probability event based upon the protection systems installed.

Notwithstanding the above, this incident has been carried forward for further analysis to review the potential for incident propagation between the areas.

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.
- JN LPG release (from aerosol), ignition and racking fire.
- JN Flammable Gas Release, Delayed Ignition and Flash Fire or Explosion.
- Full warehouse fire and radiant heat.
- Full warehouse fire and toxic smoke emission.
- LPG unloading incident, hose rupture, LPG release, ignition and jet fire.
- LPG unloading incident, hose rupture, LPG release, ignition and jet fire and impact on LPG delivery tanker and Boiling Liquid Expanding Vapour Explosion (BLEVE).
- LPG unloading incident, hose rupture, LPG release, ignition and jet fire and impact on LPG tank and BLEVE.
- Fire in ErgoPal or High Bay and propagation between storage areas.

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
3.0	14.9	27.5

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. In addition, the flammable liquids are contained within an enclosure with a FRL 240/240/240 separating the DG store from the main warehouse; hence, it is considered should a fire occur within the bunker and the sprinkler systems fail to suppress and control the fire, it will not

propagate into the main warehouse area. Nevertheless, as offsite impact has been observed, this incident has been carried forward for further analysis.

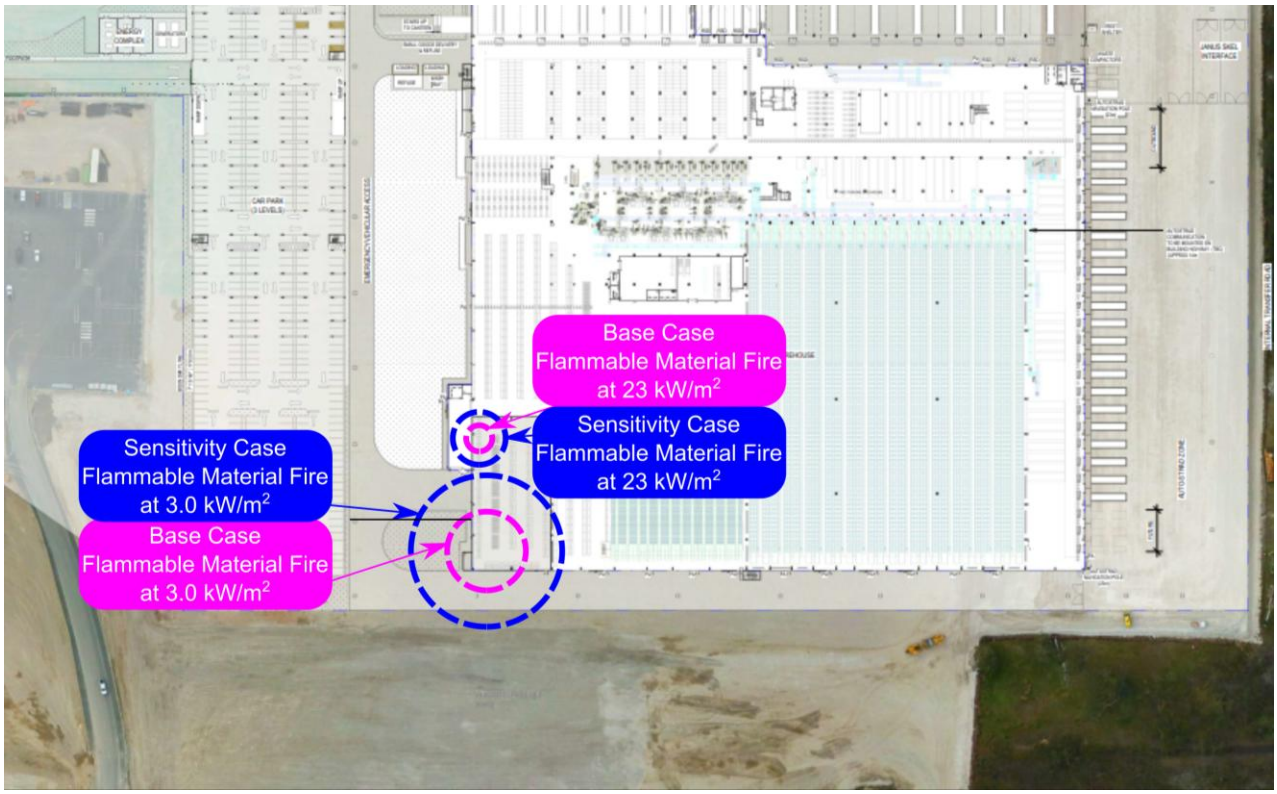


Figure 5-1: Sprinkler Controlled Flammable Material Fire Radiant Heat Contours

5.3 JN 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/m²)	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
3.0	16.9	31.5

A review of the 3.0 kW/m² contour indicates critical firefighting infrastructure (i.e. hydrants, pump house, boosters, etc.) would be unaffected; hence, would be accessible by FRNSW in both the base case and the sensitivity case scenarios as illustrated in **Figure 5-2**.

A review of the 3.0 kW/m^2 and 23 kW/m^2 impact distances indicate 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 and is not carried forward for further analysis.

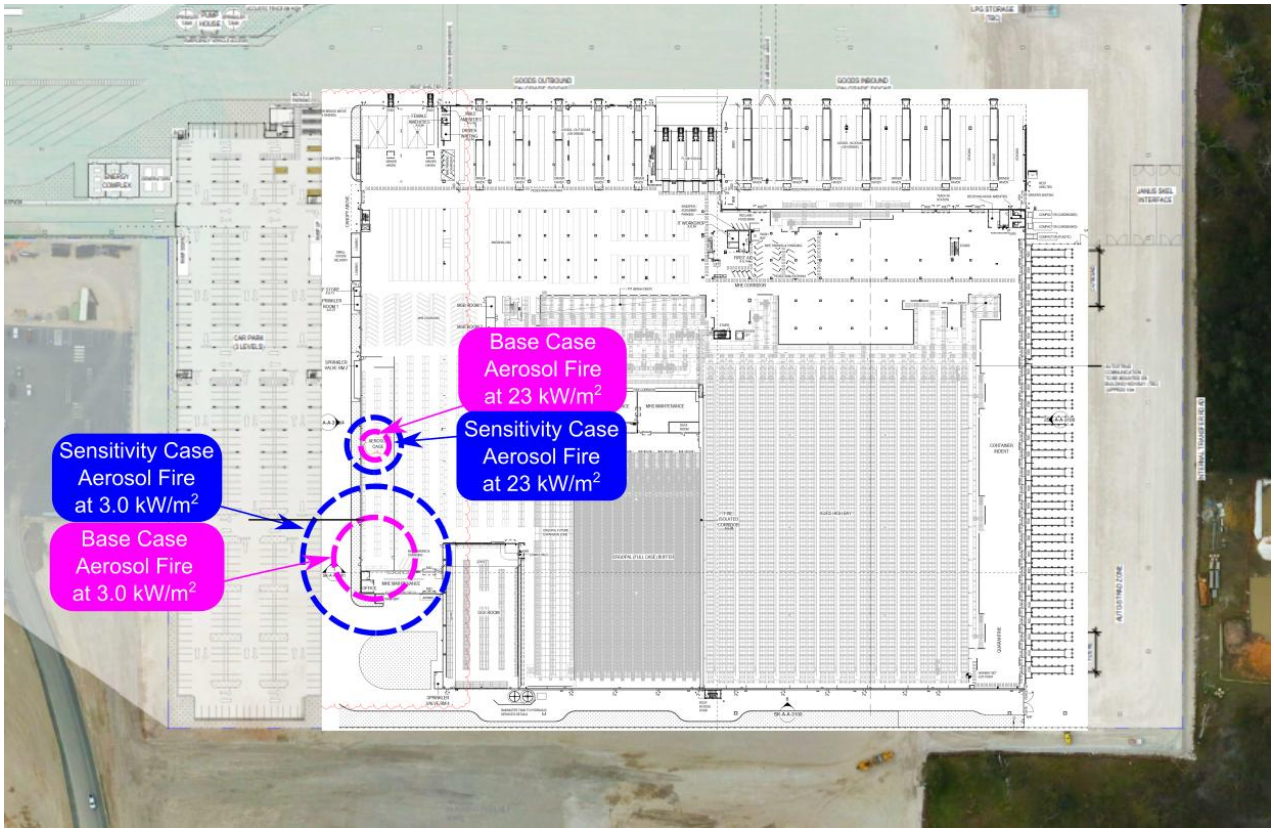


Figure 5-2: Sprinkler Controlled JN Aerosol Fire Radiant Heat Contours

5.4 JN LPG Release (from Aerosol), Ignition and Flash Fire or Explosion

This section assesses the consequence of an exploding aerosol can. The maximum size of an aerosol stored in the facility is 600 ml; however, an aerosol volume has been assumed as 1 L. The following data sourced from industry advice has been input into the fragment model of Gexcon Effects which is a consequence modelling software.

- Water capacity: 1 L
- Pressure: 10 Bar
- Dimensions (height x diameter): 265 mm x 73 mm
- Empty weight: 108 g
- Valve outlet: 7/16” (28 NS/2 Male)
- Material: Aluminium alloy
- Empty can mass: 0.108 kg
- Can burst pressure: 10 bar
- Propellant: LPG (standard flammable gas propellant)
- Filling degree: 25% (typical propellant mass based on industry advice)

The Gexcon fragment model in Effects calculates the velocity of exploding fragments from pressure vessels. The model calculated that the velocity of the exploding fragment was 30.8 m/s. As the can has a mass of 0.06 kg, the momentum of the can would be 30.8 x 0.1 (mass of fragment) = 3.08 kg.m/s.

To estimate whether the cage is likely to fail when impacted by a projectile with a momentum of 3.08 kg.m/s, this scenario is compared to an everyday case of a staff member coming into contact with, i.e. bumping into the cage. Assuming an average walking speed of 1.25 m/s and a mass of 75 kg, the momentum that an occupant could impose on the cage is 75 x 1.25 = 93.75 kg.m/s which is 30 times the momentum of the can.

It is expected that a collision of a person at walking speed would not result in the failure of the mesh cage ; hence, it is expected that a can with 1/30 the momentum would also not result in the failure of the cage. Therefore, it is considered that an exploding aerosol can would be adequately contained and not have impact at the site boundary.

5.5 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	38.0
4.7	85.0
3.0	115.0

*Based on the research by Mudan & Croche reported in Lees (Ref. [16]) & Cameron/Raman (Ref. [17])

As shown in **Figure 5-3**, the radiant heat impacts at 3.0 kW/m^2 have an extensive impact from the warehouse; however, it must be noted that the analysis is based upon the full warehouse containing representative DG products with burning rates above those of normal products. It also assumes that the entire footprint is composed of combustible materials; hence, the true impact would likely be less than that shown.

Regardless, a full warehouse fire would likely render all protection systems impacted by a 3.0 kW/m^2 which would prevent FRNSW intervention based upon their accessibility criteria. Nonetheless, the warehouse has been designed using protection systems designed specifically for use in the configuration proposed for this warehouse. Therefore, a full warehouse fire is not expected to occur based upon the reliability of the sprinkler systems installed.

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

that propagation to adjacent facilities would not occur. Nevertheless, as offsite impact has been observed, this incident has been carried forward for further analysis.

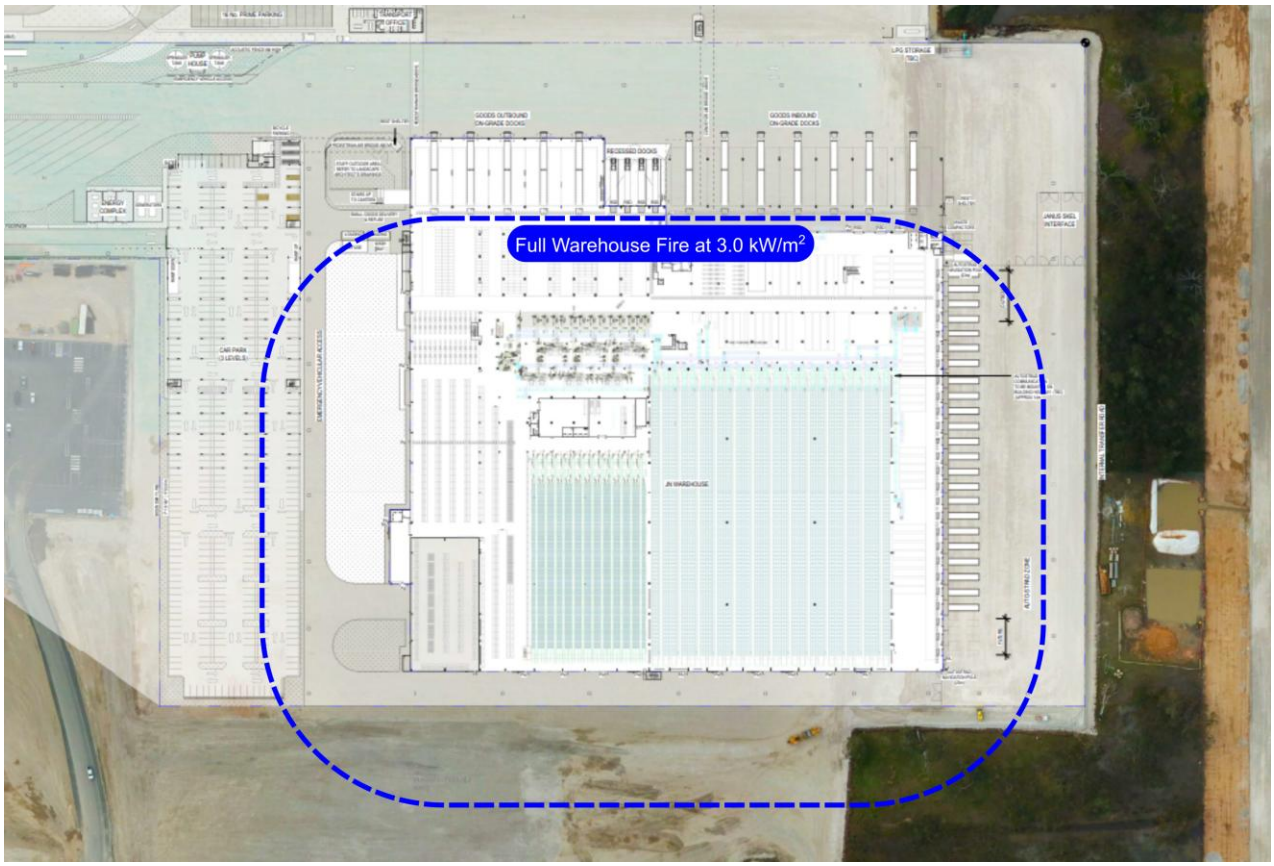


Figure 5-3: Full Warehouse Fire Radiant Heat Contours

5.6 Full Warehouse Fire and Toxic Smoke Emission

A detailed analysis has been performed in **Section B9** of **Appendix B** to estimate the impact of toxic products of combustion on the surrounding area. It was identified that no toxic substances are stored within the warehouse; hence, the formation of toxic smoke would be unlikely from materials stored. However, toxic products from combustion of other materials within the warehouse may form which could have downwind impacts. **Table 5-5** summarises the toxic by-product formation rates that would be expected to occur within the warehouse based upon the warehouse predominantly storing non-DG products and the DG products that are stored being non-toxic in nature.

Table 5-4: Toxic By-Product Formation Rates

Material	Release Rate (kg/s)
Nitrogen Dioxide	86.7
Sulphur Dioxide	150.2
Hydrogen Chloride	76.2
Soot (Carbon)	172.4

The analysis modelled the plume dispersion which showed that the heat of the plume would be sufficient to penetrate the inversion layer which would then prevent the majority of by-products from returning to ground level within the immediate vicinity. Therefore, the potential for the toxic smoke plume to directly impact attending fire fighters is considered low with the exception of any down

drafts which may force the cloud downward. However, as FRNSW personnel attending the site carry breathing apparatus, it is expected that should such an eventuality occur attending firefighters will have sufficient protection against exposure to the smoke plume.

5.7 LPG Unloading Incident, Hose Rupture, LPG Release, Ignition and Jet Fire

There is the potential for a hose to rupture and release high pressure LPG if the excess flow valve on the tanker fails and operator intervention does not occur. If this stream ignited, a jet fire could occur. A detailed analysis has been conducted in **Appendix B10** for this scenario which indicates the jet fire would have an impact of distance of 38 m. The impact distances for this incident are shown in **Figure 5-4**.

There are several protection systems to prevent hose rupture including hose pressure testing and inspections, non-return valves on the tank and vehicle, excess flow valves on the tanker, earthing connections, ignition source controls. Therefore, it is unlikely that a release of LPG would occur and subsequent ignition. In addition, the area has been subject to a hazardous area classification in accordance with AS/NZS 60079.10.1:2009 (Ref. [12]) to ensure ignition sources are controlled within the vicinity to control the risk of ignition.

Based upon the protection systems incorporated into tanker trucks, the ignition source controls within the area, a scenario which escalates into a jet fire scenario from the tanker truck is not expected to occur. Nevertheless, as offsite impact has been observed, this incident has been carried forward for further analysis.

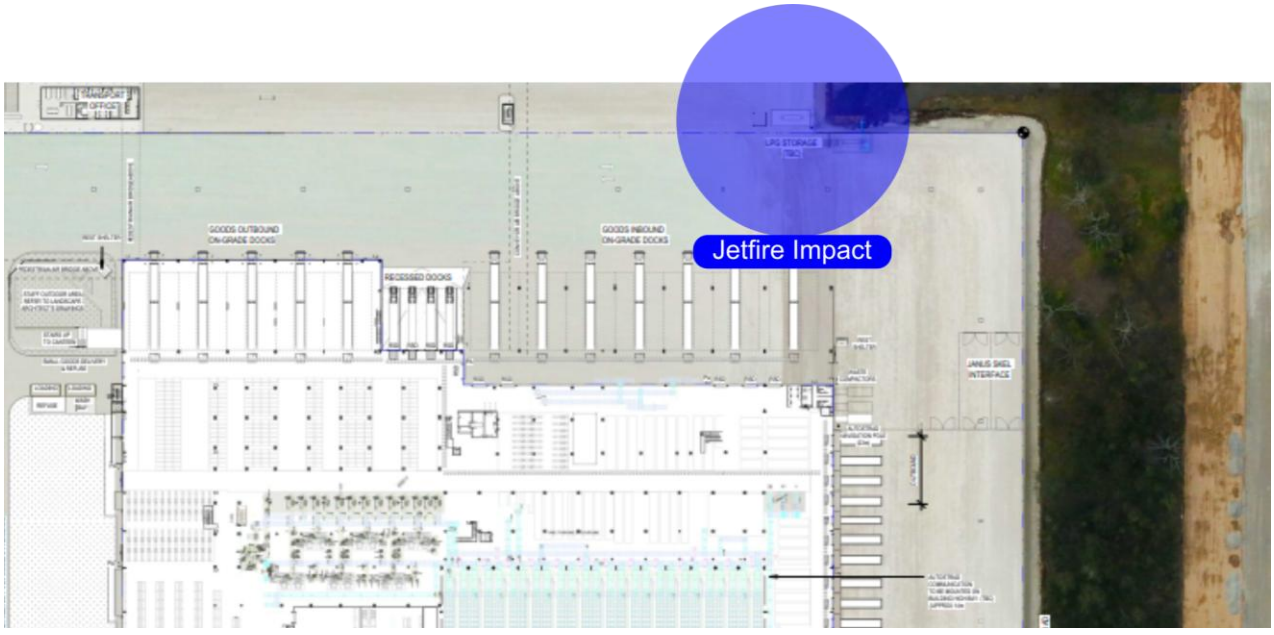


Figure 5-4: Impact from a Jet Fire

5.8 LPG Unloading Incident, Hose Rupture, LPG Release, Ignition and Jet Fire and Impact on LPG Delivery Tanker and BLEVE

In the event of a jet fire and impingement on the delivery tanker there is potential for the LPG in the tanker to boil escalating to a BLEVE if intervention measures fail. A detailed analysis has been conducted in **Appendix B11** which indicates the diameter of the BLEVE would be 63.9 m and would last for 5.0 seconds. The impact distances for this incident are shown in **Figure 5-5**.

Similarly, to the jet fire scenario, several layers of protection are required to fail before the initiating event could occur. In addition, the jet fire would need to be impinged on the tanker before it could BLEVE which takes considerable time as the LPG must boil off such that the liquid level is below the impact point.

It is noted that a BLEVE scenario is a highly unlikely eventuality as it requires a jet fire scenario to occur with the associated impingement of the jet flame onto the tanker. Based upon the protections to prevent a jet fire, escalation to a BLEVE is unlikely. Nonetheless, for the scenario to further escalate where the BLEVE occurs, considerable time must pass which provides substantial potential for intervention which would include cooling of the impinged vessel. Nevertheless, as offsite impact has been observed, this incident has been carried forward for further analysis.

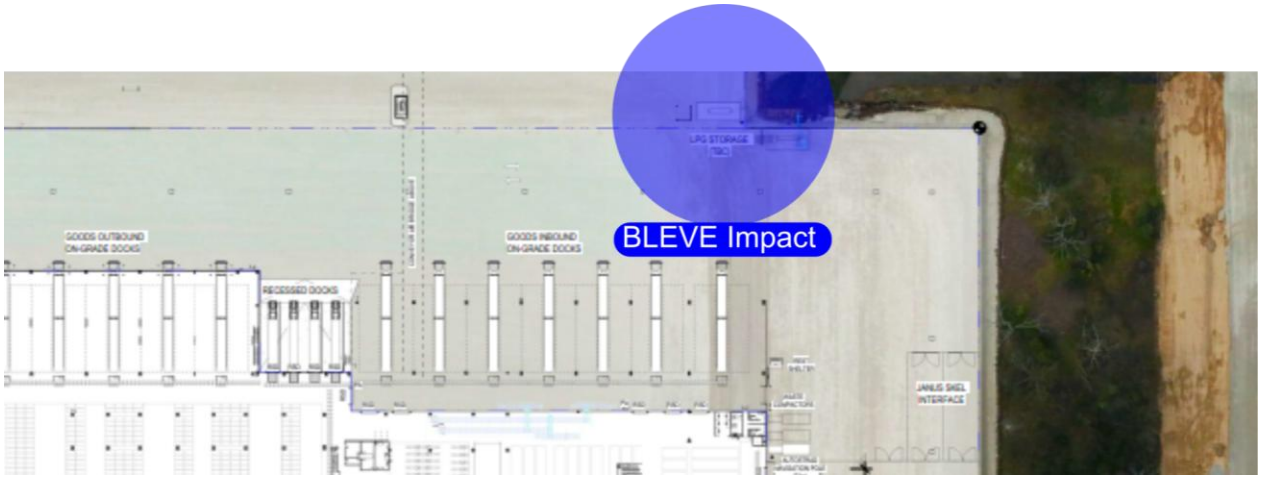


Figure 5-5: BLEVE Impact

5.9 LPG Unloading Incident, Hose Rupture, LPG Release, Ignition and Jet Fire and Impact on LPG Tank and BLEVE

In the event of a jet fire and impingement on the LPG tank there is potential for the LPG in the tank to boil escalating to a BLEVE if intervention measures fail. A detailed analysis has been conducted in **Appendix B12** which indicates the diameter of the BLEVE would be 63.9 m and would last for 5 seconds. The impact distances for this incident are shown in **Figure 5-5** as this has the same fuel profile as the tanker scenario.

The eventuality of this scenario is the same as that analysed in **Section 5.8**, in that the initiating events are unlikely to occur, escalation takes time which allows substantial time for intervention should this unlikely event occur. Nevertheless, as offsite impact has been observed, this incident has been carried forward for further analysis.

5.10 Fire in ErgoPal or High Bay and Propagation Between Storage Areas

In the event a fire occurred within the ErgoPal or the High Bay area it would create sufficient heat to activate the in-rack sprinklers which would control and suppress the fires and minimise propagation by cooling and wetting adjacent packages. Notwithstanding this, it was necessary to assess the potential fire scenarios which could occur within these areas to determine whether incident propagation could occur between the ErgoPal and High Bay and vice versa. A detailed analysis has been conducted in **Appendix B** with the results presented in **Table 5-5**.

Table 5-5: Radiant Heat from Sprinkler Controlled Fires within the ErgoPal & High Bay

Heat Radiation (kW/m^2)	Distance (m)			
	ErgoPal Base Case	ErgoPal Sensitivity	High Bay Base Case	High Bay Sensitivity
35	0.4	1.6	0.9	1.6
23	0.6	2.2	1.3	2.2
12.6	1.0	3.2	1.9	3.2
4.7	1.8	5.6	3.3	5.6
3.0	2.3	7.1	4.2	7.1

Incident propagation would occur at radiant heat values of 23 kW/m^2 which was shown in the worst scenarios identified to occur at 2.2 m from the fire source. The distance between the ErgoPal and High Bay area is an aisle way of 3 m; hence, the radiant heat impacting in either direction would be insufficient to result in incident propagation between the areas.

Furthermore, the analysis does not take into account the reduction of transmissivity which would occur from the sprinklers discharging (i.e. the water spray attenuates radiant heat reducing the radiant heat transmitted through the air). Therefore, it is considered that the analysis provides a very conservative assessment which demonstrate radiant heat propagation would not occur.

In addition, the sprinkler systems have been designed and tested empirically where a successful test only occurs if propagation across an aisle way does not occur. Therefore, the above calculations would support the findings of the sprinkler system design (i.e. it is appropriate for the commodities to prevent incident propagation between the storage areas). As no incident propagation was identified to occur, it is considered that the protection systems are adequate to protect the commodities as required.

Based upon the above, the lateral spread of fire within both the ErgoPal and High Bay storage are controlled by in-rack sprinkler systems. For the ErgoPal the totes are protected by in-rack sprinklers which are provided at 3 m increments vertically. Each column of totes is protected by two (2) heads within each increment as shown in **Appendix D**. Above the ErgoPal are additional ceiling mounted sprinklers which will activate if the in-racks become overwhelmed providing additional cooling and control. Based upon the structure of the ErgoPal, the flow from ceiling mounted sprinklers would be able to penetrate the structure to provide the required cooling.

The High Bay system has four (4) sprinkler heads provided at the corner of each pallet column (i.e. columns stacked up to 9-12 m high have four heads directly above the top pallet immediately below the in-racks). Therefore, activation of the sprinkler heads will form a wall of water around the pallets beneath the sprinkler heads which will control and suppress and cool adjacent pallets to minimise the potential for lateral spread. The system has been designed to have 12 sprinkler heads operating to ensure if lateral spread occurs the system is able to continue to respond. The layout of the sprinklers is provided in **Appendix D**.

This scenario is considered to have sufficient fire protection and the potential propagation impacts are minimised SFAIRP. Hence, no further recommendations have been made.

6.0 Frequency Analysis

6.1 Incidents Carried Forward for Frequency Analysis

The following item has been carried forwards for frequency analysis;

- JN Flammable material spill, ignition and racking fire.
- Full warehouse fire and radiant heat.
- Full warehouse fire and toxic smoke emission.
- LPG unloading incident, hose rupture, LPG release, ignition and jet fire and impact on LPG delivery tanker and Boiling Liquid Expanding Vapour Explosion (BLEVE).
- LPG unloading incident, hose rupture, LPG release, ignition and jet fire and impact on LPG tank and BLEVE.

This incident has been assessed in the following section.

6.2 Probability of Failure on Demand

The failure rates for each component identified in the safety systems which protect against the scenarios in the following sections were sourced from 3rd party databases such as; OREDA, Exida, UK Health and Safety Executive (HSE). A summary of the failure rate information has been conducted in **Appendix C**. Also included in this appendix are the calculations for the probability of failure on demand (PFD) for each component which is estimated using **Equation 6-1**.

$$PFD = \frac{1}{2}\lambda_{du}t$$ **Equation 6-1**

Where:

- λ_{du} = dangerous undetected failures of a component
- t = 1/number of test intervals per annum

6.1 JN Flammable Material Spill, Ignition and Racking Fire

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). The fire frequency has been selected from general fire frequency data.

A detailed fire frequency analysis has been conducted in **Appendix C**. The results of this analysis indicate that an initiating fire frequency would be in the order of $1x10^{-3}$ p.a. To estimate the probability of fatality it is necessary to review the susceptibility to personnel exposed to radiant heat that may occur at the site boundary. Tolerance to an exposure (i.e. radiant heat or toxicity) differs across a population which may be estimated using Probit analysis. For radiant heat exposure, the Probit equation is shown in **Equation 6-2**.

$$Y = K_1 + K_2 lnV$$ **Equation 6-2**

Where:

- K1 = -36.38
- K2 = 2.56

- V = I4/3t
- I = radiant heat intensity (W/m2)
- t = time (seconds)

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

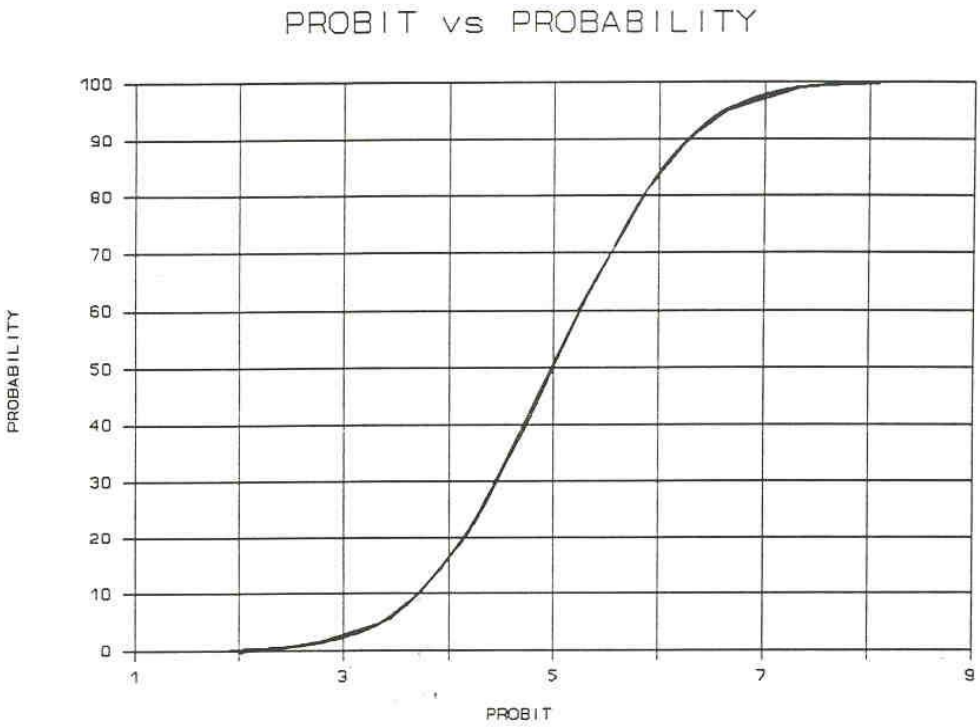


Figure 6-1: Probit vs Probability

Before calculating the radiant heat experienced at the site boundary it's necessary to identify any mitigating circumstances with respect to the radiant heat experienced. The sprinkler system operates by discharging a 'wall' of water around the fire with the aim of suppressing the preventing propagation to adjacent areas. Water is a very effective method for attenuating radiant heat and thus the activation of the sprinklers will actually reduce the radiant heat experienced outside of the sprinklers. However, to ascertain such an effect in this scenario requires complex modelling and extensive literature review which is outside of the scope of this report; hence, the failure rate of sprinkler systems, which is 3.53 x 10^{-3}. has been taken to consider the impact of sprinkler protection on the initiating fire frequency.

The distance from the fire seat to the site boundary is 14 m which when substituted into the spreadsheet calculator results in a radiant heat flux experience at the boundary of 8.0 kW/m^2. Exposure time is taken to be 30 seconds which is considered conservative as personnel in the area would feel the intensity of the flame and would be able to evacuate the area to an area of lower radiant heat within 30 seconds.

Substituting these values into the Probit equation results in a Probit value of 100%. When read from the graph shown in **Figure 6-1** the probability of fatality is 0%. Therefore, the fatality risk at the site boundary becomes 1x10^{-3} x 1 x 3.53 x 10^{-3} = 3.53 x10^{-6} p.a., or 3.53 per million per year (pmpy).

6.2 Full Warehouse Fire Frequency and Risk Assessment

For the same incident to occur within the JN warehouse, it is necessary for the fire to escape the containment of the fire rated enclosure. It has been conservatively assumed this may occur 50% of the time. Adding in the failure of the fire wall results in the fault tree shown in **Figure 6-2**.

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 $1.77x10^{-6}$ x 1 = $1.77x10^{-6}$ chances of fatality per year or 1.77 chances of a fatality in a million per year (pmpy) from a JN warehouse fire.

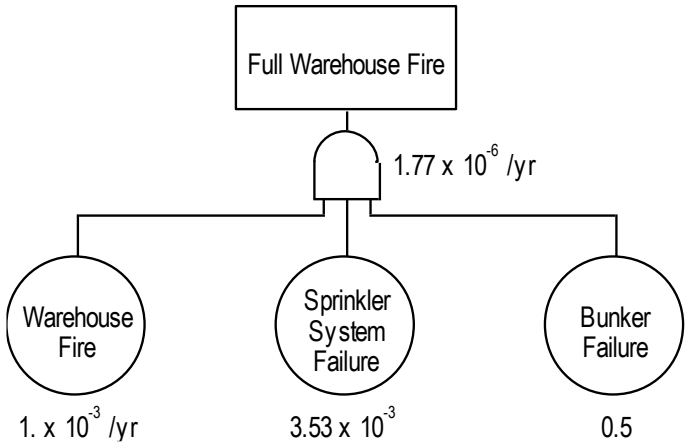


Figure 6-2: JN Full Warehouse Fire Fault Tree

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 $3.53x10^{-6}$ 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 $3.53x10^{-6}$ x 1 = 1.77 chances pmpy.

6.4 LPG Release and ignition and jet fire

For a jet fire to occur, it is necessary for several of the layers of protection to fail such that a high-pressure LPG release is present prior to ignition and jet fire. A review of the safety systems at the sites indicates the following items must fail for a jet fire to occur:

- Rupture of the hose.
- Failure of the excess flow valve.
- Failure of the non-return valve.
- Failure of the emergency stop button to activate the isolation valves.
- Failure of the isolation valves.

Failure rate information for each component has been taken from **Appendix C** and is summarised in **Table 6-1**.

Table 6-1: Failure Rate Data

Component	PFD
Hose	$1.04x10^{-5}$ (Frequency)
Excess flow valve	$6.5x10^{-3}$
Non-return valve	$6.5x10^{-3}$
Emergency Stop	$2.71x10^{-5}$
Isolation Valves	$5x10^{-3}$

In addition to the components of the safety system to fail, it is necessary for the operator to fail to initiate an emergency stop and the release needs to ignite. HEART human error probabilities (Ref. [18]) and Human Factors in QRA (Ref. [19]) provide failure rates of operators for tasks similar to that required by an operator to initiate an emergency stop. These are;

- Routine, highly-practised, rapid task involving relatively low level of skill – 0.02;
- Restore or shift a system to original or new state following procedures, with some checking – 0.003; and
- A more complex task, less time variable, some care necessary – 0.01.

Based on a review of these documents a value toward the more conservative end of 0.01 has been selected for use in this assessment.

Ignition probabilities were sourced from Lees - Loss Prevention in the Process Industries (Ref. [16]) which provides ignition probabilities based on the number of ignition sources at the site. The site contains very few ignition sources; hence, from Lees, a conservative probability of ignition is estimated as 0.2.

The PFD for each piece of equipment, operation failure and ignition were input into a fault tree to determine the overall probability of a failure resulting in a jet fire. The fault tree is shown in **Figure 6-3**. The analysis indicates a jet fire will occur with a frequency of $4.04x10^{-10}$ chances per annum (p.a.). The very low frequency indicates that there are many layers of protection at the site, minimising the potential for incident.

It is noted that for conservatism, the automatic Isolation provided by the plastic air lines, operating the Isolation valves at the site, have not been included in this assessment. This would provide further reduction to the already low incident frequency.

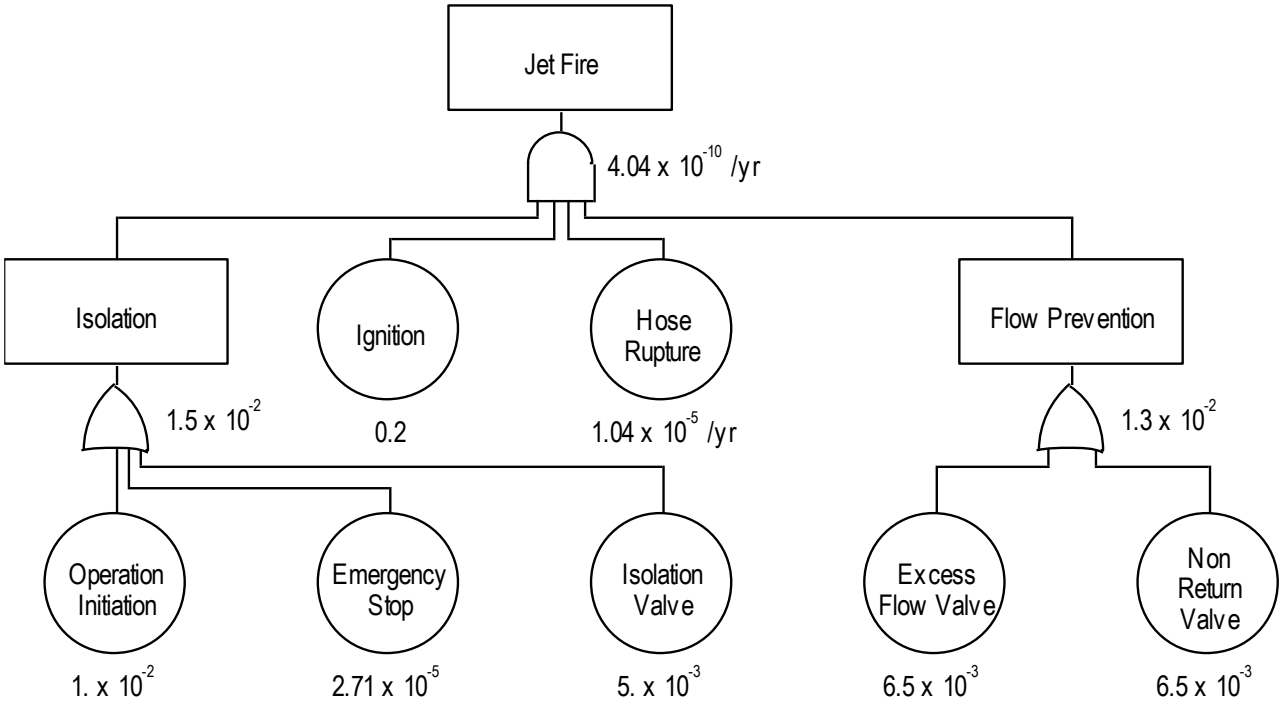


Figure 6-3: Jet Fire Frequency

6.5 LPG Unloading Incident, Hose Rupture, LPG Release, Ignition and Jet Fire and Impact on LPG Delivery Tanker and Boiling Liquid Expanding Vapour Explosion (BLEVE)

The initiating event for a tanker BLEVE is an incident involving a jet fire impinging on the delivery tanker; hence, for conservatism, a tanker BLEVE event frequency of 4.04×10^{-10} chances per annum (p.a.) has been selected. This is conservative as it does not take into account fire brigade intervention which may prevent the event from escalating; hence, lowering the event frequency.

6.6 LPG Unloading Incident, Hose Rupture, LPG Release, Ignition and Jet Fire and Impact on LPG Tank and BLEVE

The initiating event for a tank BLEVE is an incident involving a jet fire impinging on the delivery tanker; hence, for conservatism, a tank BLEVE event frequency of 4.04×10^{-10} chances per annum (p.a.) has been selected. This is conservative as it does not take into account fire brigade intervention which may prevent the event from escalating; hence, lowering the event frequency.

6.7 Total Fatality Risk

Provided in **Table 6-2** is a summary of the incidents which may result in a fatality at the site boundary. It is not credible for these incidents to occur in normal operation simultaneously and have been broken down into their subject areas / incidents.

Table 6-2: Total Fatality Risk

Incident	Fatality Risk
JN Sprinkler Controlled	
JN Sensitivity Case Fire	3.53×10^{-6}

Incident	Fatality Risk
JN Full Warehouse Scenarios	
JN Full Warehouse Fire	$1.77x10^{-6}$
JN Full Warehouse Fire Smoke Emission	$1.77x10^{-6}$
Total	*$3.53x10^{-6}$*
JN LPG Incidents	
JN Tank Jet fire	$4.04x10^{-10}$
JN Tanker BLEVE	$4.04x10^{-10}$
JN Tank BLEVE	$4.04x10^{-10}$
Total	*$1.32x10^{-9}$*

6.8 Comparison Against Risk Criteria

The NSW Department of Planning and Environment has issued a guideline on the acceptable risk criteria (Ref. [2]). The acceptable risk criteria published in the guideline relates to injury, fatality and property damage. The values in the guideline present the maximum levels of risk that are permissible at the land use under assessment. The adjacent land use would be classified as an industrial site as it is restricted access and only industrial operations are permitted to occur in this area.

For industrial facilities, the maximum permissible fatality risk is 50 pmpy. The absolute worst-case incident would be a full warehouse fire within the JN building resulting in a fatality risk at the southern boundary of 3.53 pmpy.

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.

6.9 Cumulative Assessment

A review of the surrounding area indicates there are two warehouses (JR & JN) which may contain DGs; however, it is unlikely that they would both be subject to an incident resulting in both warehouses being on fire while simultaneously having the sprinkler systems fail. Therefore, the potential for cumulative incidents to occur is not considered credible and have not been assessed further.

7.0 Transport

7.1 Assessment Since PHA

An initial transport assessment was conducted within the PHA to determine whether the SEPP 33 limits for transport were exceeded. The findings of the original assessment indicated that the transport limits within SEPP 33 would not be exceeded; hence, the development would be acceptable in terms of transporting of DGs to and from the site.

A review of the updated DG information indicates the transport movements have not altered substantially nor the loads of DGs which would be transported. Therefore, it is considered that the findings of the existing assessment would apply to the FHA. Subsequently, the findings of the original PHA have been reiterated below:

"*A significantly large number of small volume transportations of dangerous goods occur per week, as is expected of a large retail distribution centre servicing up to 266 retail stores per day. Whilst a significant number of transport events occur exceeding the SEPP33 cumulative annual and peak weekly movements, the quantity of dangerous goods carried on these movements is insignificant compared with the potential volume, being the product of threshold vehicle movements and minimum dangerous goods volumes per load.*

In most cases (Class 2.1 (aerosols), 3PGII, 5 and 8), the total cumulative volumes transported is less than 3% of the SEPP33 amount below allowable threshold levels. The exception to this is Class 4.1, where small retail items such as shoe polish and deodorant sticks, which are packaged in a primary container, then packaged in an outer carton, then a further secondary carton, then shrink wrapped in sturdy plastic packaging. These products are considered to be insignificant risks during transport.

It is recommended that this is not a significant risk, as the results of the SEPP 33 (Ref. [1]*) Transportation Threshold screening test indicates."*

8.0 Conclusion and Recommendations

8.1 Conclusions

A hazard identification table was developed for the 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 worst-case incident in terms of fatality risk would be an JN full warehouse fire with a fatality risk of 3.53 chances per million per year (pmpy) at the site boundary, with lesser risk at further distances from the boundary. HIPAP No. 4 (Ref. [2]) publishes acceptable risk criteria at the site boundary of 50 pmpy (for industrial sites). Therefore, the probability of a fatality from a full warehouse fire at the site boundary is within the acceptable risk criteria.

In addition, no incidents were identified to result in offsite impact which could propagate incidents into adjacent sites (i.e. the 23 kW/m^2 contours did not impact offsite). Therefore, the risk of incident propagation would be below the acceptable criteria.

The two assessed warehouses, JN & JR, were the only contributors to the risk profile of the site; hence, cumulative risk was not a considered at this stage. Notwithstanding this, the cumulative risk of all incidents would be 10.6 pmpy assuming they could overlap which would still be below the acceptable criteria of 50 pmpy. Therefore, the development of the JN & JR warehouses do not increase the cumulative risk of the site to an unacceptable level.

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

8.2 Recommendations

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

- Multiple spill kits be provided around the DG storage areas to ensure spills can be cleaned up immediately following identification.
- The LPG tanks shall be protected from impacts by bollards, railings or similar physical barriers.

9.0 References

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Appendix A

Hazard Identification Table

A1. Hazard Identification Table

ID	Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
1	JN Warehouse	• Dropped pallet • Damaged packaging (receipt or during storage) • Deterioration of packaging	• Release of Class 1.4s, 3, 4.1, 5.1, and 8s to the environment.	• Small retail sized packages (< 20 L). • 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. [7])
2		• 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 • Ignition of Class 1.4s materials	• Small retail sized packages (< 20 L). • Inspection of packages upon delivery to the site. • Control of ignition sources according to AS/NZS 60079.14:2017 (Ref. [10]). • 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. [7]).
3		• Failure of fire protection systems.	• Uncontrolled fire spreading throughout JN warehouse. • Potential toxic bi-products of combustion released from warehouse.	• DGs contained within DG bunker minimises potential for high risk products to escalate into main warehouse area. • Separation distances to site boundaries.

ID	Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
4	Sprinkler activation	• Fire activates SMSS resulting in fire water release and potential contaminated fire water offsite.	• Environmental impact to surrounding areas (e.g. stormwater drainage).	• Dangerous Goods Stores are bunded to contain in excess of the maximum required fire water, per AS/NZS 3833:2007 (Ref. [7]) • Site drainage to comply with the Best Practice Guide for Potentially Contaminated Water Retention and Treatment Systems (Ref. [11]).
5	Sprinkler activation	• Fire activates SMSS resulting in fire water release and potential contaminated fire water offsite.	• Environmental impact to surrounding areas (e.g. stormwater drainage).	• Dangerous Goods Stores are bunded to contain in excess of the maximum required fire water, per AS/NZS 3833:2007 (Ref. [7]). • Site drainage to comply with the Best Practice Guide for Potentially Contaminated Water Retention and Treatment Systems (Ref. [11]).
6	LPG Tanks	• Releases from pipework due to corrosion, flange leaks, hose/pump leaks, weld failure, operator error, maintenance error, mechanical damage (e.g. tanker impact on fill point) etc. • Overfilling of tank due to operator error (incorrect tank reading). • Overfilling of tanker due to equipment fault or procedures not followed	• Minor leak (5 mm hole) • Major leak (50 mm hole) • If ignition then: ○ Flash fire, jet fire, pool fire, VCE or BLEVE (tanker), possible explosion if enters drains, and potentially hazardous heat radiation, direct fire involvement, and/or overpressure/ projectiles. ○ Potential fire spreading to adjacent sites.	• LPG facilities to be designed to comply with AS/NZS 1596:2014 (Ref. [14]) and will be installed by an experienced LPG facility supply company. • Tank and associated pipework/fitting will be pressure tested in accordance with the requirements of the pressure vessels code • Ignition source control including earthing to prevent static sparks. • Hoses tested annually as per AS/NZS 1596:2014 and the ADG (Ref. [13]). • Excess flow valves installed in pipework. • Valves to fill point closed until air connected to truck.

ID	Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
		(e.g. leaving operation unattended). • Hose failure or coupling failure or coupling not properly engaged during transfers due to mechanical damage or undetected wear and tear or operator error. • Drive away with hoses attached.		• Valves shut on breaking of air connection to truck. • All staff including contract drivers will be trained in the specific transfer operations at the site. • Tanker fitted with Emergency Shut Down. • Excess flow valve on tanker. • Manual shutdown valve. • Non-return valve on delivery line. • Emergency Shutdown on delivery line. • Manual valve on delivery line. • Overfill protection device. • Fusible link on tanker and vessel.
7	LPG Cylinders	• Damage to cylinders, valves, pipework, etc	• Minor leaks which may result in gas accumulation, ignition, and flash fire or explosions.	• Minor storage under AS 4332-2004 (Ref. [20]) • Relatively low volume of gas prevents accumulation to levels which may have offsite impacts. • Adequately ventilated. • Hazardous area classification per AS/NZS 60079.10.1:2009 (Ref. [12]). • Electrical equipment controlled per AS/NZS 60079.14:2017 (Ref. [10]).

Appendix B

Consequence Analysis

B1. Incidents Assessed in Detailed Consequence Analysis

The following incidents are assessed for consequence impacts.

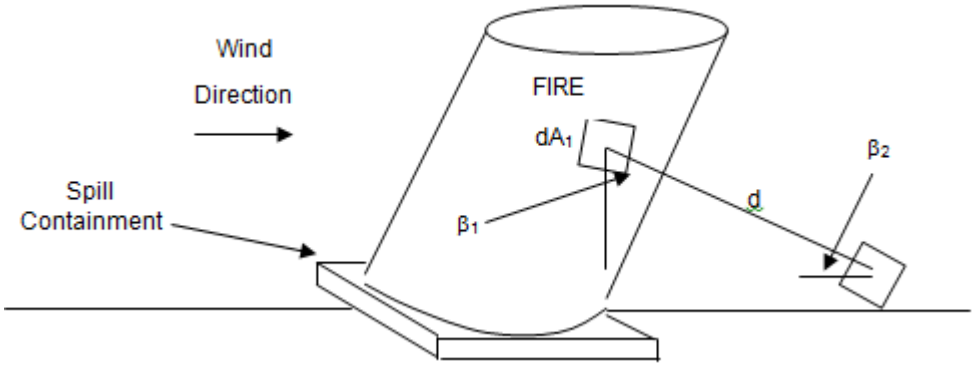
- Flammable material spill, ignition and racking fire.
- JN LPG release (from aerosol), ignition and racking fire.
- JN Flammable Gas Release, Delayed Ignition and Flash Fire or Explosion.
- Full warehouse fire and radiant heat.
- Full warehouse fire and toxic smoke emission.
- LPG unloading incident, hose rupture, LPG release, ignition and jet fire.
- LPG unloading incident, hose rupture, LPG release, ignition and jet fire and impact on LPG delivery tanker and Boiling Liquid Expanding Vapour Explosion (BLEVE).
- LPG unloading incident, hose rupture, LPG release, ignition and jet fire and impact on LPG tank and BLEVE.
- Fire in ErgoPal or High Bay and propagation between storage areas.

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. [17]).

$$Q = EF\tau$$ **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. [17]). The formula can be shown as:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The sum is taken of the View Factors in **Equation B-3**. Actually the sum is taken without the 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. [16] & Ref. [17]) 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**.

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

Where;

E_{max} = 140

S = 0.12

E_s = 20

D = pool diameter

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

The flame height is estimated using the Thomas Correlation (Ref. [17]) which is shown in **Equation B-6**.

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

Where;

d_p = pool diameter (m)

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

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

g = 9.81 m/s^2

The transmissivity is estimated using **Equation B-7** (Ref. [17]).

$$\tau = 1.006 - 0.01171(\log_{10} X(H_2O) - 0.02368(\log_{10} X(H_2O))^2 - 0.03188(\log_{10} X(CO_2) + 0.001164(\log_{10} X(CO_2))^2$$ **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^{o}C S_{mm} = 23.756)
- T = Atmospheric temperature (K)

B3. Jet Fire Modelling

The flow rate of a liquid from a hole may be calculated from **Equation B-8** (Ref. [21]).

$$m = C_d A (2\rho \Delta P)^{0.5}$$ **Equation B-8**

Where:

- m = Mass flow rate (kg/s)
- C_d = Discharge coefficient (0.6 for irregular holes)
- A = area of the orifice (m^2)
- ρ = Density of the material (kg/m^3)
- ΔP = Pressure difference across the orifice (Pa).

The flame length and width, as a result of a release, can be estimated from the empirical formula published by Lees (Ref. [16]). The equations for the length and width are shown in **Equation B-9** and **Equation B-10**.

$$L = 9.1{G_L}^{0.5}$$ **Equation B-9**

Where:

- L = Length (m)
- G_L = Mass flow rate (kg/s)

$$W = 0.25L$$ **Equation B-10**

Where:

- W = Width (m)
- L = Length (m)

B4. BLEVE Modelling

The diameter of the fireball and the duration of the BLEVE may be estimated using the following formulae (Ref. [21]):

$$D = 6.48m^{0.325}$$ **Equation B-11**

$$t = 0.852m^{0.25}$$ **Equation B-12**

Where:

- D = diameter of the fire ball (m)
- m = mass of LPG in the tank (kg)
- t = duration of the BLEVE (seconds)

B5. Radiant Heat Physical Impacts

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

Heat Radiation (kW/m^2)	Impact
	• Causes the temperature of wood to rise to a point where it can be ignited by a naked flame after long exposure • Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure
4.7	• Will cause pain in 15-20 seconds and injury after 30 seconds exposure (at least second degree burns will occur)
2.1	• Minimum to cause pain after 1 minute

B6. 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 $kg/m^2.s$ (this value encompasses a large range of flammable liquid burning rates and is considered conservative due to the nature of the flammable liquids stored, Ref. [16])

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
3.0	14.9	27.5

B7.JN 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/m^2.s (the burning rate for LPG, Ref. [16]).

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-10**.

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-10** were input in to the SSC with the results for each scenario shown in **Appendix Table B-11**.

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
3.0	16.9	31.5

B8. Full Warehouse Fire

To estimate the impact of a full warehouse the area of storage has been used to estimate a diameter of the fire. The DGs are located within the JN warehouse; hence, the storage areas within this facility have been modelled. While it is considered unlikely for a fire to propagate from the SGS into the main warehouse due to the fire walls, this could potentially occur. The area where product is stored within the warehouse has an approximate area of 21,000 m^2. The equivalent diameter for the fire can be calculated by:

$$D = \sqrt{\frac{4 \times 21{,}000}{\pi}} = 163.5\, m$$

Provided in **Appendix Table B-6** is a summary of the DGs which may be stored across JR or JN, the applicable burning rates based on commodities stored and the contribution of each product to the total burning rate. It is considered this methodology is highly conservative as not all products are stored within the one warehouse and that other non-DG products are contained within the warehouse which would result in the average burning rate trending downward.

Appendix Table B-6: Estimation of Average Burning Rate

Class	Quantity (kg)	% of Total Quantity	Burning Rate (kg/m^2.s)	Burning Rate Based on %
2.1	40,000	17%	0.099	0.0167
3	91,500	39%	0.067	0.0259
4.1	5,150	2%	0.022	0.0005
5.1	2,800	1%	0.022	0.0003
8	97,000	41%	0.022	0.0090
Total	**236,450**	**100**	-	**0.0524**

The following information was input into the models;

- Equivalent fire diameter – 163.5 m
- Burning rate – 0.0524 kg/m^2.s
- Fire wall height: no fire wall

The models provided the following information for the warehouse fire;

- SEP – 20 kW/m^2
- Flame Height - 107 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	38.0
4.7	85.0
3.0	115.0

* Research conducted in relation to large fires (Ref. [17]) 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. [16]) indicates that fires will generate a SEP within a range of between 20 kW/m^2 for larger fires and 130 kW/m^2 for smaller fires. Hence, a full warehouse fire would be of significant dimensions, generating large quantities of black smoke, shielding the flames at the fire surface. Hence, for the analysis of a full warehouse fire in this study, an SEP value of 20 kW/m^2 has been used.

B9. 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.

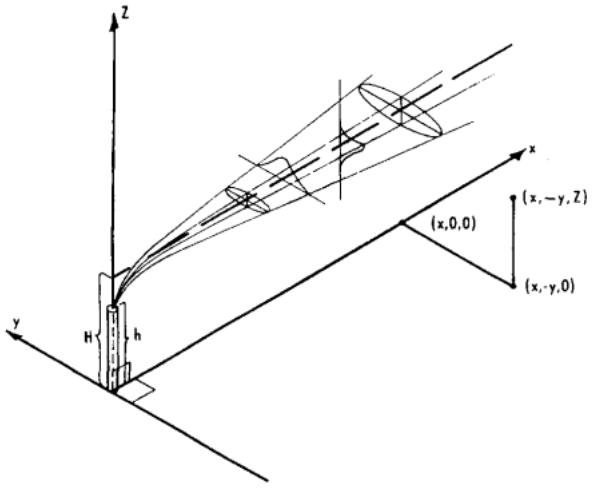
The atmospheric conditions are classified as Pasquill Guifford's Stability categories which are summarised in **Appendix Table B-8** (Ref. [17]).

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 ≥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. [17]).



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

Effects has been used to model a smoke plume arising from the warehouse. 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. As noted, the more onerous conditions occur during stable air conditions which allow far reaching effects with reduced

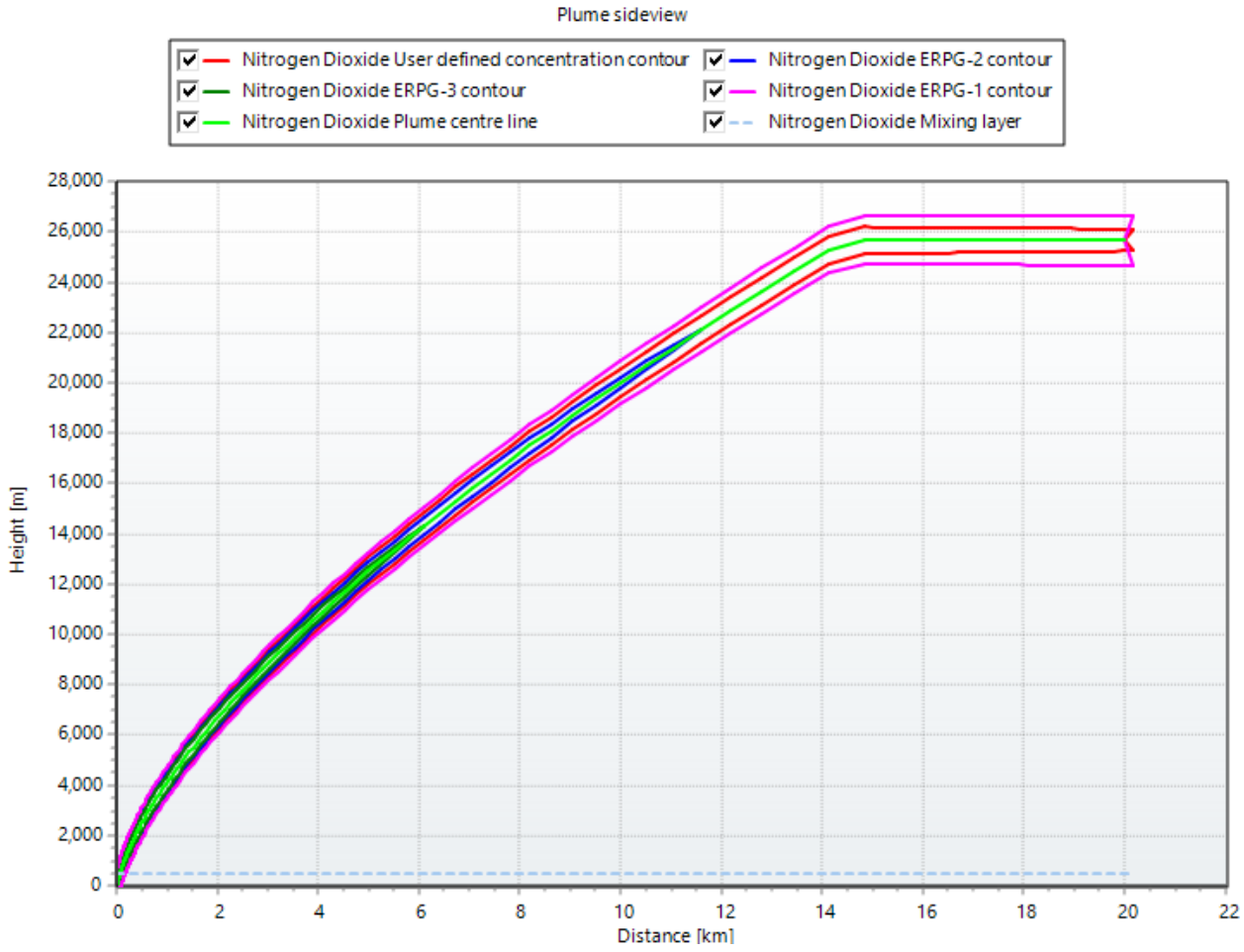
dispersion due to low air velocities and vertical mixing. D3 conditions have been used to model the plume dispersion.

The warehouse was modelled based upon solid product stored within the warehouse and the default settings for solid product within the warehouse was adopted which is based upon typical warehouse configurations within the Netherlands which would be expected to be similar to those expected in Australia. The model then generates the bi-products which may be released from the combustion of the mass which are then individually modelled for each component. Provided below is a summary of the pollutant release rates generated by the model.

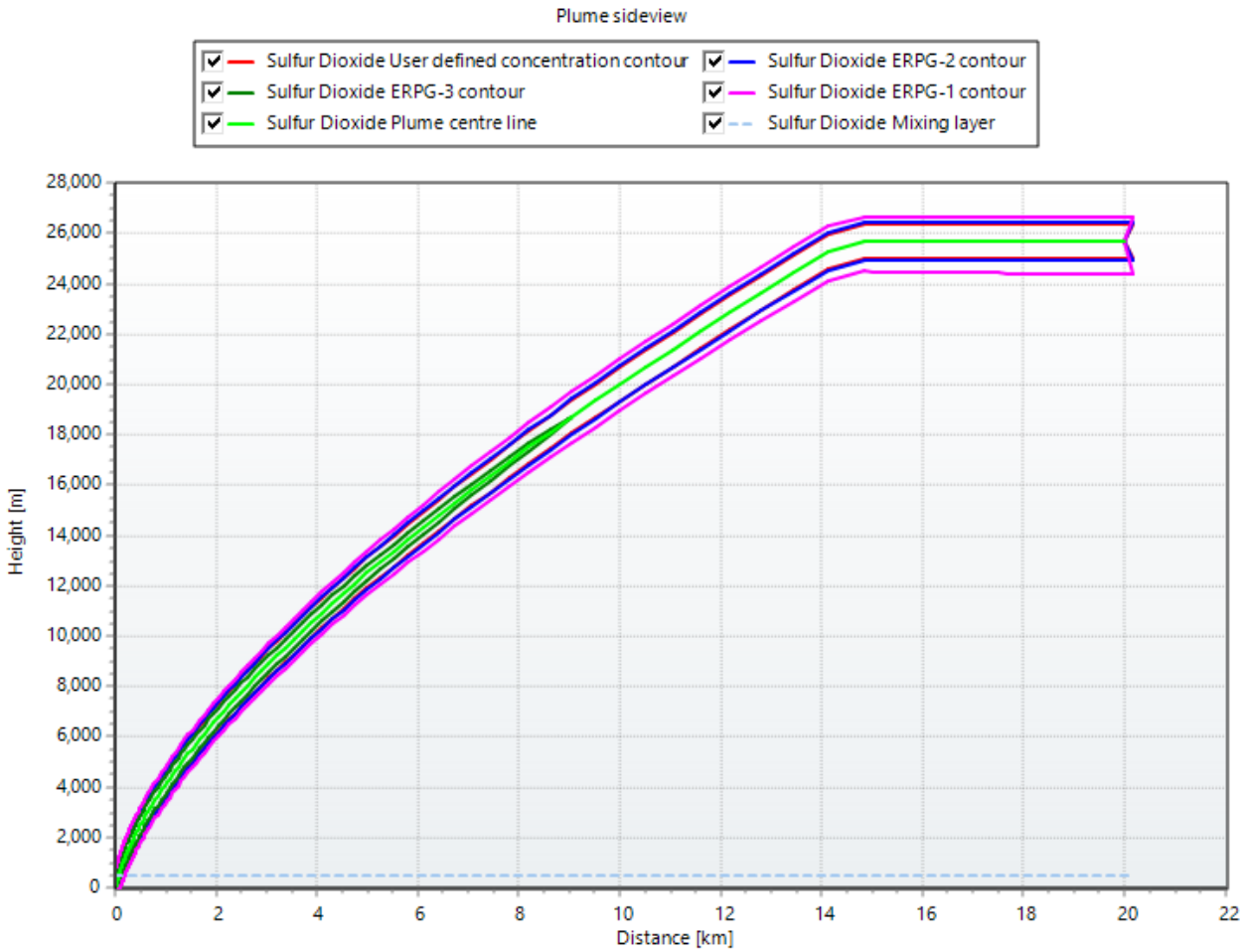
Appendix Figure B-3: Pollutant Release Rates

Material	Release Rate (kg/s)
Nitrogen Dioxide	289.02
Sulphur Dioxide	500.59
Hydrogen Chloride	253.96
Soot (Carbon)	574.55

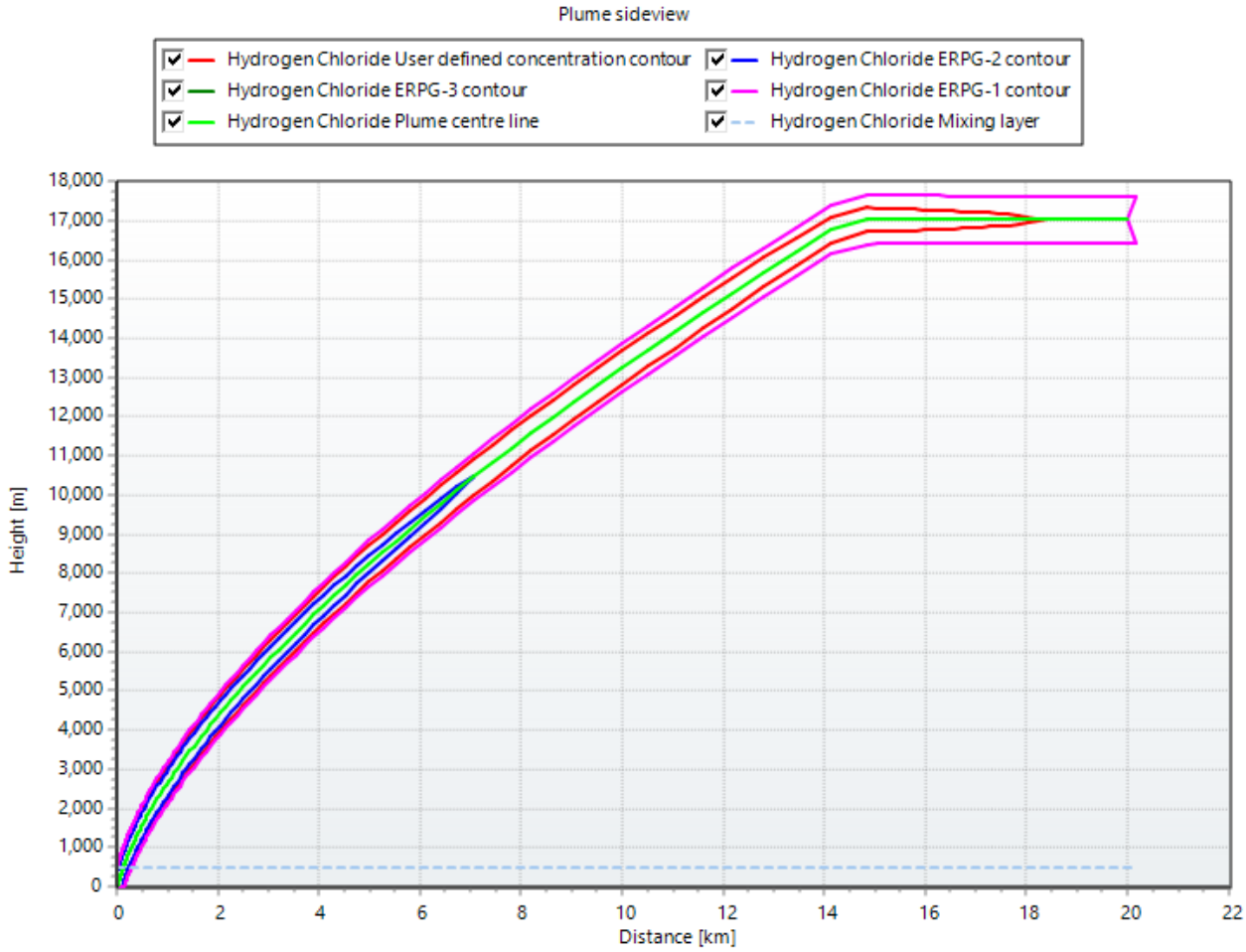
Each of the pollutants were modelled to determine their plume shape and determine whether the plume would puncture through an inversion layer and what the downwind dispersion would look like as the plume cools and settles in the atmosphere. The plume shapes are shown in the following figures.



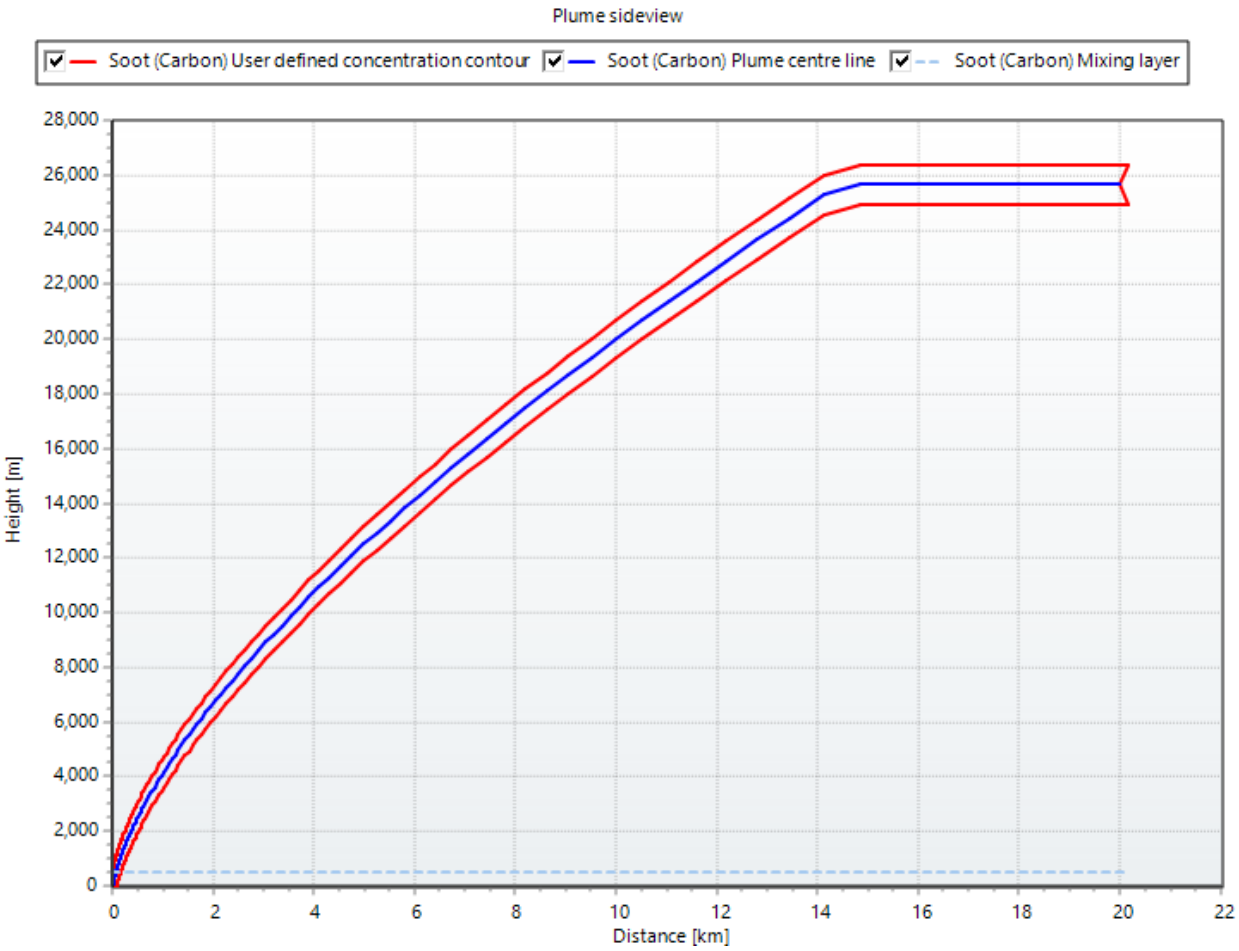
Appendix Figure B-4: Nitrogen Dioxide Downwind Plume Dispersion



Appendix Figure B-5: Sulphur Dioxide Downwind Plume Dispersion



Appendix Figure B-6: Hydrogen Chloride Downwind Plume Dispersion



Appendix Figure B-7: Soot (Carbon) Downwind Plume Dispersion

B10. LPG Unloading Incident, Hose Rupture, LPG Release, Ignition and Jet Fire

A hose rupture could occur and ignite which would result in a jet fire. To estimate the dimensions of a jet fire, the flow rate of the liquid from the hose must be estimated. The following data was input into **Equation B-8** to estimate the flow rate through the ruptured hose:

- C_d = Discharge coefficient (0.6 for irregular holes)
- A = 50 mm hose = $\frac{\pi D^2}{4} = \frac{\pi \times 0.050^2}{4} = 0.002\ m^2$
- ρ = 508 kg/m^3
- ΔP = 8.6 bar = 860000 Pa

Substituting the information into **Equation B-8** gives a flow rate of 34.8 kg/s.

$$m = 0.6 \times 0.004 \times (2 \times 508 \times 860000)^{0.5} = 34.8\ \frac{kg}{s}$$

Now, a liquid LPG release would be too fuel dense to ignite as it would be above the LEL so the only portion that could ignite would be the liquid that vapourises upon release. Assuming a flash fraction of 50%, the vapour flow rate from the release would be 0.5 x 34.8 = 17.4 kg/s.

Substituting the mass flow rate of vapour into **Equation B-9** gives a jet fire length of 38 m.

$$L = 9.1 \times 17.4^{0.5} = 38\ m$$

B11. LPG Unloading Incident, Hose Rupture, LPG Release, Ignition and Jet Fire and Impact on LPG Delivery Tanker and BLEVE

In the event of a jet fire and impingement on the delivery tanker there is potential for the LPG in the tanker to boil escalating to a BLEVE if intervention measures fail. It is assumed that impingement will occur at the 30% fill level of the tanker and that the tanker holds a maximum 7,500 L. A BLEVE will only occur once the liquid level falls below the impingement level; hence, the maximum volume of LPG that could be involved in the BLEVE is 2,250 L. As noted, the density of LPG is 508 kg/m3; therefore, the mass of LPG involved in the BLEVE is 1,143 kg.

Inputting the mass into **Equation B-11** and **Equation B-12** yields an impact diameter of 63.9 m and a resonance time of 5 seconds.

$$D = 6.48 \times 1{,}143^{0.325} = 63.9\ m$$

$$t = 0.852 \times 1{,}143^{0.25} = 5\ s$$

B12. LPG unloading Incident, Hose Rupture, LPG Release, Ignition and Jet Fire and Impact on LPG Tank and BLEVE

In the event of a jet fire and impingement on the above ground tank there is potential for the LPG in the tanker to boil escalating to a BLEVE if intervention measures fail. It is assumed that impingement will occur at the 30% fill level of the tank. The tank holds 7,500 L; hence, at the 30% fill level 2,250 L of LPG is involved in the BLEVE. As noted, the density of LPG is 508 kg/m3; therefore, the mass of LPG involved in the BLEVE is 1,143 kg.

Inputting the mass into **Equation B-11** and **Equation B-12** yields an impact diameter of 63.9 m and a resonance time of 5 seconds.

$$D = 6.48 \times 1{,}143^{0.325} = 63.9\ m$$

$$t = 0.852 \times 1{,}143^{0.25} = 5\ s$$

B13. Fire in ErgoPal or High Bay and Propagation Between Storage Areas

There is the potential for a fire to occur within the ErgoPal or the High Bay area which may result in sufficient radiant heat to impact between the storage areas resulting in incident propagation. The two systems have different protection systems in terms of sprinkler design; hence, there are a range of sprinkler activation scenarios which must be assessed. There are identified as follows:

1. In-rack sprinkler control (ErgoPal base case)
2. Activation of primary array of ceiling mounted sprinklers (ErgoPal sensitivity)
3. Activation of primary array of in-rack sprinklers (High Bay base case)
4. Activation of secondary array of in-rack sprinklers (High Bay sensitivity)

The sprinkler spacing has been used to estimate an equivalent diameter for each fire scenario with the results presented in **Appendix Table B-9**.

Appendix Table B-9: Fire Area Equivalent Diameters

Scenario	Equivalent Diameter (m)
ErgoPal Base Case	0.5
ErgoPal Sensitivity	1.9

High Bay Base Case	1
High Bay Sensitivity	1.9

- Burning rate – 0.022 kg/m^2.s (the burning rate of combustible liquids which is considered conservative for the products stored, Ref. [16]).

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-10**.

Appendix Table B-10: Flame Height and SEP for Sprinkler Controlled Fires (ErgoPal & High Bay)

Output	ErgoPal Base Case	ErgoPal Sensitivity	High Bay Base Case	High Bay Sensitivity
Flame Height (m)	1	2.9	1.7	2.9
SEP (kW/m^2)	133.7	115.4	127.0	115.4

The inputs summarised in **Appendix Table B-10** were input into the SSC with the results for each scenario shown in **Appendix Table B-11**.

Appendix Table B-11: Heat Radiation from Sprinkler Controlled Scenarios (ErgoPal & High Bay)

Heat Radiation (kW/m^2)	Distance (m)			
	ErgoPal Base Case	ErgoPal Sensitivity	High Bay Base Case	High Bay Sensitivity
35	0.4	1.6	0.9	1.6
23	0.6	2.2	1.3	2.2
12.6	1.0	3.2	1.9	3.2
4.7	1.8	5.6	3.3	5.6
3.0	2.3	7.1	4.2	7.1

Appendix C

Warehouse Fire Frequency Estimation

C1. Estimation of the Frequency of a Full Warehouse Fire

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

- Health and Safety Executive (HSE) in the United Kingdom [Hymes & Flynn, UKAEA - SRD/HSE R578, 2002] – this document lists the major warehouse fire frequency to be $2.5x10^{-3}$ p.a.;
- Baldwin, Accident Analysis and Prevention (Vol.6) – indicates a serious fire frequency in warehouses to be in the order of $1x10^{-3}$ p.a.;
- Environmental Impact Assessment Report for the Commission of Inquiry into Proposed Manufacturing Plant by WR Grace Australia Ltd., Kurnell, Sydney, October 1987 – indicates a fire frequency of $4.6x10^{-3}$ per warehouse year; and
- VROM 2005, Guidelines for quantitative risk assessment CPR 18E (Purple Book), Publication Series on Dangerous Substances (PGS 3), The Netherlands. – $4x10^{-4}$ p.a.

It is noted that the mix of overseas data and local data (albeit some is dated) correlates to indicate a fire frequency in warehouses to be in the order of $1x10^{-3}$ to $4x10^{-4}$. The data presented in the reports reviewed was for general warehouses, where stringent controls for spill and ignition sources (such as flame and explosion proof fittings, bunding, smoking and naked flame controls, isolation of power supplied on warehouse closure, etc.) were not part of the warehouse hazard controls. Hence, for a DG warehouse, containing specific ignition and fire control systems, it would be expected that a major fire would occur with a lesser frequency than that of general warehouses. Notwithstanding this, to ensure a conservative assessment has been provided within the study, the estimated initiating fire frequency for the JN facility has been estimated as $1x10^{-3}$ p.a. (i.e. the upper end of the range).

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