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Consultants Advice Notice

Project:	JANUS Project	**Ref No.:**	RCE-20100
From:	Renton Parker	**Date:**	6th of October, 2020
		Revision:	0

	Attention	Company	Email
To:	Thomas Stock	Woolworths Limited	tstock@woolworths.com.au

1.0 Introduction

Woolworths Limited (Woolworths) has proposed to develop a new warehousing facility to house products prior to distribution to retail stores. The facility will store a range of household goods which may be classified as Dangerous Goods (DGs). As part of the Modification Application (SSD 7709 MOD 1) a State Environmental Planning Policy No. 33 (SEPP 33) assessment was prepared which required that a Preliminary Hazard Analysis (PHA) in accordance with the amendment proposed to Condition B176 to allow Dangerous Goods to be stored on-site following the appropriate assessments being undertaken with respect to the relevant Policies and Guidelines pertaining to DGs being analysed.

The PHA concluded that the potential for offsite impacts were acceptable; however, due to recent global incidents substantial scrutiny from the community resulted in several comments / objections to the develop in relation to proximity to DGs and general community safety concerns. In addition, the Department of Planning, Industry and Environment (DPIE) has requested additional analysis within the PHA as part of the approval process and to address the community concerns.

In an effort to provide additional support to the Modification Application, Woolworths has requested a 3rd party analysis of the PHA and comments to demonstrate that the facility is safe and acceptable for the proposed land use. Subsequently, Woolworths has engaged Riskcon Engineering Pty Ltd (Riskcon) to conduct and review and assessment in the form of a Consultants Advice Notice (CAN).

2.0 Methodology

The following methodology has been adopted in this assessment:

- The DPIE / Community queries will be reviewed, and a response will be developed to assess the query.
- Where modelling is required to resolve the query, this will be prepared within an Appendix of this CAN.
- Where required, the methodologies and assessment criteria provided in the Hazardous Industry Planning Advisory Paper (HIPAP) No. 4 and No. 6 will be adopted.

3.0 Queries

The queries received have been condensed into essentially four (4) main categories which have been summarized as follows:

- Dangerous Goods Storage Locations and Incident Contours
- Full Warehouse Fire
- Fatality Risk Criteria
- Community Health and Safety with respect to Dangerous Goods Storage

Each of these have been assessed in further detail in the following subsections.

3.1 Dangerous Goods Storage Locations and Incident Contours

The specific requirements of this query are:

Clear plans/diagrams indicating:

a) the location of the subject warehouses in context of the other warehouses within SSD-7709 and other land uses around SSD-7709;

b) the location of all dangerous goods and hazardous chemicals storages (class and maximum quantities) within the site plans of the subject warehouses and verify that this storage arrangement would be able to comply with the relevant Australian Standards; and

c) *consequence areas and risk contours based on plans/diagrams a and b above;*

Each has been assessed further in the following subsections.

3.1.1 Location of Warehouses

Provided in **Figure 3-1** is a markup of the site layout showing the layout of the JANUS warehouses JR and JN.

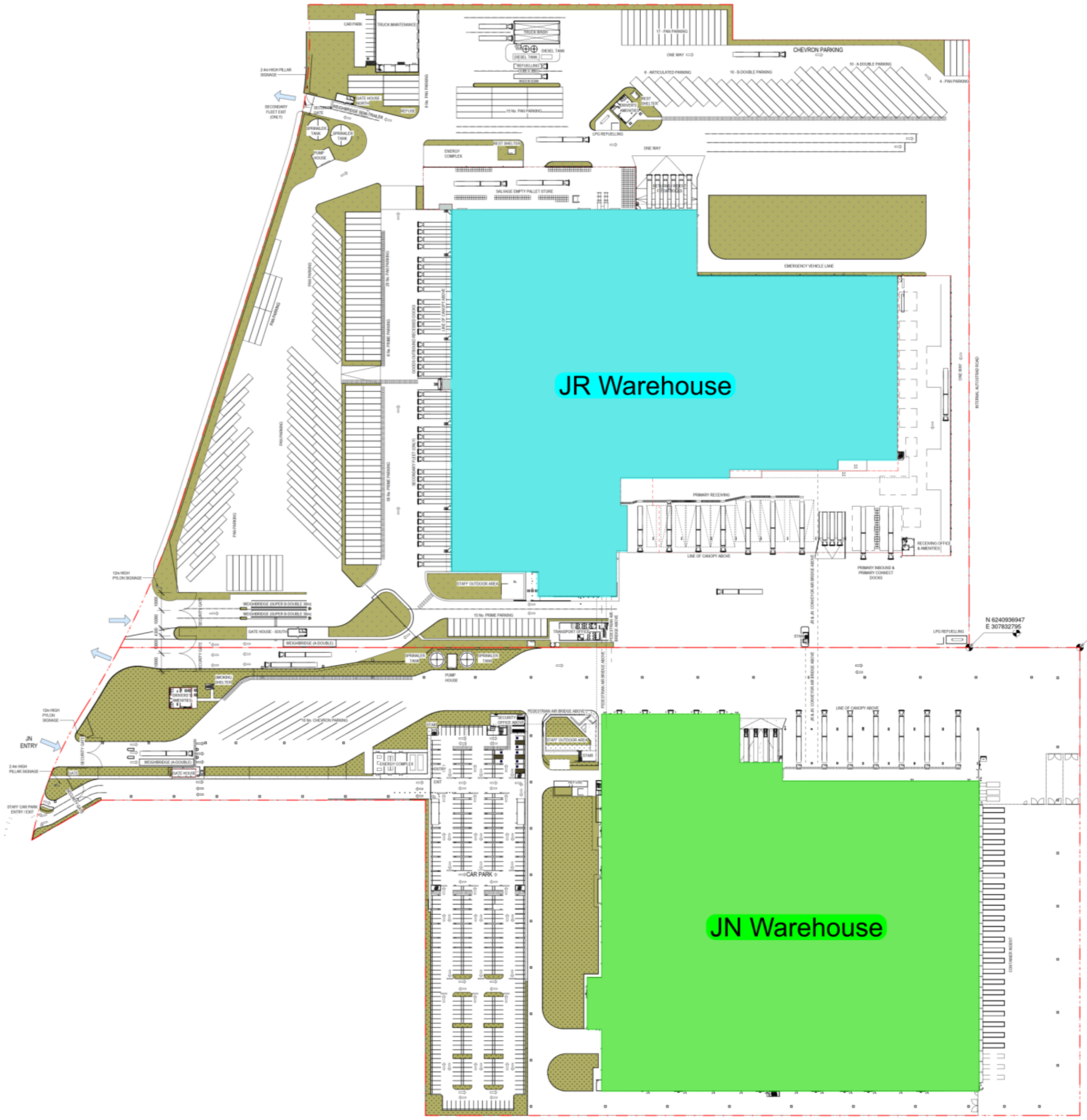


Figure 3-1: Woolworths Warehouse Locations

3.1.2 DG Storage Locations

3.1.2.1 DG Classes

A range of DGs will be stored and handled at the site in terms of product storage and ancillary DGs used as part of site operations. **Table 3-1** summarises the quantities of DGs proposed to be stored at the site.

Table 3-1: Classes and Quantities of DGs Stored and Handled

Location	Class	Description	PG	Quantity (kg)
SGS	1.4s	Explosives (i.e. party poppers)	n/a	200
LPG Tank(s)	2.1	Liquefied Petroleum Gas (LPG) – Bulk	n/a	6,160
External store	2.1	Aerosols (LPG)	n/a	40,000*
SGS	3	Flammable Liquids (i.e. paints)	II	32,700
			III	44,100
	4.1	Flammable solids (i.e. matches)	III	4,200
High Bay Store	5.1	Oxidising Agents (i.e. hair dyes)	III	1,300
High Bay Store	8	Corrosive substances (i.e. cleaners)	II	12,000
			III	33,000
Diesel Tank	C1	Diesel	n/a	60,000

**Net quantity of LPG taken from Mendham Consultants PHA*

3.1.2.2 DG Storage Locations

The classes, quantities, and storage locations shown in **Table 3-1** are shown in **Figure 3-2**.

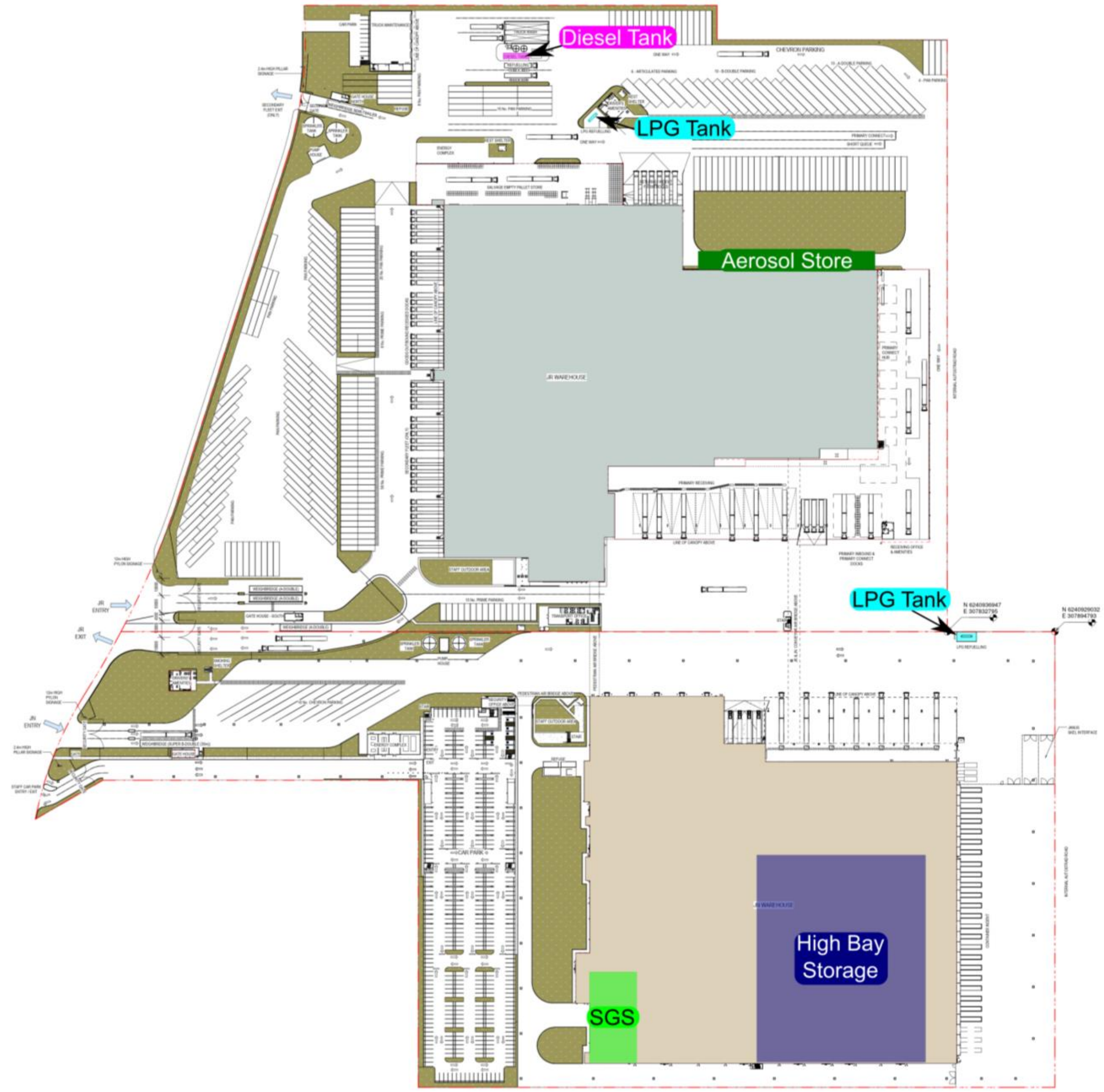


Figure 3-2: Dangerous Goods Storage Locations

3.1.2.3 DG Design

The DG design has not been reviewed; however, the Mendham Consultants PHA refers to the product sizes and facility operations being consistent with a Retail Distribution Centre (RDC) and was assessed based upon AS/NZS 3833:2007. This standard covers the mixed storage of DGs in various configurations including RDC storage. The RDC storage section takes into account the reduced risk posed by the storage and handling of DGs in retail sized products (i.e. <20 L).

The PHA also refers mechanical ventilation and fire walls which exceed the requirements of the RDC section of the standard. Therefore, it would be considered that the design would comply with the standard by virtue of exceeding the minimum requirements.

3.1.3 Consequence Contours

The PHA prepared by Mendham Consultants identified the following incidents as having the potential for offsite impacts:

- Dangerous goods store fire, and
- Aerosol café fire.

Each of these has been discussed further in the following subsections.

3.1.3.1 Special Goods Store (SGS) Fire

The results of the consequence analysis for the SGS fire from the Mendham Consultants have been summarized in **Table 3-2** with the impact contours shown in **Figure 3-3**.

Table 3-2: SGS Fire Radiant Heat Impact Distances

Heat Radiation (kW/m^2)	Distance (m)
4.7	7.0

As can be seen from **Figure 3-3** the SGS fire radiant heat contour at 4.7 kW/m^2 does not impact over the site boundary; hence, a fatality would not occur at the site boundary. Therefore, this incident has not been carried forward for further analysis.

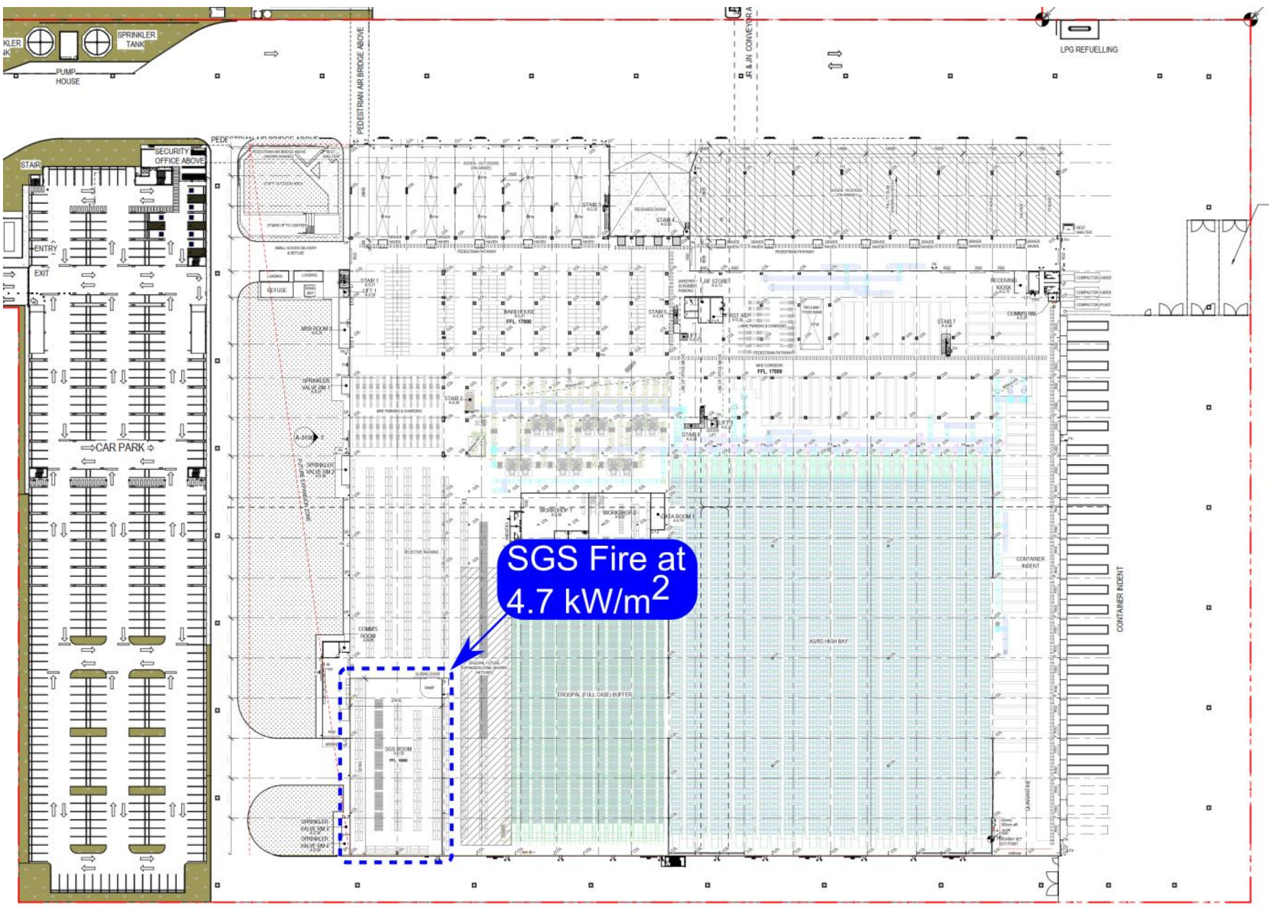


Figure 3-3: SGS Fire Radiant Heat Contours

3.1.3.2 Aerosol Fire

The results of the consequence analysis for the aerosol fire from the Mendham Consultants have been summarized in **Table 3-3** with the impact contours shown in **Figure 3-4**.

Table 3-3: Aerosol Fire Radiant Heat Impact Distances

Heat Radiation (kW/m^2)	Distance (m)
4.7	7.0

As can be seen from **Figure 3-4** the Aerosol fire radiant heat contour at 4.7 kW/m^2 does not impact over the site boundary; hence, a fatality would not occur at the site boundary. Therefore, this incident has not been carried forward for further analysis.

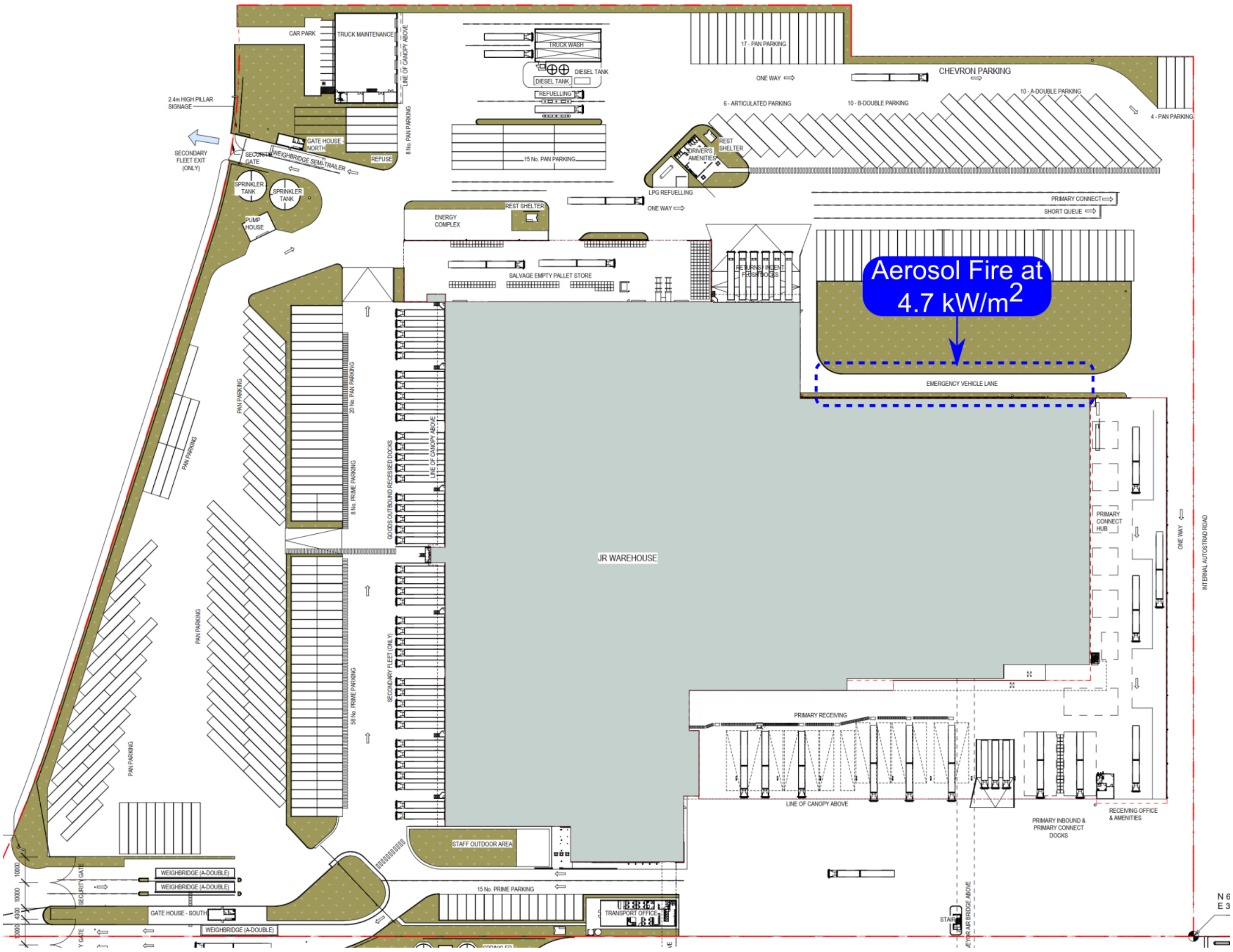


Figure 3-4: Aerosol Fire Radiant Heat Impact Contours

3.2 Full Warehouse Fire

It was raised that a full warehouse fire could occur within the warehouse spaces which may arise from the storage and handling of DGs within the facility in the event that the sprinkler systems fail. While unlikely, this is a key concern as there are well documented instances of sprinkler system failures which result in uncontrolled escalation of a fire throughout the warehouse. This may result in substantial radiant heat impact contours in addition to the potential for formation of toxic smoke dispersion downwind from the fire due to the toxic bi-products of combustion.

A detailed analysis of a full warehouse fire and smoke emission has been prepared in **Appendix A**.

3.2.1 Full Warehouse Fire Radiant Heat

A detailed analysis of the full warehouse fire has been prepared in **Appendix A** with the results of summarised in **Table 3-4** with the impact contours shown in **Figure 3-5**. It is noted the radiant heat contours shown are based upon where the actual storage of material occurs.

Table 3-4: Full Warehouse Fire Radiant Heat Impacts

Heat Radiation (kW/m^2)	Distance (m)
35	Maximum heat flux is 20*
23	Maximum heat flux is 20*
12.6	40.3
4.7	90.3

As can be seen from **Figure 3-5** that the contours at 4.7 kW/m^2 impact over the site boundary; hence, this incident has been carried forward for further analysis. The 23 kW/m^2 contour is not observed in this scenario due to the thick smoke generated based upon the fire size which obscures / blocks the radiant heat emitted from the flame surface.

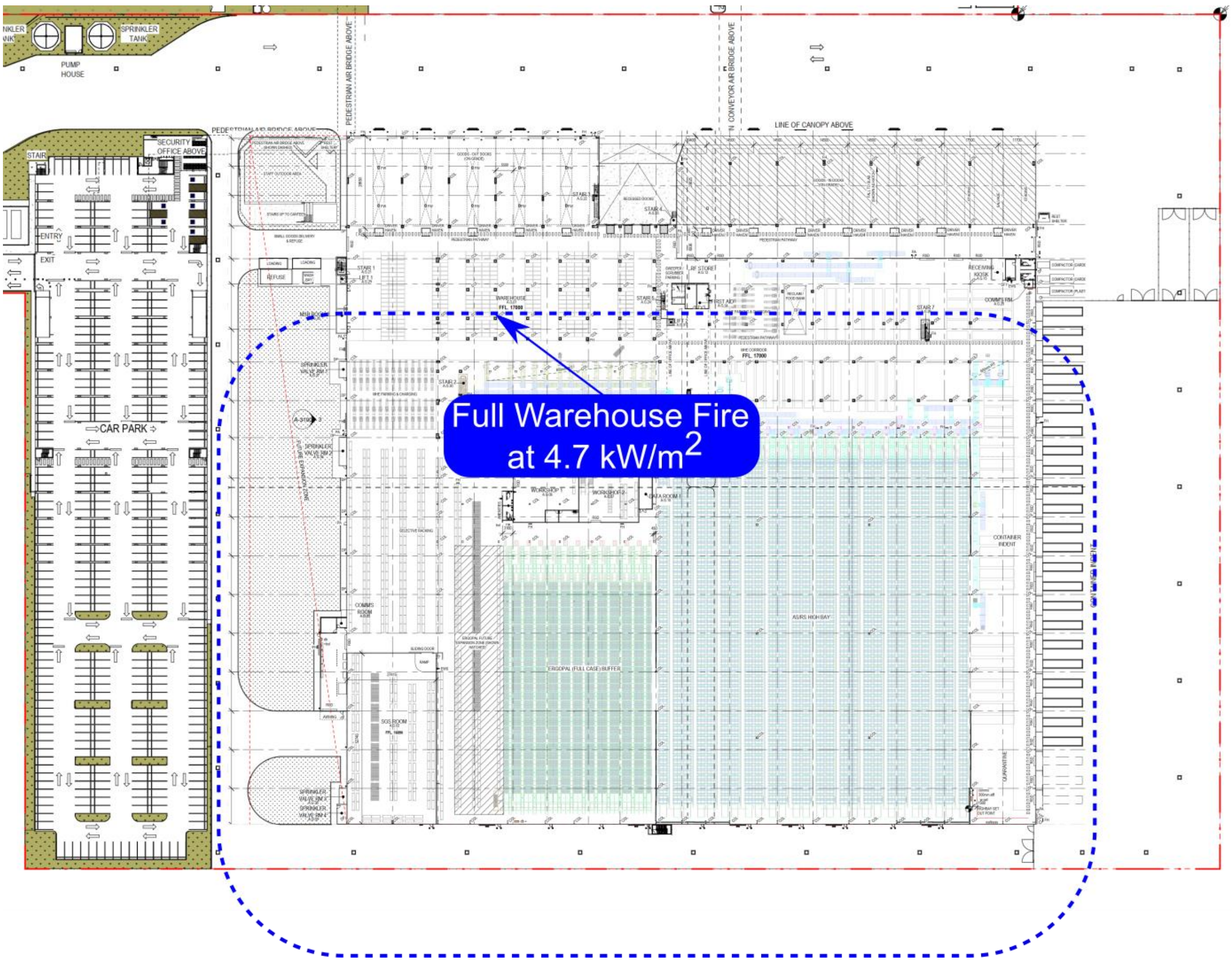


Figure 3-5: Full Warehouse Fire Radiant Heat Emission (measured from storage area)

It is noted that only a full warehouse fire for the JN building has been analysed as it contains a substantial storage of flammable DGs within the facility which, albeit unlikely, may result in incident propagation within the storage should the sprinklers fail resulting in a full warehouse fire. The aerosol adjacent to JR building is not considered to pose such a risk for incident propagation into the warehouse.

3.2.2 Full Warehouse Fire and Smoke Emission

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

Provided in **Table 3-5** is a summary of several toxic products of combustion which may be present in the smoke plume and their acceptable concentration of exposure for the Acute Exposure Guideline Levels (AEGL). These levels provide guidance on exposure concentrations for general populations, including susceptible populations over a range of exposure times to assist in the assessment of releases which may result in a toxic exposure.

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

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

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

Table 3-5: Concentrations of Toxic Products of Combustion from a Smoke Plume

Pollutant	Fatality or Serious Injury (ppm)	Injury (ppm)	Concentration (ppm)
Carbon monoxide	600	150	27.9
Nitric Dioxide	25	15	26.1
Hydrogen cyanide	21	10	29.0
Hydrogen chloride	210	43	21.5
Sulphur dioxide	30	0.75	12.2

The analysis indicates all quantities except nitric oxide and hydrogen cyanide are below the AEGL-3 values. It is noted the analysis conducted is based on the primary toxic bi-product (carbon monoxide) which forms at rates higher than other toxic bi-products. Therefore, application of this result to other components is considered conservative. As these concentrations are taken at the point of release, they will disperse downwind resulting in substantially lower concentrations at residential areas and would be at a plume height of several hundred metres above ground.

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

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

3.3 Fatality Risk Criteria

The following incidents have been carried forward for frequency analysis based upon a review of the Mendham Consultants PHA and the additional incidents required by the DPIE:

- Full Warehouse Fire and Radiant Heat
- Full Warehouse Fire and Smoke Emissions.

Each has been assessed further in the following subsections.

3.3.1 Full Warehouse Fire and Radiant Heat

The initiating event frequency for a full warehouse fire is taken to be $1x10^{-3}$ p.a from the analysis conducted in **Appendix B.**

It is noted that the site is fitted with multiple automatic sprinkler systems that will initiate on fire detection, controlling the fire and preventing the fire growth to a full warehouse fire. The Centre for Chemical Process Safety (CCPS) provides failure rate data for water fire protection systems including all components (pump, distribution system, nozzles, seals, piping, controls and base plate) of 9.66 per 10^6 hours (Ref. [1]). The hourly failure rate is converted to failures per annum by:

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

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

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

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

Where:

λ_{du} = dangerous undetected failures of a component

t = 1/number of test intervals per annum

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

The DGs are stored within a fire rated bunker, so a modifier for this passive system failing of 50% has been included. Hence, the frequency of a full fire within the warehouse is the frequency of an initiating fire x the probability of fail on demand (PFD) of the automatic fire fighting system x DG bunker failure as shown in **Figure 3-6**.

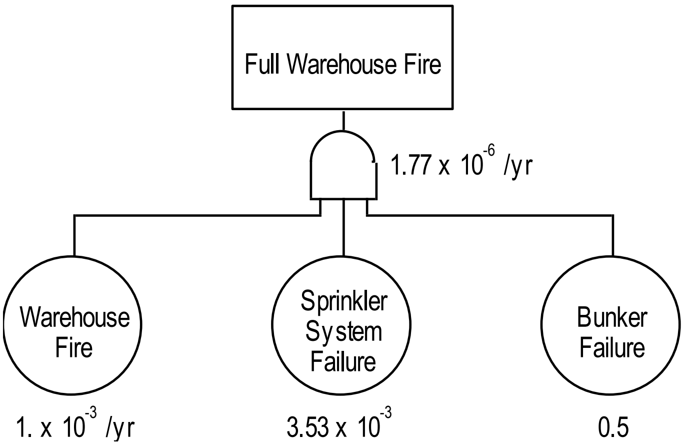


Figure 3-6: Full Warehouse Fire Fault Tree

Conservatively assuming a 100% chance of fatality at the site boundary for a person exposed to radiant heat from a full warehouse fire, the probability of fatality at the site boundary becomes 1.77×10^{-6} x 1 = 1.77×10^{-6} chances of fatality per year or 1.77 chances of a fatality in a million per year (pmpy).

3.3.2 Full Warehouse Fire and Smoke Emission

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 1.77×10^{-6} p.a.

For conservatism, it has been assumed exposure to the smoke will result in a fatality at the site boundary; therefore, the fatality risk of exposure to the toxic smoke becomes 1.77×10^{-6} x 1 = 3.53 chances pmpy.

3.3.3 Total Fatality Risk

Provided in **Table 3-6** is a summary of the incidents which may result in a fatality at the site boundary. The total fatality risk at the site boundary was calculated to be 3.54 chances per million per year (pmpy)

Table 3-6: Total Fatality Risk

Incident	Fatality Risk
Aerosol Fire	0
SGS Fire	0
Full warehouse fire	1.77×10^{-6}
Smoke emission	1.77×10^{-6}
Total	**3.54×10^{-6}**

3.3.4 Comparison Against Risk Criteria

The NSW Department of Planning and Environment has issued a guideline on the acceptable risk criteria (Ref. [2]). The acceptable risk criteria published in the guideline relates to injury, fatality and property damage. The values in the guideline present the maximum levels of risk that are permissible at the land use under assessment. The adjacent land use would be classified as an industrial site as it is restricted access and only industrial operations are permitted to occur in this area. For industrial facilities, the maximum permissible fatality risk is 50 pmpy. The assessed highest fatality risk is 3.54 pmpy at the closest site boundary (eastern boundary); hence, the highest risk is within the permissible criteria and therefore all other risk points beyond the boundary would be within the acceptable criteria.

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

3.3.5 Incident Propagation

The NSW Department of Planning and Environment has issued a guideline on the acceptable risk criteria (Ref. [2]) which indicates the risk for incident propagation is 50 chances pmpy. A review of the scenarios that may lead to incident propagation shows that the sensitivity case for flammable liquids and aerosol are the only incidents which may impact over the site boundary at a radiant heat flux of 23 kW/m^2.

There were no scenarios identified which resulted in 23 kW/m^2 contours extending over the site boundary; hence incident propagation would not be considered to occur. However, given that the assessment is based upon the Linfox storage area catching on fire and a “full warehouse” fire for this area is based upon the sprinklers failing, should this occur the fire would continue throughout the whole warehouse. The frequency with which this would occur would be 1.77×10^{-6} p.a. which is below the acceptable criteria of 50 chances pmpy.

3.4 Dangerous Goods Storage and Community Health and Safety

The Community has expressed concerns relating to the health and safety and well-being of the community which is a valid concern where DG products are stored. However, the DPIE has a robust approval process to assess the potential for offsite impacts to occur which may affect the community. A further discussion around the products stored, the design and the assessment criteria has been provided below.

The products proposed to be stored within the JANUS warehouses are the same product suite one would expect to find in any Woolworths store (i.e. deodorants, cleaners, insecticides, etc.) and are all in small retail sized packages (i.e. <20 L). The risk posed by these products is relatively limited by virtue of the small container volumes. Should an incident occur within the site (i.e. spill of flammable liquid) the consequence is restricted to the volume of the container which can easily be cleaned up using site spill kits.

In terms of the design, the storage of the products is subject to the Work Health and Safety Regulation 2017 which requires the risks associated with the storage of the products to be assessed and minimized So Far As Is Reasonably Practicable (SFARP). The WHS Regulation focus upon the safety of personnel working within the facility (i.e. people directly exposed to the storage and handling) with the intention of making their work activities as safe as possible. Therefore, personnel who are not directly working with the products will be exposed to a risk profile which is less than onsite workers.

The risk reduction required by the WHS Regulations is achieved by complying with an applicable DG design standard. Based upon the proposed design consideration incorporated into the design, the protection requirements would exceed the standard used to assess the facility and thus the potential for an incident to result in far reaching effects would be considered to be incredibly low.

Furthermore, the fire protection requirements incorporated into new build warehouses is incredibly stringent and is driven by empirical testing. For example, where aerosols are stored, tests have been conducted on the aerosol products by setting them on fire in various sprinkler configurations. Only the configurations which have been demonstrated to control and suppress a fire, preventing it from escalated, are included within the sprinkler design standards.

The HIPAP No. 4 risk criteria aims to ensure that people who are not directly exposed to the activity are assessed at a much more conservative criteria depending upon the land use. Industrial land has less stringent criteria than general public areas (i.e. sports stadiums) which in turn has a less stringent criteria than residences and other sensitive receptors (i.e. childcares, hospitals).

Based upon the analysis conducted within this CAN, it has been demonstrated that the far reach effects which may be posed by the facility do not result in an exceedance of the criteria within the HIPAP No. 4 and thus the facility would only be considered potentially hazardous.

4.0 Conclusion and Recommendations

4.1 Conclusions

Due to concerns raised by the Community and the DPIE, it was necessary to conduct a 3rd party, independent review of the PHA to close out the queries raised. A review of the PHA and analysis of outstanding queries was conducted to determine whether there would be offsite impacts exceeding the acceptable fatality risk criteria as outlined in HIPAP No. 4 (Ref. [2]). As part of the review, additional incidents relating to a full warehouse fire and associated smoke emission were analysed in conjunction with the incidents modelled within the PHA.

The results of the analysis showed that minor incidents relating to retail goods would not result in offsite impacts; however, should an incident progress to a full warehouse fire, the radiant heat and smoke would impact over the site boundary at a level which may result in a fatality. These incidents were carried forward for frequency analysis.

To estimate the potentially fatality risk, it was assumed a fatality would occur with a probability of 100% which is incredibly conservative. The results of the analysis indicated that the chances of a fatality occurring at the site boundary would be 1.77 chances pmpy which is below the acceptable criteria of 50 chances pmpy for the industrial land zoning surrounding the site.

The smoke which may have toxic bi-products present would impact father afield but would remain elevated and would disperse prior to impacting ground level downwind; hence, a fatality would not be expected to occur and thus would also be below the acceptable criteria for residential areas of 0.5 chances pmpy.

In addition, the potential for incident propagation was reviewed which showed that there was no potential for a 23 kW/m^2 contour to impact over the site boundary and thus incident propagation would not be expected to occur.

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

4.2 Recommendations

No recommendations have been made as part of the assessment.

5.0 References

[1] Centre for Chemical Process Safety, "Guidelines for Process Equipment Reliability Data with Data Tables," Centre for Chemical Process Safety, 1989.

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

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

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

[5] Thermal-Fluids Central, "Heat of Combustion," Global Digital Central, 8 July 2011. [Online]. Available: https://www.thermalfluidscentral.org/encyclopedia/index.php/Heat_of_Combustion. [Accessed 4 July 2017].

Appendix A

Consequence Analysis

A1. Incidents Assessed in Detailed Consequence Analysis

The following incidents are assessed for consequence impacts.

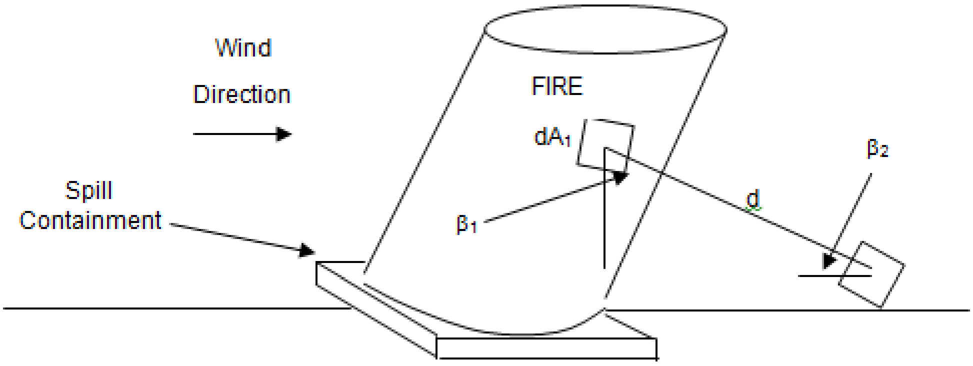
- Full warehouse fire.
- Full warehouse fire and smoke emission.

Each incident has been assessed in the sections below.

A2. 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 A-1** shows a typical pool fire, indicating the target and fire impact details.



Appendix Figure A-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 A-1** (Ref. [3]).

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

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 A-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. [3]). The formula can be shown as:

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

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

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

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

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

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

$$VF = \Delta A\frac{\sin\gamma}{\pi \times X4 \times X4}$$ **Equation A-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 A-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 A-4 (**(Derived from **Equation A-3**):

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

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

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

The sum is taken of the View Factors in **Equation A-3**. Actually the sum is taken without the ∆A term. This sum is then multiplied by ∆A which is constant. The value is then multiplied by 2 to give both sides of the cylinder. This is now the integral of the incremental view factors. It is dimensionless so when we multiply by the emissivity at the "face" of the flame (or surface emissive power, SEP), which occurs at the same diameter as the fire base (pool), we get the radiation flux at the target.

The SEP is calculated using the work by Mudan & Croche (Ref. [4] & Ref. [3]) 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 A-5**.

$$SEP = E_{max}e^{-sD} + E_s(1 - e^{-sD})$$ **Equation A-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. [3]) which is shown in **Equation A-6**.

$$H = 42d_p\left[\frac{\dot{m}}{\rho_a\sqrt{gd_p}}\right]^{0.61}$$ **Equation A-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 A-7** (Ref. [3]).

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

A3. Radiant Heat Physical Impacts

Appendix Table A-1 provides noteworthy heat radiation values and the corresponding physical effects of an observer exposed to these values (Ref. [2]).

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

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

A4. 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 A-2** is a summary of the classes of materials stored within the facility, the applicable burning rates based on commodities stored and the contribution of each product to the total burning rate. 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 A-2: 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	25%	0.099	0.0252
3	76,800	49%	0.067	0.0327
4.1	4,200	3%	0.022	0.0006
5.1	1,300	1%	0.022	0.0002
8	35,000	22%	0.022	0.0049
Total	**157,300**	**100**	-	**0.0635**

The following information was input into the models;

- Equivalent fire diameter – 163.5 m
- Burning rate – 0.0635 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 - 120 m (from model without roof restriction)

Provided in **Appendix Table A-3** are the results generated by the SSC.

Appendix Table A-3: 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	40.3
4.7	90.3

* Research conducted in relation to large fires (Ref. [3]) 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. [4]) 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.

A5. 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.

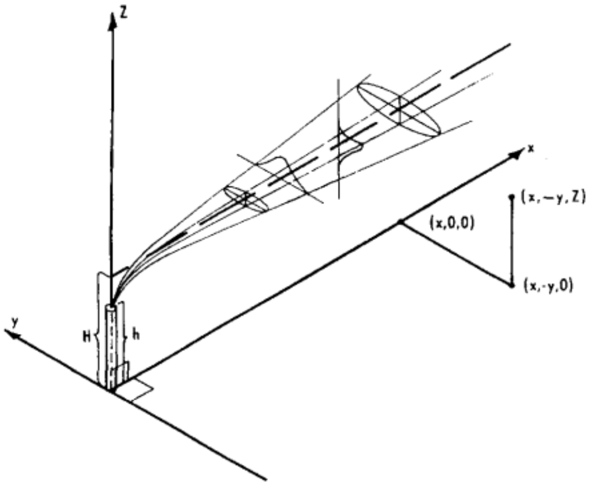
The atmospheric conditions are classified as Pasquill Guifford's Stability categories which are summarised in **Appendix Table A-4** (Ref. [3]).

Appendix Table A-4: 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 A-2** (Ref. [3]).



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

Ian Cameron, professor of Risk Engineering at the University of Queensland, has developed a risk assessment tool known as Risk Assessor produced by DAESIM Technologies. The tool has numerous risk engineering applications; however, the component of interest for this assessment is the smoke plume modelling from fire scenarios. The model has been developed based on a Gaussian dispersion model accounting for modifications to the plume drag coefficients required to model a plume dispersion from a warehouse fire (Ref. [3]).

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

Appendix Table A-5: Input Data for Plume Gaussian Dispersion

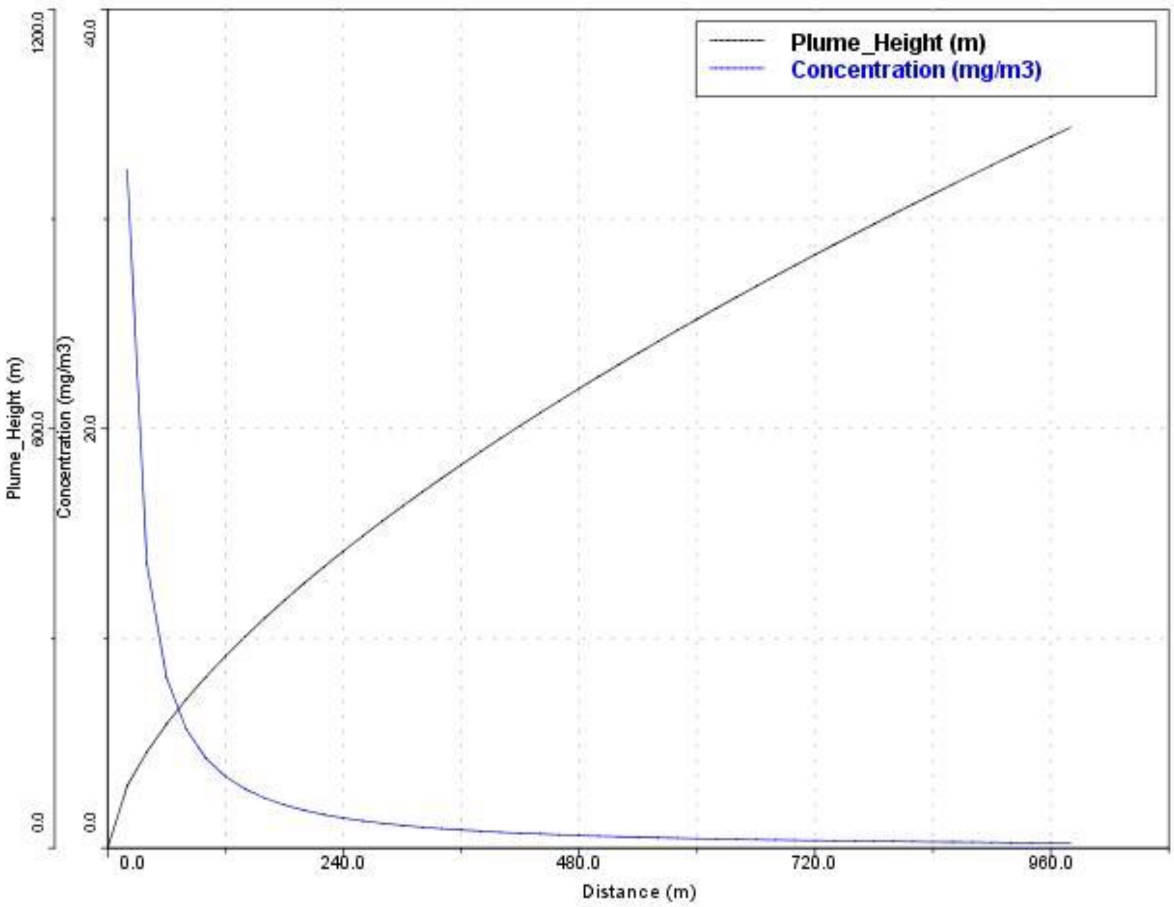
Input	Selected Values	Justification
Max burning rate (kg/m^2.s)	0.0635	Taken from full warehouse fire above
Warehouse Area	21,000	Warehouse Area
Heat of combustion (kJ/kg)	45,000	Heat of combustion for combustible liquid which is considered to take into account the lesser non-DG products which would be the bulk of the warehouse (Ref. [5]
Fraction energy radiated	0.5	Conservative assumption based on high radiant heat blocking which occurs from dense smoke
Pollutant Rate (kg/s)	80,000	Burning rate multiplied by area multiplied 2/3 (amount of space allocated for racking) by 15

Input	Selected Values	Justification
		(number of racks) multiplied by 6 (number of surfaces on a pallet which can burn)
Wind speed (m/s)	1.5	Industry standard
Stability	F	Industry standard

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

The worst-case concentration occurs in the initial phases of the fire and rapidly decrease with distance from the fire. It has been assumed that an inversion occurs at low level and the plume has insufficient heat to 'punch through' the inversion and remains trapped relatively close to the ground. A maximum value of 32 mg/m^3 has been selected per **Appendix Figure A-3** that may impact the surrounding area with regards to potential toxic bi-products of combustion.

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



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

Provided in **Appendix Table A-6** is a summary of several toxic products of combustion which may be present in the smoke plume and their acceptable concentration of exposure for the Acute Exposure Guideline Levels (AEGL). These levels provide guidance on exposure concentrations for general populations, including susceptible populations over a range of exposure times to assist in the assessment of releases which may result in a toxic exposure.

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

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

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

Appendix Table A-6: Concentration of Toxic Products of Combustion in Smoke Plume

Pollutant	Fatality or Serious Injury (ppm)	Injury (ppm)	Concentration (ppm)
Carbon monoxide	600	150	27.9
Nitric Dioxide	25	15	26.1
Hydrogen cyanide	21	10	29.0
Hydrogen chloride	210	43	21.5
Sulphur dioxide	30	0.75	12.2

Appendix B

Warehouse Fire Frequency Estimation

B1. Estimation of the Frequency of a Full Warehouse Fire

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

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

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

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