RISK EQUIVALENCE REVIEW

AS1940:2017 SEPARATION DISTANCE NON COMPLIANCES

CALTEX NEWCASTLE TERMINAL

CALTEX AUSTRALIA PETROLEUM PTY LTD

PREPARED FOR: [redacted] Caltex

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RELIANCE NOTICE

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Risk equivalence review **AS1940:2017 Separation distance non compliances** **Caltex Newcastle Terminal**	**Date: 5 Sep 2019**

CONTENTS

ABBREVIATIONS

AS	Australian Standard
BPCS	Basic Process Control System
CCTV	Closed Circuit Television Cameras
EFR	External Floating Roof
IFR	Internal Floating Roof
LFL	Lower Flammable Limit
LOPA	Layer of Protection Analysis
MHF	Major Hazard Facility
SIL	Safety Integrity Level
VCE	Vapour Cloud Explosion

1. SUMMARY

1.1. Background

Caltex Australia Petroleum Pty Ltd (Caltex) operates a hydrocarbon fuel terminal in Wickham near Newcastle, NSW.

There are several examples of tank separation distances to boundary, to onsite protected places, to offsite protected places and distances between tanks that have been confirmed to be non-compliant with AS1940:2017.

SafeWork NSW provided advice to Caltex to establish an improvement plan to ensure all deficiencies are satisfactorily addressed to minimise risk so far as is reasonably practicable. The improvement plan indicating all area of non-compliance, existing controls, proposed controls and actions and an estimated timeframe for completion is to be submitted to SWNSW.

To address this request Caltex retained Sherpa Consulting Pty Ltd (Sherpa) to carry out a risk comparison review for the non-compliances in AS1940:2017 separation distances. Note: the risk review does not include any other type of non-compliance, these are being addressed separately.

The overall objective of the study is to assess the relative difference in risk for each specific non-compliance in separation distance.

The base case risk assumes all mandatory[1] AS1940:2017 control measures (i.e. controls that 'shall' be implemented under the standard) are in place. This is compared against the risk with the control measures as installed at the site to determine whether the risk is equivalent, higher or lower with the installed controls.

1.2. Approach

Given the relatively small magnitude of the non-compliances, for example separation from T-214 is 46m versus the requirement of 50m to a protected place, the 'risk' at these locations will be dominated by fire events (i.e. flame impingement or radiant heat) and any potential material difference in consequence will be a function of different heat radiation levels.

Industry incidents and subsequent investigations by bodies such as the UK HSE, show that large flammable vapour clouds and resulting flashfire or overpressures from a gasoline tank overfill event (the 'Buncefield' scenario) have potential effect distances of many hundreds of metres. Separation distance of the scale required in AS1940:2017 is not a mitigation for this event, so these events are not covered in this review.

[1] Compliance with AS1940:2017 is not a statutory requirement under NSW legislation hence is not mandatory. However AS1940:2017 is a recognised 'good practice' by Worksafe. 'Mandatory' in the context of this study means a control that 'shall' be implemented under AS1940:2017.

The scope of the risk equivalence review covered:

1. Summarising the mandatory control measures required under AS1940:2017 (which are relevant to reducing the likelihood of loss of containment from tanks and associated equipment, or mitigating the consequence of tank or bund fires) and comparison of the mandatory controls with the control measures installed at the site.
2. Consequence modelling using PHAST 8.2 for tank top fire and bund fire scenarios for each tank with a non-compliant separation distance to establish any material differences in radiant heat at the required and actual separation distance for each scenario.
3. Estimating the likely change in likelihood of fire per tank due to any additional controls using Layer of Protection Analysis (LOPA) factors to adjust a base statistical frequency (from LASTFIRE 2012).
4. For any non-compliances where the risk of the installed system is higher than the AS1940:2017 equivalent risk, identifying potential additional controls to reduce the risk to an AS1940:2017 equivalent or lower level.

Note that this approach is intended to show the relative difference in risk from a specific tank or bunded area. Probability of exposure factors such as wind direction or wind speed are not included. Therefore the results are not suitable for cumulating or comparison to risk criteria.

1.3. Results

All mandatory controls required under AS1940:2017 (with the exception of separation distances) were found to be installed at the Terminal, including the requirements from the most recent standard update (i.e. from AS1940:2004 to 2017) for:

- independent tank high level alarms
- gas or hydrocarbon detection in bunds.

Additional control measures beyond the requirements of AS1940:2017 which are installed at the Terminal are:

- Independent high-level shutdown function on each tank
- CCTV covering all bunds (i.e. flammables, mixed storage and combustible only).
- Bund foam pourers in flammable bunds
- In tank foam systems for all combustible tanks except T352 (which is a diesel tank in a separate bund).

Consequence modelling was carried out using PHAST 8.2. In summary, the fire modelling results show that:

- There is no material difference in the probability of a fatality due to heat radiation or flame impingement from fires at the AS1940:2017 required separation distance compared against the actual separation distances.
    - For non-compliance with separation distances from tanks or bund walls to boundaries, there is no material difference in the probability of fatality as the receptor is directly under the tilted flame in both compliant and current separation distance and the predicted fatality probability is 100%.
    - For non-compliant separation distances to offsite protected places the predicted heat radiation levels are below fatality levels for the current separation distances and hence compliant separation distances would not result in reduced consequences.
- For tank to tank escalation there is no material difference at the AS1940:2017 required separation distance compared against the actual separation distances. The heat radiation at a neighbouring tank at a separation distance of the required range of 7.5m to 15m is in excess of 23 kW/m^2 (where structural failure may occur).

From these consequence results it is concluded that, given a fire occurs, there is no material difference in the fatality or escalation outcomes at defined receptors between the current and AS1940:2017 compliant separation distances.

As risk is a combination of consequence and likelihood, the likelihood of realising the consequences of a non-compliant separation distances tank or bund fire was assessed. The likelihood was determined for the current 'all installed additional controls case' and AS1940:2017 compliant case.

Publicly available statistical data for tank fire, bund fire and overfill events (LASTFIRE 2012) was collected and assumed to be applicable to the base case including all AS1940:2017 mandatory controls. This was then adjusted for each relevant tank or bund using Layer of Protection Analysis (LOPA) factors based on industry guidance from CCPS (Ref (1)).

Figure 1.1 shows a summary of the relative risk to receptors (e.g. protected places) for the case with AS1940:2017 mandatory controls compared with risk with all installed additional controls. These are presented for each tank fire or bund fire. All risks are equivalent to or lower than the case with AS1940:2017 mandatory controls.

Figure 1.2 shows a summary of the relative risk of tank to tank escalation with AS1940:2017 mandatory controls compared with escalation risk with all installed additional controls. All risks are equivalent to or lower than the case with AS1940:2017 mandatory controls.

1.4. Conclusions

Overall, the results demonstrate that the risk from tank top fires or bund fires to receptors defined in AS1940:2017 (i.e. protected places, site boundary, security fences,

neighbouring tanks) with additional installed controls at the Terminal and slightly reduced separation distances, is the same or lower than the risk with all mandatory AS1940:2017 control measures at the required separation distance.

Additional control measures have therefore not been identified or further assessed as risk equivalence has been demonstrated.

Figure 1.1: Relative risk – to receptors such as protected places

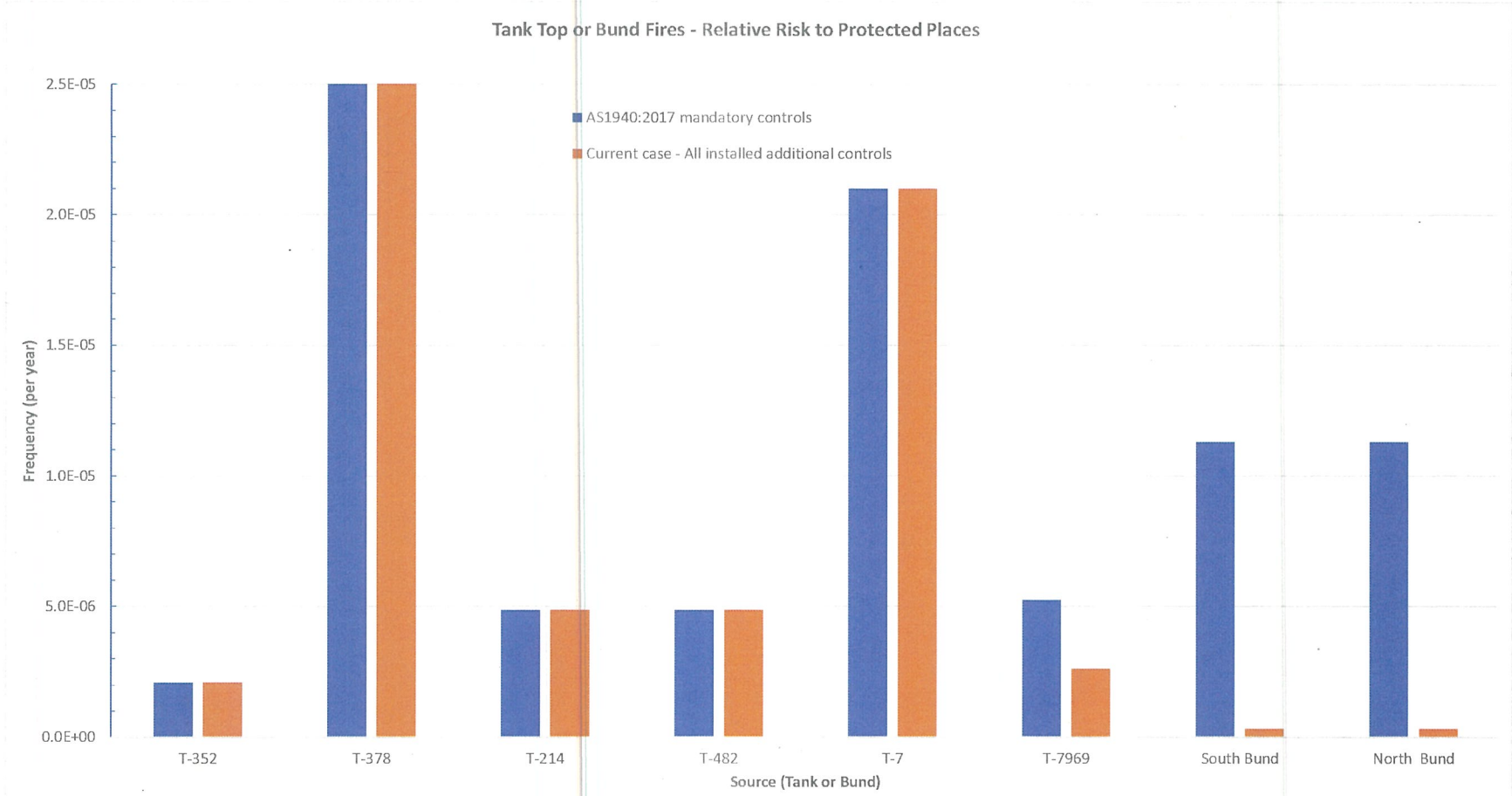
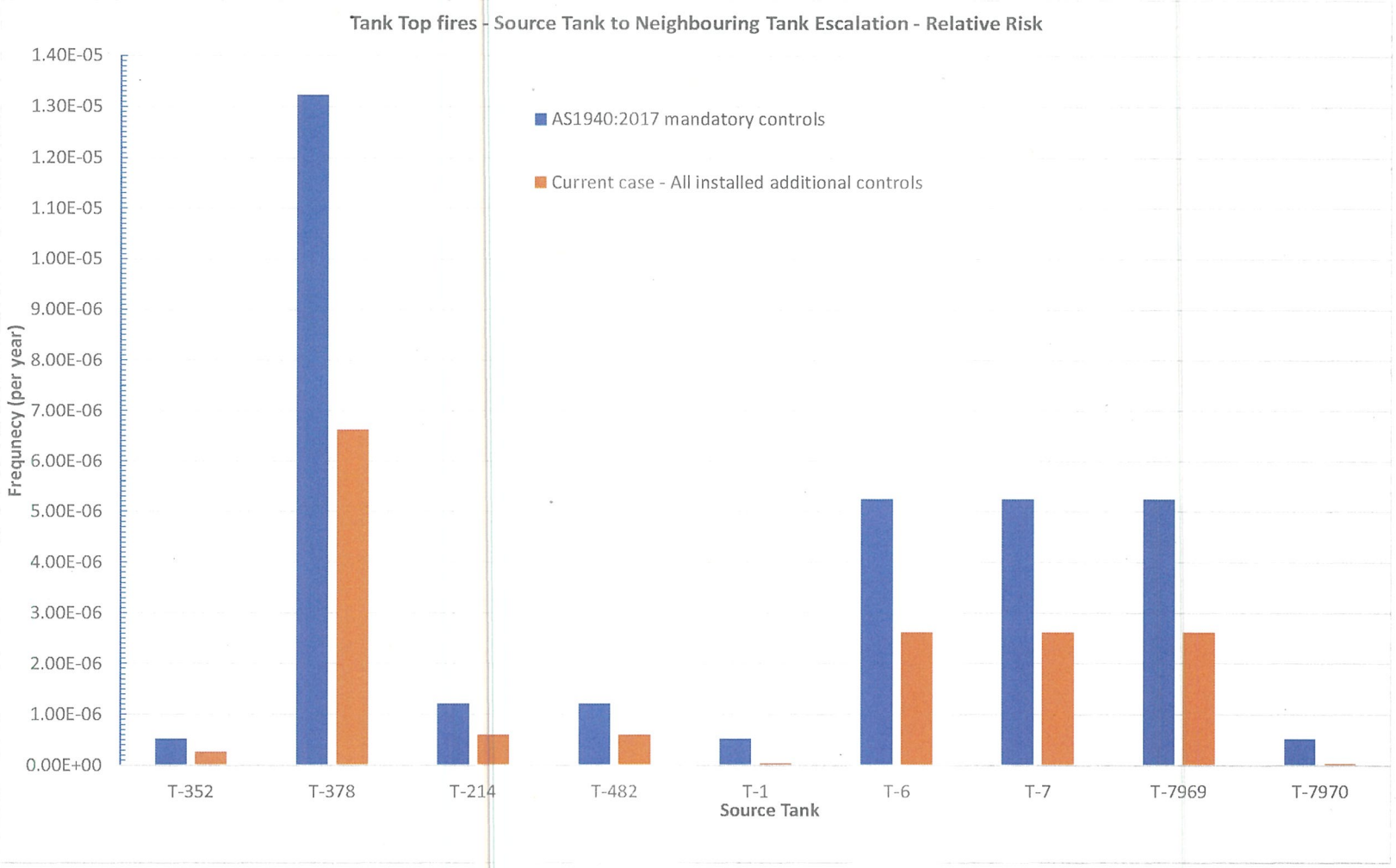


Figure 1.2: Relative risk - tank to tank escalation



2. INTRODUCTION

2.1. Background

Caltex Australia Petroleum Pty Ltd (Caltex) operates a hydrocarbon fuel terminal in Wickham near Newcastle, NSW. Petroleum fuels are generally imported by pipeline and exported by road tanker. Small quantities may also be imported from road tankers. The Terminal is not a Major Hazards Facility (MHF), although has notified SafeWork NSW that the facility storage capacity for flammable materials exceeds 10% of the MHF threshold.

The Terminal has been in use since the 1960s with numerous changes and upgrades implemented. This includes additional control measures that exceed requirements of the relevant Australian Standard AS1940:2017 *The storage and handling of flammable and combustible liquids.* However there are also a number of existing non-compliances with the separation distances defined in the current version of AS1940:2017[2].

There are several examples of tank separation distances to boundary, to onsite protected places, to offsite protected places and distances between tanks that were confirmed to be non-compliant with AS1940 (2017). SafeWork NSW provided advice to Caltex to establish an improvement plan to ensure all deficiencies are satisfactorily addressed to minimise risk so far as is reasonably practicable. The improvement plan is to be submitted to SWNSW that indicates all area of noncompliance, existing controls, proposed controls and actions and an estimated timeframe for completion.

To address this request Caltex retained Sherpa Consulting Pty Ltd (Sherpa) to carry out a risk comparison review for the non-compliances in AS1940:2017 separation distances.

The intent of the comparison is to demonstrate that the 'risk' with the control measures installed at the Terminal is equivalent to or better than the risk level with mandatory control measures defined in AS1940:2017 if the separation distances were met.

2.2. Scope and objectives

The scope of the study covers the identified non-compliances in AS1940:2017 separation distances summarised in Table 3.1.

The overall objective of the study is to assess the relative difference in risk for each specific non-compliance identified in Table 3.1.

[2] Separation distance requirements have not changed in AS1940:2017, i.e. remain as per AS1940:2004 so the non-compliances are not new.

The base case risk assumes mandatory[3] AS1940:2017 control measures (i.e. controls that 'shall' be implemented under the standard) are in place, and this is compared against the risk with the control measures as installed at the site.

2.3. Scenarios

Historically, pool fires due to ignition of hydrocarbon spills, bund fires, tank top fires and internal explosions in storage tanks have been regarded as credible incident scenarios at fuel terminals.

Large flammable clouds and resulting flashfires or vapour cloud explosions (VCEs) were regarded for many years as barely credible, largely due to the relatively open and uncongested layout of most terminal sites. (Flashfires are very intense short duration fires without overpressure, significant overpressure may also be generated if environmental factors causing high flame speeds are present, resulting in a VCE).

However, in 2005, an overfill of gasoline from a storage tank at the HOSL terminal in Buncefield, UK, resulted in a large flammable vapour cloud and extremely damaging explosion, followed by an extensive fire and emergency response effort that continued for several days. Investigations identified a number of common factors in similar incidents that have occurred. These included:

- Potential for overfill or other release of hydrocarbon containing volatile material that continues undetected for some time resulting in significant droplet formation and vapourisation, and good mixing with air resulting in a flammable mixture
- Low wind speed, stable atmospheric conditions (ie poor dilution of cloud)
- An ignition source in the vicinity
- Localised congestion or confinement of dispersing flammable vapour clouds or some other factor resulting in high flame speeds.

Subsequent guidance developed by the UK HSE based on extensive investigation and modelling (Ref (2)) suggests that there is a flammable vapour cloud risk for vertical aboveground gasoline storage tanks more than 5m high, with import rates greater than approximately 100m^3/hr. These factors are applicable to most fuel terminals that store gasoline, including the Newcastle Terminal.

However as has been clearly established by previous incidents and modelling produced by the UK HSE, these events have potential effect distances of hundreds of metres, i.e. separation distance of the scale required in AS1940:2017 is not a mitigation for this event.

[3] Compliance with AS1940:2017 is not a statutory requirement under NSW legislation hence is not mandatory. However AS1940:2017 is a recognised 'good practice' by Worksafe. 'Mandatory' in the context of this study means a control that 'shall' be implemented under AS1940:2017.

For the purposes of this study the scenarios considered to contribute to off site risk are:

- Tank top fires (full surface area)
- Bund fires (caused by overfill or major tank failure).

Other scenarios such as rim seal fires, tank vent fires or internal explosions are not assessed by themselves, as, in the worst case, these will also result in a tank top fire. Large flammable vapour clouds and resulting flashfire or overpressures from a gasoline tank overfill event (the 'Buncefield' scenario) are also not covered in this review.

2.4. Methodology

Given the relatively small magnitude of the non-compliances, for example separation from T-214 is 46m versus the requirement of 50m to a protected place, the 'risk' at these locations will be dominated by fire events (i.e. flame impingement or radiant heat) and any potential material difference in consequence will be a function of different heat radiation levels.

The scope of the risk equivalence review covered:

1. Preparation of a summary of the mandatory control measures required under AS1940:2017 which are relevant to reducing the likelihood of loss of containment from tanks and associated equipment or mitigating the consequence of tank or bund fires (excluding the 'mandatory' separation distances).
2. Comparison of AS1940: 2017 mandatory controls (excluding separation distances) with the control measures installed at the site.
3. Define consequence criteria expressed as heat radiation levels resulting in fatality or asset damage.
4. Complete consequence modelling using PHAST 8.2 for each non-compliant tank top fire and associated bund fire scenario to establish the difference in radiant heat at required and actual separation distance for each scenario impact compared against the consequence criteria. A worst case wind condition was used for this modelling.
5. Estimate the change in risk of fire per tank or bund taking into account installed non-mandatory controls using Layer of Protection Analysis (LOPA) factors to adjust a base statistical frequency (from LASTFIRE, Ref (3)). Note that this approach is intended to show the relative difference in risk from a specific tank or bunded area and is not intended to be cumulated for comparison to risk criteria.
6. As the non-compliance issues relate to separation distance, the risk is typically assessed in the form of frequency of effect at specific locations. Probability of presence of a receptor or escape potential is not accounted for.
7. Escalation risk between tanks is assessed using damage threshold levels (i.e. within flame or specific radiant heat levels).

8. For any non-compliances where the risk of the installed system is higher than the AS1940:2017 equivalent risk, potential additional controls to reduce the risk to an AS1940:2017 equivalent or lower level were identified.

2.5. Exclusions and limitations

The following exclusions and limitations apply:

- This advice covers non-compliances relating to AS1940:2017 separation distance requirements only. Review of any other non-compliance is not with the scope of this review.
- Modelling is only included for tanks or bunds with an identified non-compliance in separation distances, no other modelling is included.
- The tanker loading bay is not covered as there are no identified non-compliances relating to AS1940:2017 separation distance.
- This advice covers risk comparison for an individual non-compliance on a specific tank or bund basis only. An assessment of overall Terminal cumulative risk is not within the scope of this study.
- The risk review is consistent with the risk analysis / assessment steps given in AS1940:2017 Appendix E, section E2.3, however is limited to the issues relating to separation distances only.
- Identified non-compliances in required separation distance have been advised to Sherpa by Caltex as per Table 3.1 based on site surveys. Sherpa has also cross checked these using Google Earth imagery (which would be less accurate than the survey data).
- Additional control measures at the site are assumed to be designed to meet their design intent and tested to meet reliability requirements, with supporting documentation available within Caltex.

3. AS1940:2017 CONTEXT

3.1. Overview

In the context of AS1940:2017 relevant terminal characteristics are:

- Category 6 tanks
- Flammables and combustibles stored in same bund
- Aboveground tank storage of aggregate capacity 2000m^3 and greater
- High volume tank fills (i.e. pipeline transfers at rates > 100m^3/hr).

A site layout and tank schedule is provided in Figure 3.1.

Locations of tanks storing gasoline or bunds storing flammables in at least one tank are shown in Figure 3.2.

3.2. Protected places

Broadly, AS1940:2017 *The storage and handling of flammable and combustible liquids* specifies separation distances from tanks or bund walls to receptors such as protected places (both onsite and offsite), or a site boundary or security fence. A protected place is defined as:

1.4.56 Protected place is any of the following:

> *(a) A dwelling, residential building, place of worship, public building, school or college, hospital, theatre, and any building or open area in which persons are accustomed to assemble whether it is within or outside the property boundary of the installation.*
>
> *(b) A factory, workshop, office, store, warehouse, shop, or building where persons are employed, that is outside the property boundary of the installation.*
>
> *(c) A ship lying at permanent berthing facilities.*
>
> *(d) Any storage facility for dangerous goods outside the property boundary of the installation, except for those defined as minor storages in this or other Standards or regulations.*

For tanks exceeding 2000m^3 of Class 3 PGII such as gasoline storages at the Terminal, 50m is required to a protected place (AS1940:2017 Table 5.4), and from a bund wall storing flammables 15m to a protected place (AS1940:2017 clause 5.8.3i). Distances from combustible storage are smaller than for flammables.

Locations of the tanks where a separation distance to a protected place (onsite or offsite) is non-compliant with AS1940:2017 (as summarised in Table 3.1) are identified in Figure 3.3. (Note that tank to tank separation distances are non-compliant for most tanks so these are not shown specifically in Figure 3.3).

3.3. Mandatory controls

It should be noted that the update from the previous version of the standard AS1940:2004 to AS1940:2017 significantly increased the number of mandatory controls, including requiring gas or hydrocarbon liquid detection for spills into flammable bunds, an independent high level alarm on tanks, a more extensive definition of 'tank-on fire' hence additional fire protection for cooling neighbouring tanks in a tank fire event.

Table 3.2 summarises the mandatory controls under AS1940:2017 (apart from separation distances) that affect ignited events.

The installed controls at the terminal are also summarised in Table 3.2. It can be seen that all mandatory controls under AS1940:2017 are installed at the Terminal, including the requirements from the most recent standard update for independent tank high level alarms and gas or hydrocarbon detection in bunds.

Additional control measures beyond the requirements of AS1940:2017 which are installed at the Terminal are:

- Independent high level shutdown function on each tank
- CCTV covering all bunds (i.e. flammables, mixed storage and combustible only).
- Bund foam pourers in flammable bunds
- In tank foam systems for all combustible tanks except T352 (which is a diesel tank in a separate bund).

Table 3.1: AS1940:2017 separation distance non-compliance summary

Tank	Service	Tank Type	Capacity (Litres)	Class	Issue	AS1940: 2017 ref
T-352	Diesel	Fixed roof	5,773,103	C1	Distance to west security fence is 6.6m, Should be 7.5m to security fence or protected place	5.7.2 Table 5.3
T-7	Flammables (currently jet)	Fixed roof	2,831,000	3PGIII	T-7 < 15m to a protected place Should be 15m to security fence or protected place	5.7.2 Table 5.3
T-482	PULP	IFR	5,627,651	3PGII	Distance to nearest off site protected place is Straight Line 39.149 m, around vapour barrier/blast wall 46.806 m, should be 50 m for tank > 2000m^3	5.7.3 Table 5.4
T-378	PULP	EFR	6,943,924	3PGII	Distance to nearest off site protected place is 33 m should be 50 m for tank > 2000m^3	
T-214	SPULP	IFR	2,556,217	3PGII	Distance to nearest off site protected place is Straight Line approximately 46 m Should be 50 m for tank > 2000m^3	5.7.3 Table 5.4
T-482 to T-7969 T-482 to T-7970 T-482 to T-620	Flammables			3PGII	Distance between vertical tanks for flammable liquids is 7.7m - 15m required Distance between vertical tanks for flammable liquids is 10.3m - 15m required Distance between vertical tanks for flammable liquids is 6.9m - 15m required	5.7.3
T-378 to T-214 T-378 to T15721	Flammables			3PGII	Distance between vertical tanks for flammable liquids is 7.6m -15m required Distance between vertical tanks for flammable liquids is 14.3m -15m required	5.7.3
T-214 to T15721	Flammables			3PGII	Distance between vertical tanks is 8.9 m - required 9.15m (half of T-214) required	5.7.3
T-6 to T-7 T-6 to T-1	Flammables (currently jet)			3PGIII	Distance between vertical tanks is 8.8 m - required 9.15m (half of T-6) required Distance between vertical tanks is 5.3 m - required 9.15m (half of T-6) required	5.7.3
South bund	Flammables			3PGII	Distance from bund where flammable liquid is stored is required to be 15m to a protected place or on-site protected place. Southern bund is not compliant for distance to control room and distance to neighbours building.	5.8.3
North bund	Flammables			3PGII	Distance from bund where flammable liquid is stored is required to be 15m to a protected place or on-site protected place. Southern bund is not compliant for distance to fitters workshop and distance to neighbours building / site boundary	5.8.3

Figure 3.1: Site layout

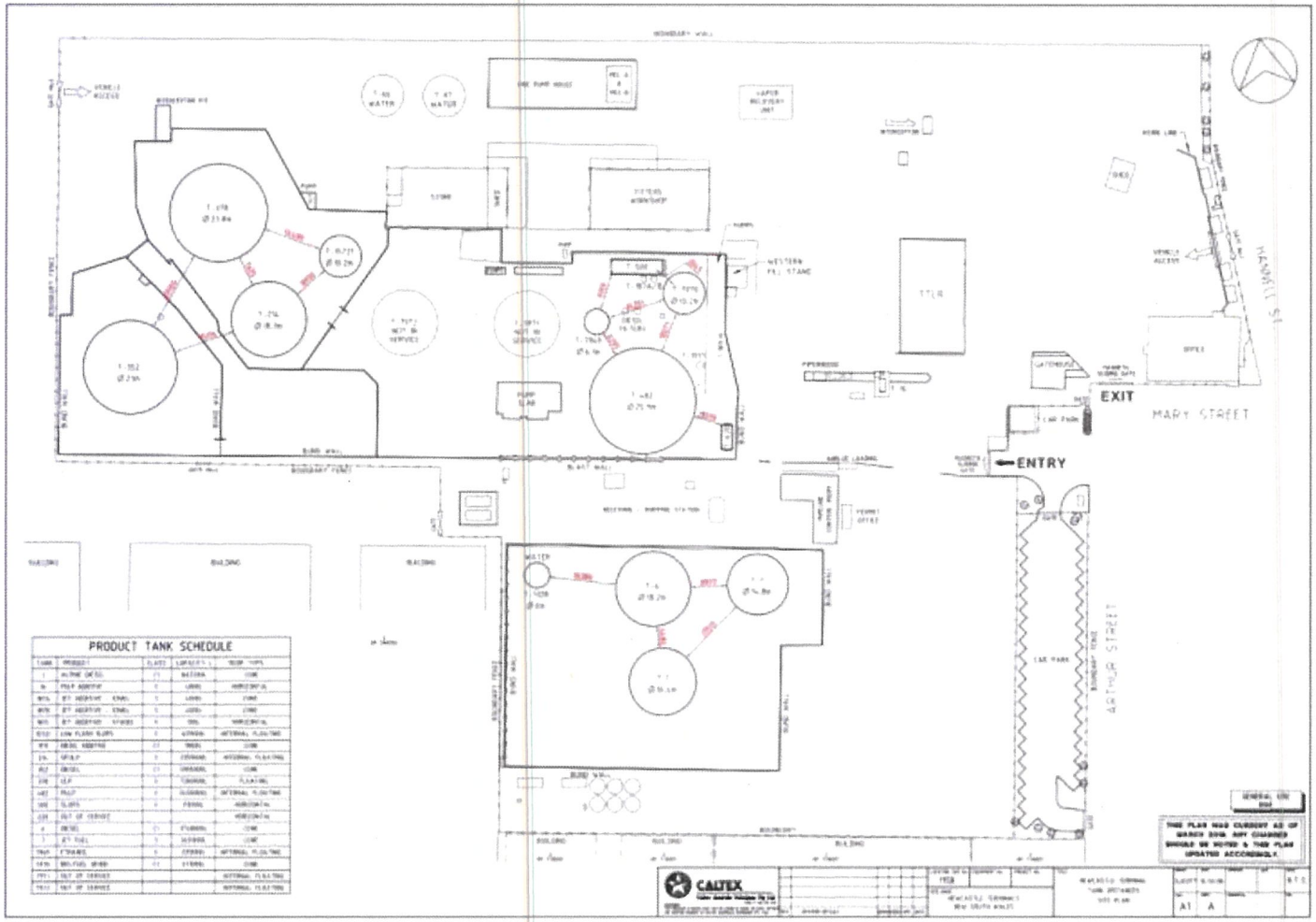
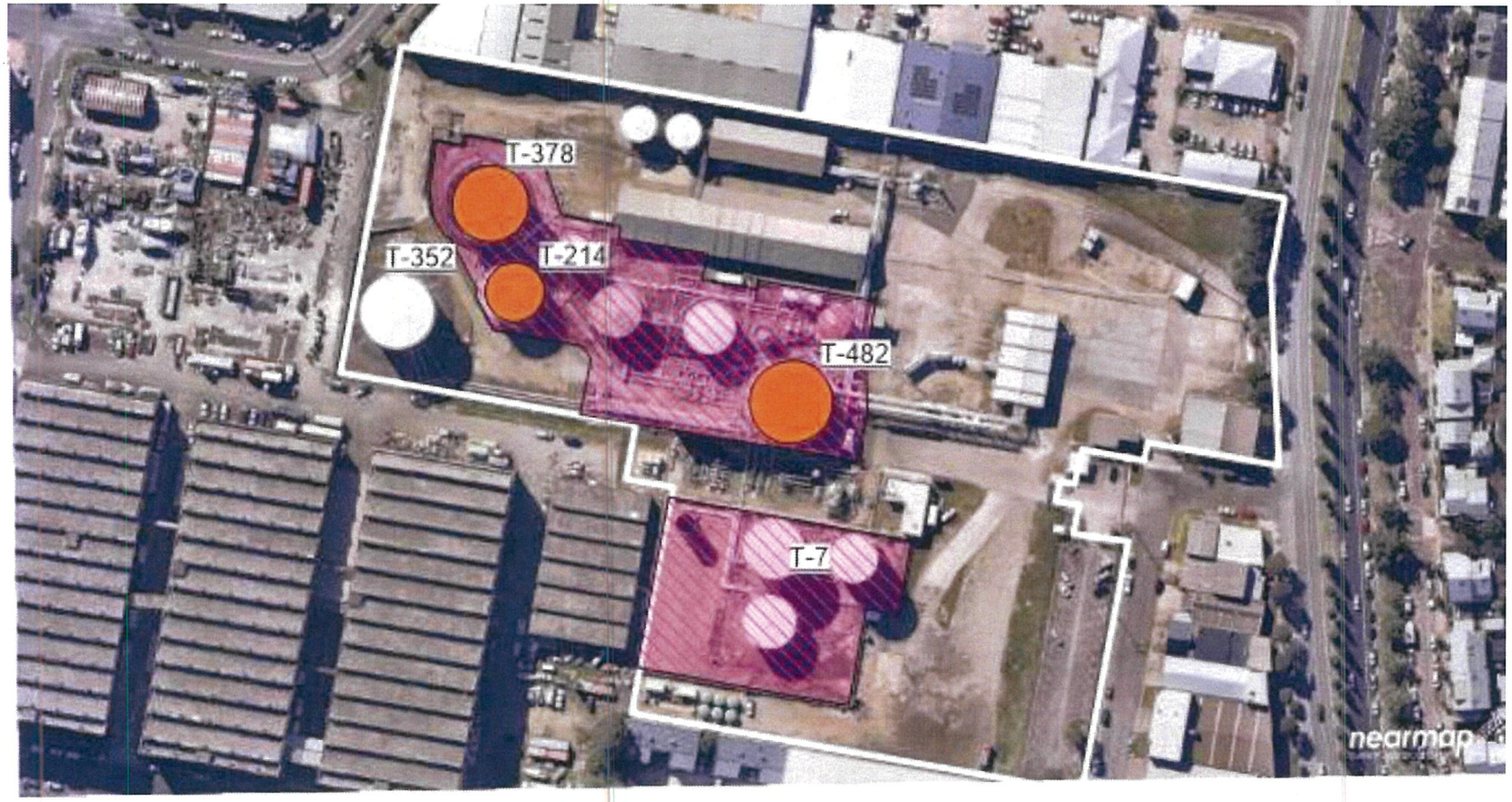
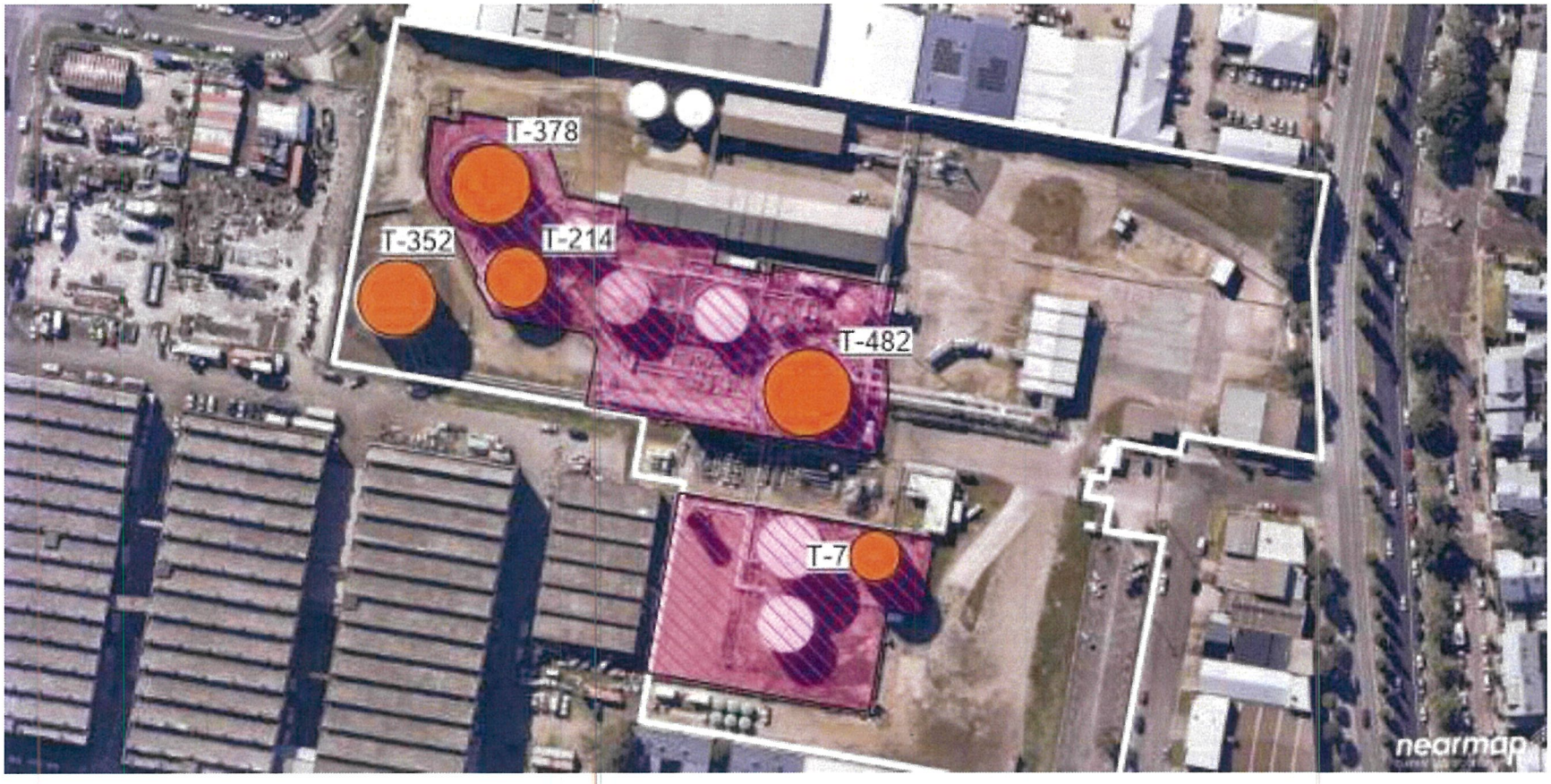


Figure 3.2: Site layout showing gasoline storage and bunds storing flammables



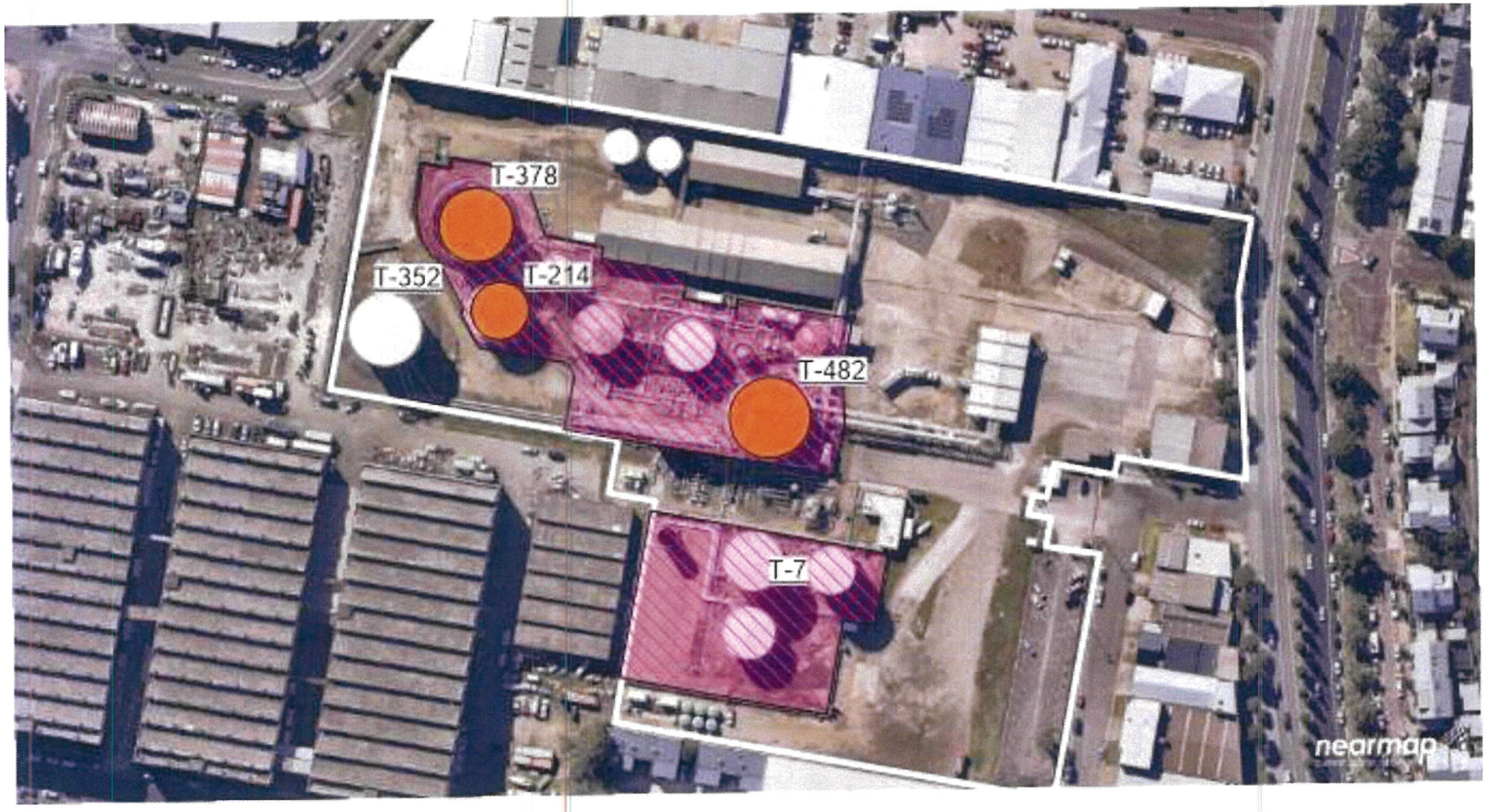
●	Gasoline tanks
■	Flammable storage bund

Figure 3.3: AS1940:2017 separation distance non-compliance to protected place (onsite or offsite) locations



●	Tanks with a non-compliance to protected place (onsite or offsite)

Figure 3.4: AS1940:2017 separation distance non-compliance to offsite protected place locations



Tanks with a non-compliance to protected place (offsite only)

Tank ID	Type	Service	Capacity	Receptor	Required Sep distance from tank edge	Actual sep distance from tank edge	Compliance with AS 1940	Flame extent (m) from tank centre	Predicted Heat radiation level (-) at 1.5m height (From Tank centre)		Predicted Heat radiation level (-)at tank height (From tank centre)		Comments	Frequency (AS1940:2017 case		Additional Controls		Installed case (additional safeguards)
			(kL)		(m)	(m)		(ie area out to 12.5 kW/m2 projected to ground - approximately under luminous flame portion)	Required sep distance	actual sep distance	Required sep distance	actual sep distance		(per year)	Directional factor (escalation only - used to adjust source tank frequency)	Tank top fire	LOPA Factor	
T-352	Fixed roof	Diesel	5773	Security fence	7.5	6.6	NO	34	13.0	11.6	64.4	67.2	No material difference in outcome - under tilted flame	2.10E-06		In tank foam pourers (combustible tank) -blocked off not functional	1	2.10E-06
T-352	Fixed roof	Diesel	5773	Adjacent tank (T-214)	15	14.7	NO	34	14.0	14.2	21.4	22.4	No material difference in escalation outcome -Spray cooling provided	5.25E-07	0.25	Nothing additional spray cooling required under AS1940. Allow for CCTV	0.5	2.63E-07
T-378	EFR	Gasoline	6944	Off-site protected places	50	33.0	NO	39	2.7	6.6	1.7	4.6	No material difference - no fatality outcome Injury risk of 4.7kW/m2 exceeded at actual but not at required sep distance	5.29E-05		Nothing additional rim seal only foam capacity installed	1	5.29E-05
T-378	EFR	Gasoline	6944	Adjacent tank (T-214)	15	7.6	NO	39	16.7	11.8	40.6	70.2	No material difference in escalation outcome -Spray cooling provided	1.32E-05	0.25	Nothing additional spray cooling required under AS1940. Allow for CCTV	0.5	6.61E-06
T-378	EFR	Gasoline	6944	Adjacent tank (T-15721)	15	7.6	NO	39	16.7	11.8	40.6	70.2	No material difference in escalation outcome -Spray cooling provided	1.32E-05	0.25	Nothing additional spray cooling required under AS1940. Allow for CCTV	0.5	6.61E-06
T-214	IFR	Gasoline	2409	Off-site protected places	50	46.0	NO	32	1.7	2.0	1.5	1.6	No material difference - no fatality outcome Injury risk of 4.7kW/m2 not exceeded at actual or required sep distance	4.84E-06	1	Nothing additional foam already installed	1	4.84E-06
T-214	IFR	Gasoline	2409	Adjacent tank (T-378)	15	7.6	NO	32	20.9	21.8	18.9	62.1	No material difference in escalation outcome -Spray cooling provided	1.21E-06	0.25	Nothing additional spray cooling required under AS1940. Allow for CCTV	0.5	6.05E-07
T-482	IFR	Gasoline	5627	Off-site protected places	50	39.0	NO	40	2.8	5.1	1.9	3.5	No material difference - no fatality outcome Injury risk of 4.7kW/m2 exceeded at actual but not at required sep distance	4.84E-06	1	Nothing additional foam already installed	1	4.84E-06
T-482	IFR	Gasoline	5627	Adjacent tank (T-7969)	15	6.2	NO	40	26.7	18.7	44.0	74.5	No material difference in outcome - Spray cooling provided	1.21E-06	0.25	Nothing additional spray cooling required under AS1940. Allow for CCTV	0.5	6.05E-07
T-482	IFR	Gasoline	5627	Adjacent tank (T-7970)	15	10.3	NO	40	26.7	18.7	44.0	74.5	No material difference in outcome - Spray cooling provided	1.21E-06	0.25	Nothing additional spray cooling required under AS1940. Allow for CCTV	0.5	6.05E-07
T-482	IFR	Gasoline	5627	Adjacent tank (T-620)	15	6.9	NO	40	26.7	18.7	44.0	74.5	No material difference in outcome - Spray cooling provided	1.21E-06	0.25	Nothing additional spray cooling required under AS1940. Allow for CCTV	0.5	6.05E-07
T-1	Fixed roof	Diesel	1786	Adjacent tank (T-6)	5.8	5.7	NO	29	17.2	17.0	60.0	60.3		5.25E-07	0.25	Fixed roof fire freq reduced by 0.1 for additional in tank pourers in source combustible tank and 0.5 for CCTV for applying cooling to neighbouring tank	0.05	2.63E-08
T-6	Fixed roof	Diesel	3548	Adjacent tank (T-1)	9.2	5.7	NO	30	9.2	9.0	64.7	65.0	No material difference in outcome - Spray cooling provided	5.25E-06	0.25	same scenario as previous T-7 to T-6 include to get T-6 on graph	0.5	2.63E-06
T-6	Fixed roof	Diesel	3548	Adjacent tank (T-7)	9.2	8.8	NO	30	9.2	9.0	64.7	65.0	No material difference in outcome - Spray cooling provided			same scenario as previous T-1 not quantified		0.00E+00
T-7	Fixed roof	Jet	2657	Office, workshops, etc	15	9.2	NO	25	5.5	5.6	11.5	16.9	No material difference in outcome - under tilted flame	2.10E-05		Nothing additional foam already installed	1	2.10E-05
T-7	Fixed roof	Jet	2657	Adjacent tank (T-6)	9.2	8.5	NO	25	5.5	5.5	11.5	19.5	No material difference in outcome - Spray cooling provided	5.25E-06	0.25	Nothing additional spray cooling required under AS1940. Allow for CCTV	0.5	2.63E-06
T-7969	Fixed roof	Ethanol	280	Adjacent tank (T-482)	15	6.2	NO	9	1.9	3.1	2.1	16.5	No material difference in outcome - Spray cooling provided	5.25E-06	0.25	Nothing additional spray cooling required under AS1940. Allow for CCTV	0.5	2.63E-06
T-7970	Fixed roof	Biodiesel	531	Adjacent tank (T-482)	15	9.6	NO	29	9.3	10.5	16.3	25.4	No material difference in outcome - Spray cooling provided	5.25E-07	0.25	Fixed roof fire freq reduced by 0.1 for additional in tank pourers in source combustible tank and 0.5 for CCTV for applying cooling to neighbouring tank	0.05	2.63E-08

Directly under flame -heat radiation underpredicted -set outcome to 100% fatality / within escalation area

specific to offsite protected places

C2.2. Bund fires

Extract from 21345 Calc heat radiation results FINAL.XLSX inserted on following page

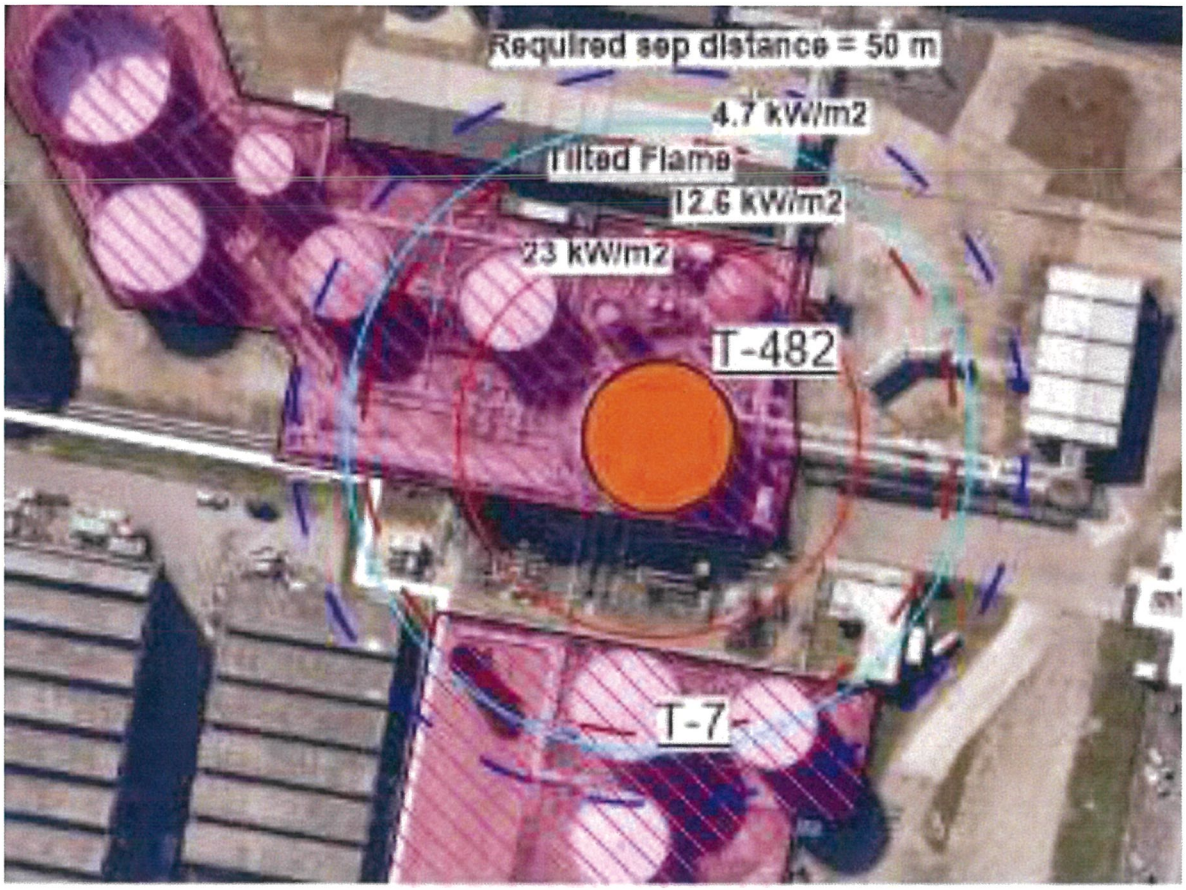
Bund	Tanks in bund	Service	DG class	Pool fire diameter	Receptor	Required Sep distance (from bund edge)	Required Sep distance (from pool fire centre)	AS1940 2017 ref	Actual sep distance (from bund	Actual Sep distance (from pool fire centre)	Compliance with AS 1940	Flame extent (m) from tank centre	Predicted Heat radiation level (kW/m2) at 1.5m height		Prob of Fatality at 1.5m height (From Tank centre)		Comments	Frequency (AS1940:2017 case	Additional Controls		Installed case (additional safeguards)
						(m)	(m)		(m)	(m)		(ie area out to 12.5 kW/m2 projected to ground - approximately under luminous flame portion)	Required sep distance	actual sep distance	Required sep distance	actual sep distance		(per year)	Bund fires	Factor	
South Bund	1, 6, 7	Gasoline	3PGII	53.6	Control room	15.0	41.8	Cl 5.8.3	1.5	28.3	NO	60	10.7	20.19	1.00	1.00	No calculated difference in fatality as both under tilted flame	1.13E-05	Bund foam pourers	0.1	3.16E-07
																			Independent high level shutdown (assume to apply to 80% of freqency attriuted to overfill	0.1	
				53.6	Site Boundary	15.0	41.8	Cl 5.8.3	1.1	27.9	NO	60	10.7	20.19	1.00	1.00					
				53.6	offsite protected place	15.0	41.8	Cl 5.8.3 (i)	3.0	29.8	NO	60			1.00	1.00					
North Bund	214, 378, 482	Gasoline	3PGII	49.8	Fitter workshop	15.0	39.9	Cl 5.8.3	5.3	30.2	NO	58	10.7	13.83	1.00	1.00	No calculated difference in fatality as both under tilted flame	1.13E-05	Bund foam pourers	0.1	3.16E-07
																			Independent high level shutdown (assume to apply to 80% of freqency attriuted to overfill	0.1	
				57.8	Site Boundary	15.0	43.9	Cl 5.8.3	0.8	29.7	NO	58	10.8	19.07	1.00	1.00					
				57.8	offsite protected place	15.0	43.9	Cl 5.8.3	0.8	29.7	NO	58	10.8	19.07	1.00	1.00					

Directly under flame -heat radiation underpredicted -set outcome to 100% fatality

APPENDIX D. REFERENCES

1. **CCPS.** *Guidelines for Initiating Events and Independent Layers of Protection.* 2016.
2. *RR1113 Review of Vapour Cloud Explosion Incidents.* **HSE, UK.** 2017.
3. **LASTFire Project Update.** *Large Atmospheric Storage Tank Fire Project, Incident Survey for 1984-2011.* 2012 Edition.
4. **NSW Department of Planning and Environment.** *Hazardous Industry Planning Adivsory Paper No 10 - Land Use Safety Planning .* 2011.
5. **TNO Institute of Environmental Sciences.** *Green Book: Method of determination for possible damage to people and objects resulting from the release of hazardous materials.* 2nd. 2005.
6. **VROM.** *Besluit Externe Veiligheid Inrichtingen (External Safety (Establishments) Decree).* 2014.
7. **Fire and Blast Information Group.** *Technical Note 12 – Vapour Cloud Development in over-filling Incidents.* April 2013.
8. **UK HSE.** *Safety and environmental standards for fuel storage sites - Process Safety Leadership Group Final Report.* 2009.
9. **TNO Institute of Environmental Sciences.** *Yellow Book: Methods for the calculation of physical effects due to releases of hazardous materials (liquids and gases).* 2005. Third Edition Second revised print.
10. **Association, Chemical Industries.** *Guidance for the location and design of occupied buildings on chemical manufacturing sites.* 2nd Edition, 2003.

B3.3. Heat radiation distances T482: Gasoline



NOTE: these show impacts in all / any direction. Actual effect would be in downwind area only.

B3.4. Tank fire consequence results

Tank ID	Type	Service	Capacity	Receptor	Required Sep distance from tank edge	Actual sep distance from tank edge	Compliance with AS 1940	Flame extent (m) from tank centre	Predicted Heat radiation level (-) at 1.5m height (From Tank centre)		Predicted Heat radiation level (-)at tank height (From tank centre)		Prob of Fatality at 1.5m height (From Tank centre)		Prob of Fatality at tank height (From tank centre)		Comments
T-352	Fixed roof	Diesel	5773	Security fence	7.5	6.6	NO	34	13.0	11.6	64.4	67.2	1.00	1.00	1.00	1.00	No material difference in outcome - under tilted flame
T-352	Fixed roof	Diesel	5773	Adjacent tank (T-214)	15	14.7	NO	34	14.0	14.2	21.4	22.4	1.00	1.00	1.00	1.00	No material difference in escalation outcome -Spray cooling provided
T-378	EFR	Gasoline	6944	Off-site protected places	50	33.0	NO	39	2.7	6.6	1.7	4.6	0.00	0.00	0.00	0.00	No material difference - no fatality outcome Injury risk of 4.7kW/m2 exceeded at actual but not at required sep distance
T-378	EFR	Gasoline	6944	Adjacent tank (T-214)	15	7.6	NO	39	16.7	11.8	40.6	70.2	1.00	1.00	1.00	1.00	No material difference in escalation outcome -Spray cooling provided
T-378	EFR	Gasoline	6944	Adjacent tank (T-15721)	15	7.6	NO	39	16.7	11.8	40.6	70.2	1.00	1.00	1.00	1.00	No material difference in escalation outcome -Spray cooling provided
T-214	IFR	Gasoline	2409	Off-site protected places	50	46.0	NO	32	1.7	2.0	1.5	1.6	0.00	0.00	0.00	0.00	No material difference - no fatality outcome Injury risk of 4.7kW/m2 not exceeded at actual or required sep distance
T-214	IFR	Gasoline	2409	Adjacent tank (T-378)	15	7.6	NO	32	20.9	21.8	18.9	62.1	1.00	1.00	1.00	1.00	No material difference in escalation outcome -Spray cooling provided
T-482	IFR	Gasoline	5627	Off-site protected places	50	39.0	NO	40	2.8	5.1	1.9	3.5	0.00	0.00	0.00	0.00	No material difference - no fatality outcome Injury risk of 4.7kW/m2 exceeded at actual but not at required sep distance
T-482	IFR	Gasoline	5627	Adjacent tank (T-7969)	15	6.2	NO	40	26.7	18.7	44.0	74.5	1.00	1.00	1.00	1.00	No material difference in outcome - Spray cooling provided
T-482	IFR	Gasoline	5627	Adjacent tank (T-7970)	15	10.3	NO	40	26.7	18.7	44.0	74.5	1.00	1.00	1.00	1.00	No material difference in outcome - Spray cooling provided
T-482	IFR	Gasoline	5627	Adjacent tank (T-620)	15	6.9	NO	40	26.7	18.7	44.0	74.5	1.00	1.00	1.00	1.00	No material difference in outcome - Spray cooling provided
T-1	Fixed roof	Diesel	1786	Adjacent tank (T-6)	5.8	5.7	NO	29	17.2	17.0	60.0	60.3	1.00	1.00	1.00	1.00	
T-6	Fixed roof	Diesel	3548	Adjacent tank (T-1)	9.2	5.7	NO	30	9.2	9.0	64.7	65.0	1.00	1.00	1.00	1.00	No material difference in outcome - Spray cooling provided
T-6	Fixed roof	Diesel	3548	Adjacent tank (T-7)	9.2	8.8	NO	30	9.2	9.0	64.7	65.0	1.00	1.00	1.00	1.00	No material difference in outcome - Spray cooling provided
T-7	Fixed roof	Jet	2657	Office, workshops, etc	15	9.2	NO	25	5.5	5.6	11.5	16.9	1.00	1.00	1.00	1.00	No material difference in outcome - under tilted flame
T-7	Fixed roof	Jet	2657	Adjacent tank (T-6)	9.2	8.5	NO	25	5.5	5.5	11.5	19.5	1.00	1.00	1.00	1.00	No material difference in outcome - Spray cooling provided
T-7969	Fixed roof	Ethanol	280	Adjacent tank (T-482)	15	6.2	NO	9	1.9	3.1	2.1	16.5	0.00	0.00	0.00	0.29	No material difference in outcome - Spray cooling provided
T-7970	Fixed roof	Biodiesel	531	Adjacent tank (T-482)	15	9.6	NO	29	9.3	10.5	16.3	25.4	1.00	1.00	1.00	1.00	No material difference in outcome - Spray cooling provided

Directly under flame -heat radiation underpredicted -set outcome to 100% fatality / within escalation area

specific to offsite protected places

B3.5. Bund fire consequence results

Bund	Tanks in bund	Service	DG class	Pool fire diameter	Receptor	Required Sep distance (from bund edge)	Required Sep distance (from pool fire centre)	AS1940 2017 ref	Actual sep distance (from bund	Actual Sep distance (from pool fire centre)	Compliance with AS 1940	Flame extent (m) from tank centre	Predicted Heat radiation level (kW/m2) at 1.5m height		Probit level (-) at 1.5m height (From Tank centre)		Prob of Fatality at 1.5m height (From Tank centre)		Comments
						(m)	(m)		(m)	(m)		(ie area out to 12.5 kW/m2 projected to ground - approximately under luminous flame portion)	Required sep distance	actual sep distance	Required sep distance	actual sep distance	Required sep distance	actual sep distance	
South Bund	1, 6, 7	Gasoline	3PGII	53.6	Control room	15.0	41.8	Cl 5.8.3	1.5	28.3	NO	60	10.7	20.19	2.96	5.13	1.00	1.00	No calculated difference in fatality as both under tilted flame
				53.6	Site Boundary	15.0	41.8	Cl 5.8.3	1.1	27.9	NO	60	10.7	20.19	2.96	5.13	1.00	1.00	
				53.6	offsite protected place	15.0	41.8	Cl 5.8.3 (i)	3.0	29.8	NO	60					1.00	1.00	
North Bund	214, 378, 482	Gasoline	3PGII	49.8	Filter workshop	15.0	39.9	Cl 5.8.3	5.3	30.2	NO	58	10.7	13.83	2.95	3.83	1.00	1.00	No calculated difference in fatality as both under tilted flame
				57.8	Site Boundary	15.0	43.9	Cl 5.8.3	0.8	29.7	NO	58	10.8	19.07	2.99	4.93	1.00	1.00	
				57.8	offsite protected place	15.0	43.9	Cl 5.8.3	0.8	29.7	NO	58	10.8	19.07	2.99	4.93	1.00	1.00	

Directly under flame -heat radiation underpredicted -set outcome to 100% fatality

APPENDIX C. FREQUENCY DATA AND RESULTS

C1. Overview

Relevant frequencies have been reproduced below from LASTFIRE 2012 Ref (3).

C1.1. Tank top fire

Table 7.1(c) shows rim seal fire and full surface fire incident frequencies by tank type.

Rim Seal Fires		Full Surface Fires		
Fires/tank year (OTFR)	Fires/tank year (IFR)	Fires/tank year (FIXED)	Fires/tank year (OTFR)	Fires/tank year (IFR)
2.27×10^{-4}	4.39×10^{-5}	2.1×10^{-5}	5.29×10^{-5}	None recorded

Table 7.1(c) – Rim Seal/Full Surface Fire Incident Probabilities By Tank Type

C1.2. Bund Fires

7.1 Current Data

Table 7.1(a) summarises calculated incident probabilities based on the data received for the LASTFIRE Update Incident Survey:-

Rim Seal Fire	Vent Fire	Pipe, Flange, Valve Fire	Bund Fire	Spill on Roof Fire
2.0×10^{-4}	9.71×10^{-6}	9.07×10^{-6}	1.13×10^{-5}	4.53×10^{-6}
Full Surface Fire	**Boilover**	**Other**	**Vapour Space Explosion**	**Pontoon Explosion**
2.95×10^{-5}	Note [1]	3.4×10^{-5}	2.27×10^{-5}	2.27×10^{-5}

Table 7.1(a) – Summary of Incident Probabilities

The majority of fully developed bund fires are assumed to occur as a result of major tank failures or overfills. Analysis of the causes of loss of containment data in LASTFIRE as per Section C1.3 suggests that historically about 83% of major loss of containments are due to overfill and 17% to tank mechanical failures.

For the purposes of assessment, it is assumed that large bund fires causes are approximately in the same proportion, i.e. 80% due to overfill, 20% to mechanical failure.

C1.3. Major leak data

Summary of LASTFIRE 2011 report data for leaks into bund

TOTAL	3.97E-04	Type of release (bund)	Leak freq distrib (per year)	With warning?	Notes
Corrosion of tank bottom	33	Major	7.49E-05	Yes	
Floor plate weld failure	2	Major	4.54E-06	Yes	
Bottom annular plate corrosion	2	Major	4.54E-06	Yes	
Human error	3	Minor	6.81E-06	No	?
Drain failure	20	Minor	4.54E-05	No	dewatering errors
Mixer leak	5	N/A	1.13E-05	-	not applicable
Leak from p/wrk, flange, valve	6	Minor	1.36E-05	No	
Shell weld fracture	1	Major	2.27E-06	No	
Roof / shell weld fracture	4	N/A	9.07E-06	-	roof height
Roof instability	1	N/A	2.27E-06	-	roof height
Earthquake	3	Major	6.81E-06	no	
Shell corrosion	1	Minor	2.27E-06	Yes	
Overfill	20	N/A	4.54E-05	-	
Other	74	Minor	1.68E-04	No	
Total	175	**Total**	3.97E-04		

Overall Totals	Frequency	Comments
Major	9.07E-06	'No warning' events only
Minor	2.34E-04	
N/A	0.00E+00	
TOTAL	2.43E-04	

NOTE: excludes 'with warning' events and N/A events

Bund fire freq	1.13E-05	per year
Major	9.07E-06	per year
Overfill	4.54E-05	per year
Proportion Major	0.17	
Proportion Overfill	0.83	

C2. Frequency results

The following tables provide the base frequency (i.e. AS1940:2017) for each tank and bund fire event, together with the estimated effect on frequency with the additional installed controls. (Note that the frequency estimates do not include probability of exposure factors such as wind direction or wind speed, probability of presence, successful escape. Therefore, they cannot be used for cumulating risk or comparison to risk criteria).

C2.1. Tank top fires

Extract from 21345 Calc heat radiation results FINAL.XLSX inserted on following page

Table 3.2: AS1940:2017 Mandatory Controls (except separation distances) compared with installed terminal controls

AS1940:2017 controls				Effect on scenario?							
Control measure	Mandatory under AS1940: 2017	AS1940: 2017 ref	Installed at Wickham terminal?	Tank top fire (full surface)	Tank to tank escalation	Bund fire (causes: overfill or major tank failure)	Tank overfill (and large flammable vapour cloud)	Comments	Relevant Caltex drawing / document	Additional LOPA factor	Ref
Tank contents gauging with high level alarm	Yes	5.3.3 (e) (iv)	Yes	-	-	Yes	Yes		2019_07 Tank Alarm Setting Calculator Newcastle Terminal.XLS	-	
Independent high level alarm (LAHH)	Yes	5.3.3 (f)	Yes	-	-	Yes	Yes		2019_07 Tank Alarm Setting Calculator Newcastle Terminal.XLS	-	
Independent high level shutdown (LSHH)	No	5.3.3 (f) Note 3 'consideration' to shutdown via suitable interlock	Yes	-	-	Yes	Yes	Additional control measure: All are designed and tested to meet SIL 1 requirements. Although as per Caltex SIL allocation, the combustible tanks do not require a SIL rating. Trip isolates tank feed.	2019_07 Tank Alarm Setting Calculator Newcastle Terminal.XLS Cause and Effects chart	0.1	CCPS
Flammable vapour or liquid hydrocarbon detection in bund	Yes	5.8.3. (j)	Yes	-	-	Yes (delayed ignition case only)	Yes	Gas detection installed in all flammables bunds and alarms at 20% LEL. Diesel only bund has hydrocarbon liquid detection	Drawing: 72526 Alarm Point & Detector Locations Rev 4	-	
Fixed foam system (automatic or manual) for flammables vertical fixed roof tanks over 6m diameter (with or without floating roof)	Yes	11.13.1	Yes	Yes	Yes	-	-	Manually activated on detection of tank fire T352 is a diesel tank in separate bund so is not a 'tank on fire' under AS1940:2017 - however it still has internal foam pourers.	Drawing: 73504 Fire Fighting System Plan Rev 9	-	
Fixed foam system (automatic or manual) for combustibles vertical fixed roof tanks	No	not referred to	Yes (except T352 diesel only I separate bund)	Yes	Yes	-	-	Additional control measure: Manually activated on detection of tank fire	Drawing: 73504 Fire Fighting System Plan Rev 9	0.1	CCPS
Fixed spray cooling rings - for all adjacent tanks within 1.5 diameters of 'tank on fire'	Yes	Appendix I I1(a) (f) (i)	Yes - all tanks (except T7971/7972 which comply with 1.5 diameter rule and also are decommissioned)	-	Yes	-	-	Tank on fire is any vertical fixed roof tank storing flammables (including IFR tanks) or any fixed roof tank storing combustibles in same compound as flammable tanks	Drawing: 73504 Fire Fighting System Plan Rev 9	-	
CCTV	No	not referred to	Yes covering all tanks and bunds with flammable storage as well as T352 diesel only bund	Yes	Yes	Yes	Yes	Additional control measure: Will allow early detection of tank fires, spills to bund including assisting in detecting overfill	Drawing: 71535 CCTV Layout Rev 0	0.5	estimate
Bund foam pourers	No	not referred to	Yes	-	-	Yes	-	Additional control measure: Manually activated on detection of spill (ignited or unignited)	Drawing: 73504 Fire Fighting System Plan Rev 9	0.1	CCPS

4. CONSEQUENCE ASSESSMENT

4.1. Overview

The potential impacts of fully developed tank surface fires and bund fires were modelled.

4.2. Assumptions

The largest impact areas from heat radiation distances for pool fires are experienced under high wind conditions. The NSW Fire Brigade typically request a 95 percentile wind speed be used for modelling in Fire Safety Studies for development consent and this approach has been adopted for this review. Meteorological data was reviewed as contained in APPENDIX A and 10.8 m/s selected as the wind speed. Other modelling assumptions are summarised in APPENDIX B.

The heat radiation levels have been correlated to a probability of fatality using a probit equation as per APPENDIX B. This is used to assess the effect at protected places (i.e. on people), hence evaluate any differences in impact at the required separation distance versus the actual distance.

Escalation potential at a neighbouring tank is assessed against specific heat radiation levels.

All assessment impact levels are summarised in Table 4.1.

Table 4.1: Vulnerability summary

Event	Level	Probability of fatality (20 secs exposure from probit)	Other effects
Pool fire	Within fire envelope or under tilted flame	100%	Escalation due to direct impingement
	23 kW/m^2	71%	Escalation range 23kW/m^2 structural steel failure due to heat radiation. However, spray cooling of atmospheric tanks is typically required (common industry practice) where heat radiation levels are in the range 8 – 12kW/m^2
	12.5 kW/m^2	16%	
	9.9 kW/m^2	1%	
	4.7 kW/m^2	Injury	Injury only

4.3. Results

All consequence results are provided in tabular form in APPENDIX B.

Representative side view diagrams and heat radiation versus distance charts are also provided for a tank top fire and a bund fire in APPENDIX B.

Note that the results are shown in the downwind direction. If the receptor is under the tilted flame, to account for flame drag effects, 100% fatality is assumed.

Effects upwind are minimal as can be seen from the side view diagrams in APPENDIX B.

In summary, the fire modelling results show that:

- There is no material difference in the probability of a fatality outcome due to heat radiation or flame impingement from tank top fires at the AS1940:2017 required separation distance compared against the actual separation distances.
    - For small separation distances from tanks (i.e. 7.5 to 15m to boundaries) this is because the receptor is directly under the tilted flame and the predicted fatality probability is 100%.
    - For large separation distances (e.g. 40 - 50m to offsite protected places) predicted heat radiation levels are below fatality levels.
- For bund fires, the required separation distance is 15m to various receptors compared with 1-3 m actual distance. For a fully developed bund fire, there is no material difference in the probability of a fatality outcome as the receptor is directly under the tilted flame and the predicted fatality probability is 100%. However it is recognised that direct flame contact is more likely very close (i.e. at 1 – 3 m) to the bund wall.
- For tank to tank escalation there is no material difference at the AS1940:2017 required separation distance compared against the actual separation distances. The heat radiation at a neighbouring tank at a separation distance of 7.5 m or 15m is in excess of 23 kW/m^2 (where structural failure may occur). Tank cooling is required under AS1940:2017 Appendix I for tanks within 1.5 diameters of a tank-on-fire. In all cases for tanks within 1.5 diameters of a neighbouring tank, fixed cooling sprays are already installed.

5. FREQUENCY AND RISK ASSESSMENT

5.1. Overview

Risk is a combination of frequency and consequence. As per the consequence results, there is no difference in consequence outcomes (measured as fatality due to heat radiation or flame engulfment) between the AS1940:2017 or the actual separation distances.

This means that the relative difference in risk can be assessed at the AS1940:2017 and actual distances on a frequency basis only, without accounting for any differences in consequence or severity.

The approach taken was to:

- Identify publicly available statistical data for tank fire, bund fire and overfill events.
- Assume that the data is applicable to the base case risk with all AS1940:2017 mandatory controls in place. It is noted these values will most likely represent an overestimate of event frequencies for sites with all mandatory controls in AS1940:2017. Some of these controls have not been, and still may not be present in fuel terminals (e.g. gas detection has not been commonly implemented in hydrocarbon fuel terminals). However as the purpose is to assess only the relative effect on frequency of additional controls for particular types of scenarios, adopting the industry average statistical data is regarded as suitable for this purpose.
- Adjust the base case frequency to account for additional installed controls relevant to the event using Layer of Protection Analysis (LOPA) factors based on guidance from CCPS (Ref (1)) and arrive at an adjusted frequency.
- Compare the base case and adjusted frequency for each tank or bund non-compliance to identify whether risk with installed controls is at least equivalent or lower than risk for the AS1940:2017 installed case, or whether additional control measures are required.

5.2. Frequency data

5.2.1. Incident frequencies

LASTFIRE 2012 data Ref (3) was used to approximate the frequency of tank top fires or bund fires.

Base data and assumptions for use are summarised in Table 5.1. Additional background information is provided in APPENDIX C.

Table 5.1: Incident frequency data

Incident	Frequency per year per item	Comments
Bund fires	1.13E-05	Fully developed bund fire Proportion due to overfill 80% Proportion due to major mechanical failure 20%
Fixed roof tank fire (combustible)	2.1E-06	Lastfire adjusted by a factor of 0.1 to account for reduced ignition potential of combustibles such as diesel
Fixed roof tank fire (flammable)	2.1E-05	Jet fuel and ethanol only.
IFR tank fire	4.84E-06	No records in LASTFIRE 2012 of full surface fires in IFR tanks. Assume 10% of rim seal fires plus spill on roof fires potentially result in a full surface fire. This approach accounts already for fire protection and ignition control so additional fire protection credit can't be taken.
EFR tank fire	5.29E-05	OTFR (same as EFR) data indicates rim seal fire frequency of 2.27x10-4 per year, full surface fire of 5.29x10-5

5.2.2. Control measures

It is assumed that the effect of control measures required by AS1940:2017 is already accounted for in the base data, i.e. no adjustment has been made to the historical LASTFIRE data to attempt to account for control measures that are becoming more common e.g. gas detection.

LOPA factors have been applied only for those control measures which are installed and are additional to AS1940:2017 requirements. This has the effect of reducing the event frequencies, hence reducing risk.

Table 5.2: LOPA factors for additional control measures

Additional control	Factor	Comments	Ref
Independent tank high level shutdown	0.1	Closes tank inlet valve, testing assumed to be adequate to meet reliability target of 90%. This is equivalent to an independent BPCS layer or the lowest reliability end of the SIL1 range.	CCPS
Fixed foam system (automatic or manual) for combustibles in vertical fixed roof tanks	0.1	Manually activated based on detection by operator and / or CCTV. Reduces likelihood of fire developing to the point of tank roof collapse and full surface fire.	CCPS

Additional control	Factor	Comments	Ref
CCTV covering all tanks and bunds with flammable storage	0.5	This improves detection and response time for other events. It is not a control measure by itself but helps to allow credit to be taken for manual detection and activation of other systems such as foam pourers or spray cooling. Assume this is a factor of two better than average detection via operator rounds etc. This factor is applied only for escalated scenarios as there is a longer response time before damage to neighbouring tanks occur	Estimate
Bund foam pourers	0.1	Manually activated based on detection by operator and / or CCTV. Assumed to be effective in preventing ignition if applied to large spill before ignition and to minimizing growth of fire if immediate ignition occurs.	CCPS

5.3. Frequency results

All frequency results are provided in tabular form in APPENDIX C.

Figure 5.1 shows a summary of the relative risk to receptors of the case with AS1940:2017 mandatory controls compared with risk with all installed additional controls. These are presented for each tank fire or bund fire. All risks are equivalent to or lower than the case with AS1940:2017 mandatory controls.

Figure 5.2 shows a summary of the relative risk of tank to tank escalation with AS1940:2017 mandatory controls compared with escalation risk with all installed additional controls. All risks are the same or lower than the case with AS1940:2017 mandatory controls.

Note that the frequency estimates do not include probability of exposure factors such as wind direction or wind speed, probability of presence, successful escape. Therefore the frequency results cannot be used for cumulating risk or comparison to risk criteria.

5.4. Conclusions

Overall the results demonstrate that the risk from tank top fires or bund fires to receptors defined in AS1940:2017 (i.e. protected places, site boundary, security fences, neighbouring tanks) with additional installed controls is the same or lower than the risk with all mandatory AS1940:2017 control measures.

Additional control measures have therefore not been identified or assessed.

Figure 5.1: Relative risk – to receptors such as protected places

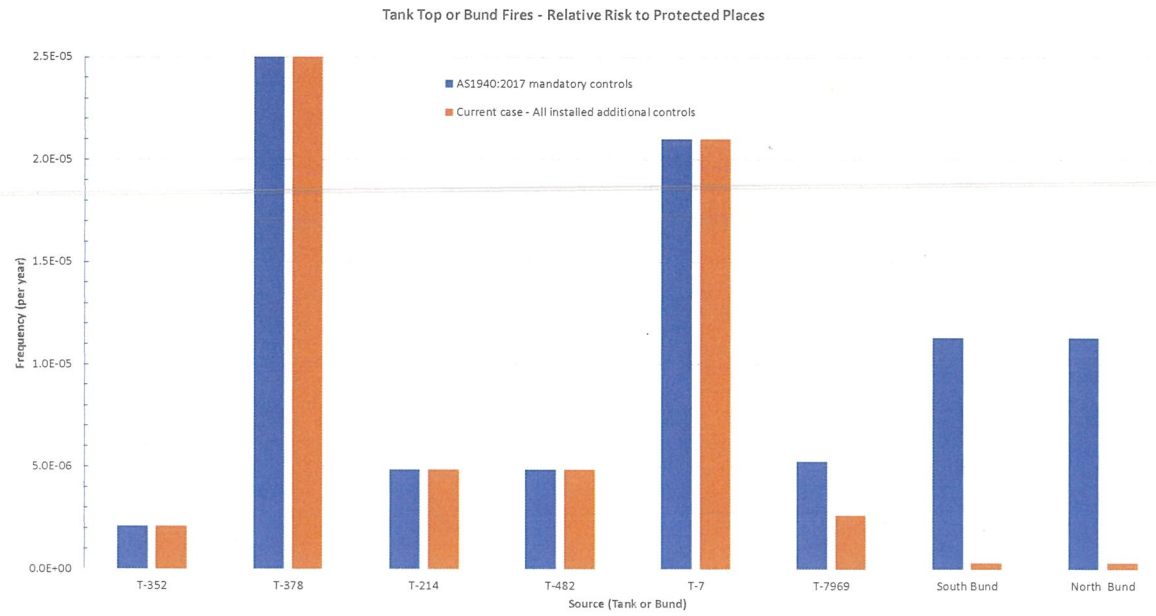
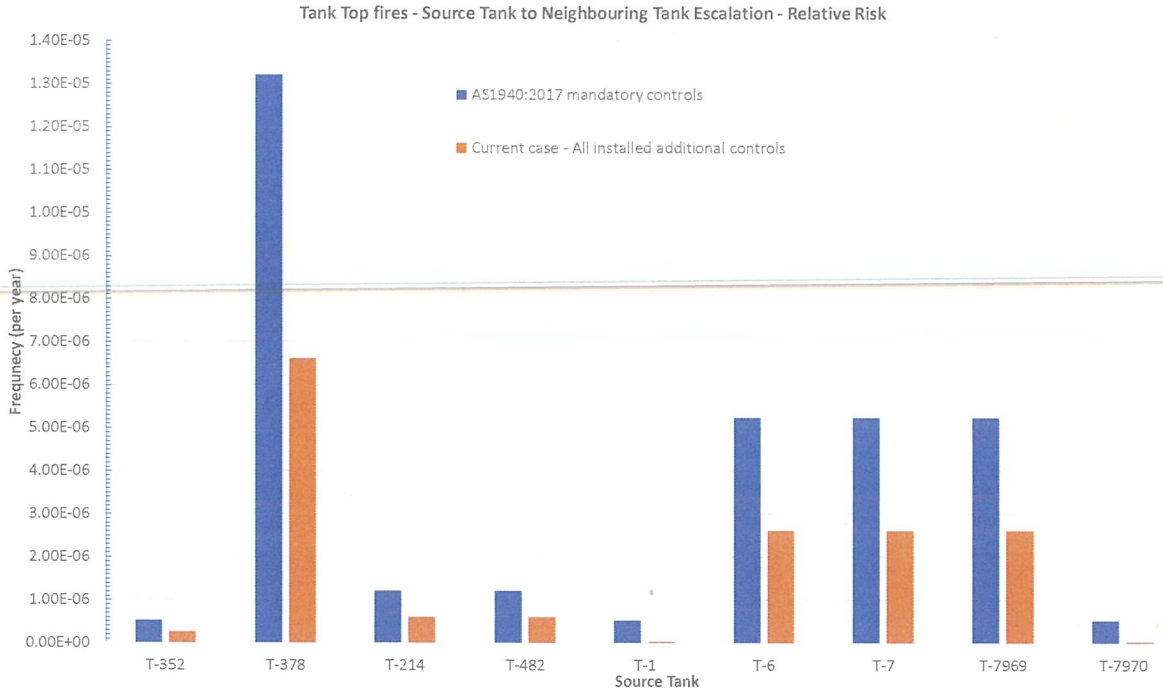
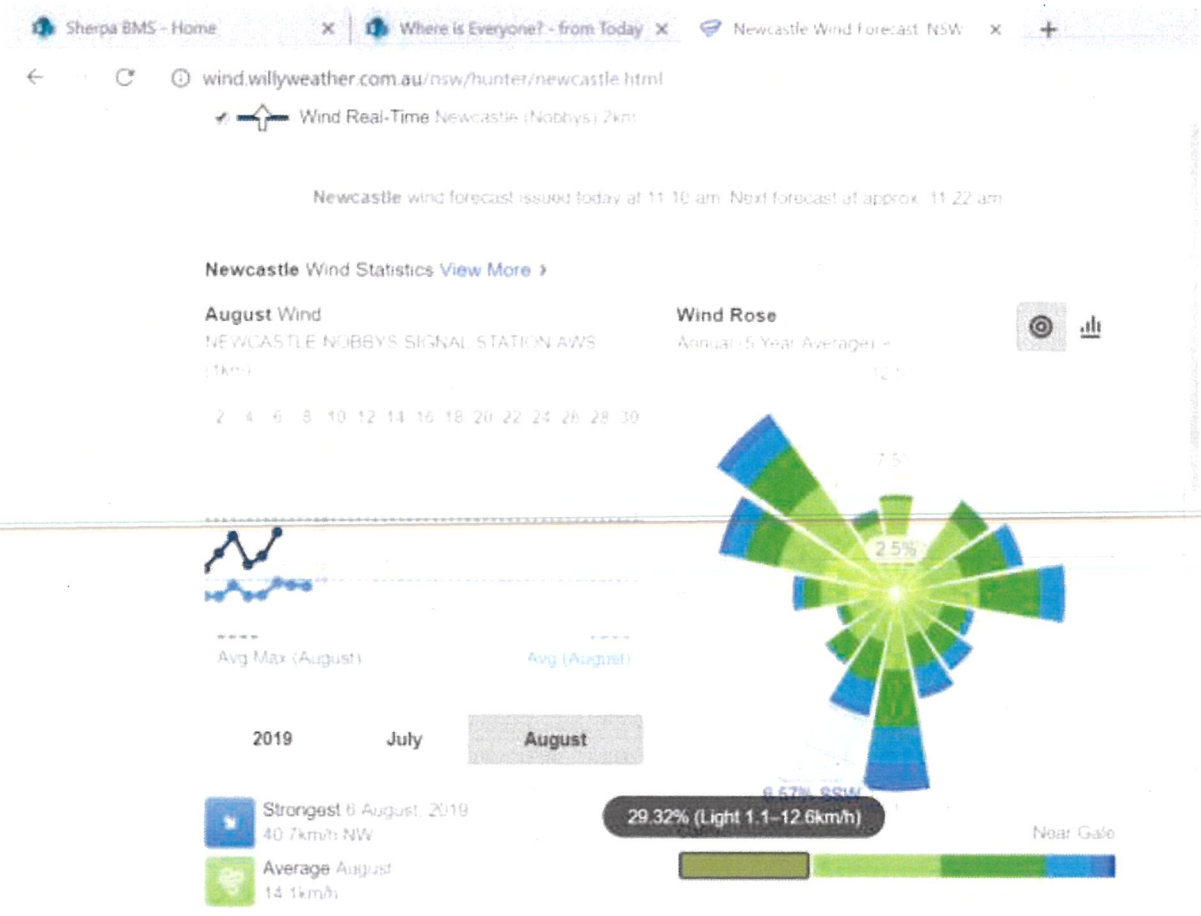


Figure 5.2: Relative risk - tank to tank escalation



APPENDIX A. WIND DATA

Wind speed range	Upper wind speed (km/h)	Upper wind speed (m/s)	percentage of the days in the wind speed range	percentage of the days under the upper bound windspeed
Calm	1.1	0.3	0.44%	0.44%
Light	12.6	3.5	29.23%	29.67%
Gentle	19.8	5.5	31.07%	60.74%
Moderate	28.8	8.0	24.37%	85.11%
Fresh	38.9	10.8	10.34%	95.45%
Strong	50	13.9	3.90%	99.35%
Near Gale	61.9	17.2	0.65%	100.00%
Gale	74.9	20.8	0.0037%	100.00%



APPENDIX B. CONSEQUENCE MODELLING

B1. Fires

Fires were modelled using PHAST v8.2. The Two Zone pool fire model was used with the source term based on an equivalent diameter pool to the bund surface area.

Modelling parameters are shown in Table B.1.

Results showing estimated heat radiation level at the AS1940:2017 distance from the tank and the heat radiation level at the actual separation distance are shown in the tables in Section B3.4 for tank top fires and Section B3.5 for bund fires, together with the predicted probability of fatality at each distance.

Note that for areas directly under a tilted elevated flame the model predicted heat radiation at ground level significantly underestimates effects as it does not count for direct flame contact due to flame drag wind effects. This is noted in the results and 100% fatality effect assumed in this area. This is also illustrated in the diagram in Section B3.1.

The results for representative bund fire and tank fire scenarios were also obtained for the following heat radiation levels defined in HIPAP 4, Ref (4):

- 23 kW/m^2 – likely fatality for extended exposure and chance of fatality for instantaneous exposure
- 12.6 kW/m^2 – Significant chance of fatality for extended exposure. High chance of injury
- 4.7 kW/m^2 – Will cause pain in 15-20 seconds and injury after 30 seconds exposure (at least second degree burns will occur).

An example of the impact area of these heat radiation levels for T482 is shown and compared against the required separation distance to offsite protected places (50m).

Table B.1: Modelling parameters

Item	Value	Basis
Product	Gasoline - ULP Summer Diesel – n-dodecane	PHAST database materials used for modelling.
Ambient temperature	10 ° C	Nominal
Soil temperature	10 ° C	Assumed equal to ambient temperature.
Relative humidity	70%	Typical
Height of the receiver	1.5 m	1.5 m around upper body/face height.
	Tank height	Tank height for receptors at height e.g. neighbouring tank
Wind speed at 10 m height	10.8 m/s	95 percentile windspeed condition. Higher wind speed would result in longer flame lengths and greater distances to specified heat radiation levels.

B2. Vulnerability

The vulnerability relationship for heat radiation is from the TNO Green Book, Ref (5), which is defined by the probit shown below:

$$Pr = -36.38 + 2.56(Q^{4/3}t)$$

where,	Pr	probit (-)	
	Q	heat radiation level	(W/m^2)
	t	exposure time	(s)

TNO recommends 20 seconds for heat radiation exposures on the basis that the average escape time is 20 seconds which includes 5 seconds reaction time and then escaping at 4 metres per second, Ref (6). This was adopted as the exposure duration.

The probit value can then be converted to a probability of fatality using the relationship below. Examples are summarised in Table B.3.

These can then be converted to a probability of fatality using the error function transform:

$$\text{Probability} = 0.5(1 + \text{erf}(\frac{\text{Pr}-5}{\sqrt{2}}))$$

Table B.2: Vulnerability summary

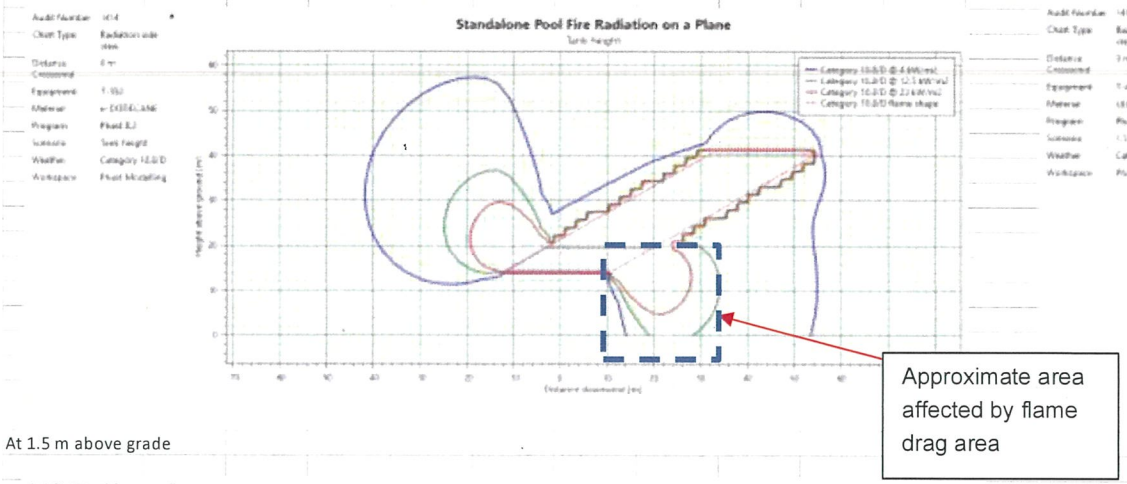
Event	Level	Probability of fatality assumed in QRA (20 secs exposure calculated from probit)	Other effects
Pool fire	Within fire envelope	100%	Escalation due to direct impingement
	23 kW/m^2	71%	Escalation - due to structural steel failure due to heat radiation.
	12.5 kW/m^2	16%	Possible fatality indoors if line of sight exposure occurs.
	9.9 kW/m^2	1%	
	4.7 kW/m^2	Injury	Injury only

B3. Example fire diagrams

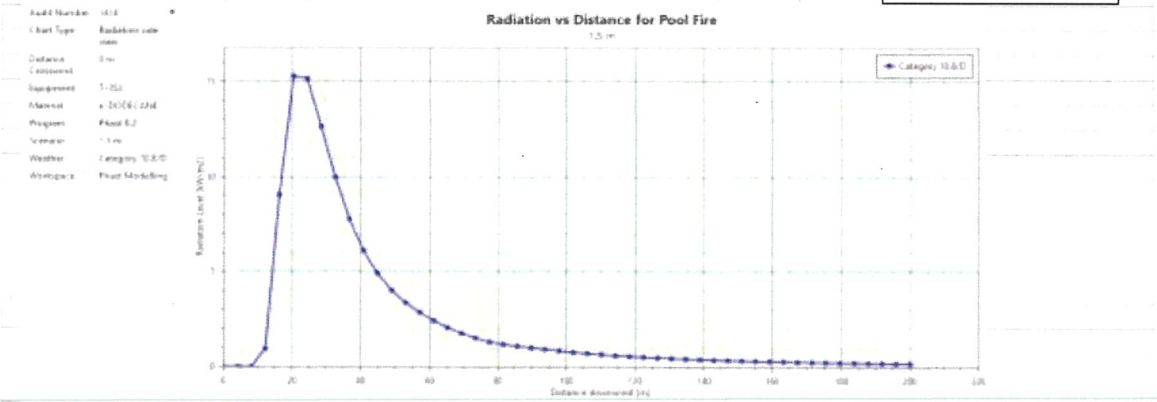
B3.1. T352: Diesel

T-352 (Diesel)

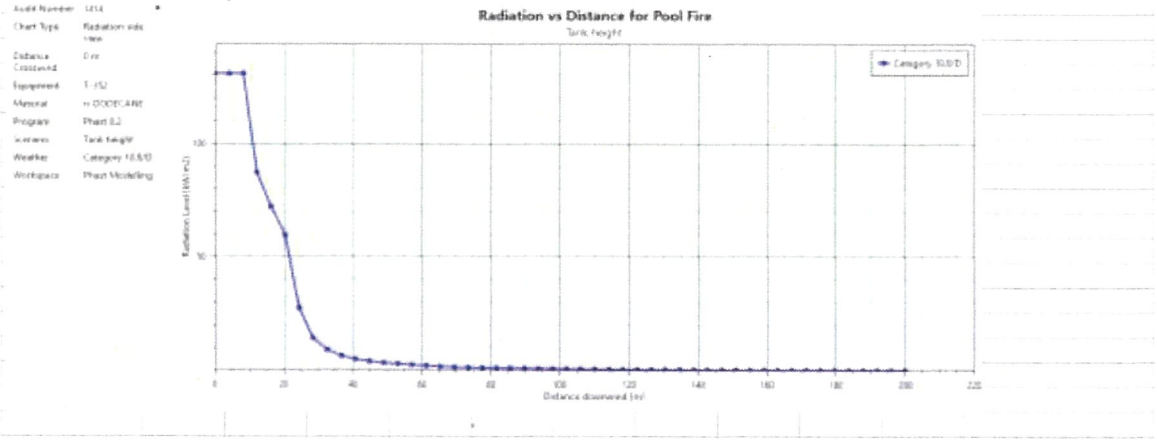
Side view



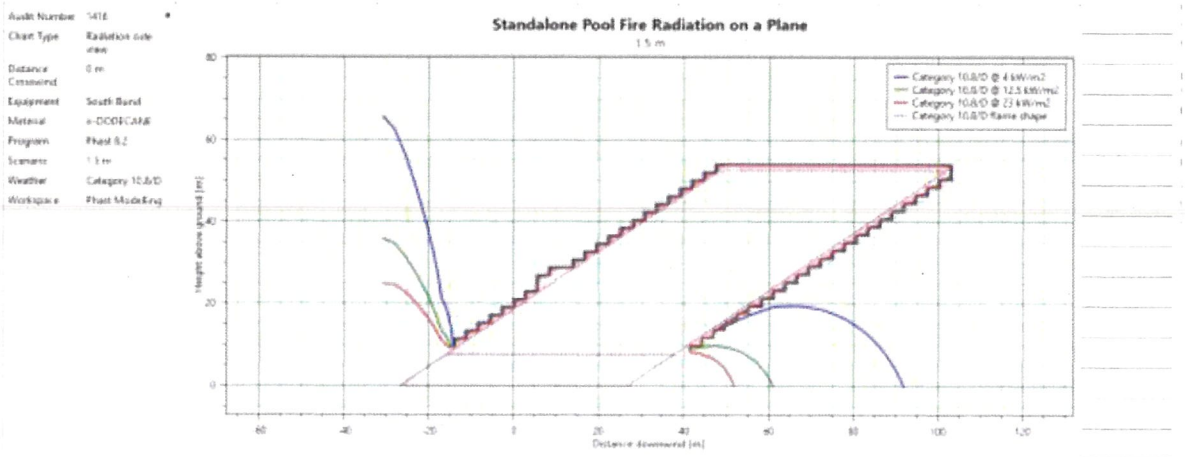
At 1.5 m above grade



At Tank height



B3.2. South Bund



At 1.5 m above grade