Hazard and Risk Assessment of Ampol Wickham Terminal and Pipeline

For the Council of the City of Newcastle, NSW

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Notation

Abbreviation	Description
24/7	24 hours in the day, 7 days a week
ABS	Australian Bureau of Statistics
AG	Above Ground
ALARP	As Low As Reasonably Practicable
Ampol	Ampol Ltd (Formerly Caltex Australia Petroleum Pty Ltd)
API	American Petroleum Institute
Arriscar	Arriscar Pty Limited
AS	Australian Standard
ATG	Automatic Tank Gauging
BoM	Bureau of Meteorology
BSI	British Standards Institute
Caltex	Caltex Australia Petroleum Pty Ltd
CIA	Chemical Industry Association (UK)
DA	Development Application
DBYD	Dial Before You Dig
DG	Dangerous Good
DoT	Department of Transport (USA)
DPIE	NSW Department of Planning, Industry and Environment
FBR	Full Bore Rupture
F-N	Cumulative Frequency vs. Number of Fatalities
HDD	Horizontal Directional Drilling
HIPAP	Hazardous Industry Planning Advisory Paper
HRA	Hazard and Risk Assessment
HSE	Health & Safety Executive (UK)
HSL	Health & Safety Laboratory (UK)
IBC	Intermediate Bulk Container
IFR	Internal Floating Roof
IHLS	Independent High Level Switch
kg	kilograms
kg/m^3	kilograms/ cubic metre

Abbreviation	Description
kg/s	kilograms/ second
km	kilometres
kPa	kilo-Pascals
kPag	kilo-Pascals gauge
kW/m^2	Kilo-Watts per square metre
L	Litres
L/min	Litres/ minute
LFL	Lower Flammability Limit
LPG	Liquefied Petroleum Gas
m	metres
m/s	metres/ second
m^2	Square metres
m^3	Cubic metres
m^3/h	Cubic metres per hour
mm	millimetres
NASA	National Aeronautics and Space Administration
NELP	Newcastle Local Environment Plan
OGP	International Association of Oil & Gas Producers
PG	Packing Group
PS	Planning Circular
PULP	Premium Unleaded Petrol
QRA	Quantitative Risk Assessment
RAAF	Royal Australian Air Force
RR	Research Report (UK HSE)
s	second
SCADA	Supervisory Control and Data Acquisition
SCI	Steel Construction Institute (UK)
SDS	Safety Data Sheet
SEPP	State Environmental Planning Policy
SEPPI	State Environmental Planning Policy Infrastructure
SNP	Sydney-Newcastle Pipeline
SPULP	Special Premium Unleaded Petrol

Abbreviation	Description
TNO	The Netherlands Organisation for applied scientific research
TPA	Third Party Activity
TTLR	Tanker Truck Loading Rack
UFL	Upper Flammability Limit
UG	Underground
UKOOA	UK Offshore Operators Association (now Oil & Gas UK)
UV/IR	Ultraviolet/ Infra-Red
VCE	Vapour Cloud Explosion
VIC EPA	Victorian Environment Protection Authority
VRU	Vapour Recovery Unit
W/m2	Watt / square metre
µ	Ignition density/ hectare

EXECUTIVE SUMMARY

Ampol Ltd (Ampol), formerly Caltex Australia, operates a refined petroleum products storage and distribution terminal at the corner of Annie and Arthur Streets, Wickham, NSW. The terminal receives petroleum products (gasoline, diesel) via the Sydney-Newcastle Pipeline (SNP) from Ampol Banksmeadow terminal in Sydney, and distributes the products through road tankers.

There are currently wool stores on the corner of Annie Street and Milford Street, to the southwest of the Ampol Terminal. These are used as self-storages. Investec Australia Loans Management Pty Ltd (Investec) has lodged a Development Application (DA) (1) to develop the Wickham Wool Stores area for commercial and residential uses.

Given the proximity of the proposed development to the Ampol Terminal, and potential land use safety issues, the Council for the City of Newcastle (the Council) engaged Arriscar Pty Ltd to undertake an independent Hazard and Risk Assessment (HRA) study, evaluating the risk from the Ampol Terminal operations on the proposed development. The study was conducted in accordance with Hazardous Industry Planning Advisory Paper (HIPAP) No.6, Hazard Analysis (2), taking into accounts the hazard and risk issues raised in the various submissions to the Council on the DA.

At the request of the Council, full cooperation for the study was extended by Ampol by providing the necessary technical and operational information on the Terminal.

The study covered the petroleum products storage tanks, product receival via Sydney-Newcastle pipeline, Tanker Truck Loading Rack (TTLR), associated pipework, pumps and instrumentation. The risk assessment software SAFETI 8.23 by DNVGL, which is accepted by the industry and regulators, was used for the study, supported by spreadsheets and other reliability software. The estimated risk values were evaluated against the risk criteria in HIPAP No.4 – Risk Criteria for Land Use Safety Planning (3), and HIPAP No.10 -, Land Use Safety Planning (4).

The following results were obtained from the risk assessment:

- The proposed development does not comply with the fatality risk criteria of not exceeding $1x10^{-6}$ per year for new residential developments.
- The proposed development does not comply with the fatality risk criteria of not exceeding 5×10^{-6} per year in for commercial developments.
- The proposed development does not comply with the fatality risk criteria of not exceeding $10x10^{-6}$ per year for open space development.
- The population increase and consequent increase in societal risk from the proposed development does not comply with the F-N criteria in HIPAP 10 (4), and falls in the 'intolerable' zone.
- The risk of injury exceeding a side on overpressure of 7 kPa at $50x10^{-6}$ per year is not generated, indicating that this criterion is complied with.
- The risk of injury exceeding a thermal radiation of 23 kW/m^2 at $50x10^{-6}$ per year falls entirely within the site and does not reach other industrial sites. The risk criterion for injury at adjacent industrial sites is complied with.
- The risk of injury exceeding a thermal radiation of 4.7 kW/m^2 at $50x10^{-6}$ per year does not reach residential developments (including existing and proposed). The risk criterion for injury at residential areas is complied with.

The major contribution to risk of fatality at the proposed development is from vapour cloud explosions arising from flammables tank overfill and Buncefield type incident.

The contribution to societal risk arises from Buncefield type incidents as well as Sydney-Newcastle fuel pipeline incidents in the vicinity of the Terminal.

The Buncefield incident in 2005 is not a one-off incident. Two similar incidents have occurred in the industry since that time (2009), and it is now accepted in the oil & gas industry as a credible risk.

On a consequence basis alone, a vapour cloud explosion can result in side-on overpressure exceeding 70 kPa on the proposed development. Mitigation against such blast load level is not possible.

The risk guidelines [(3), (4)] allow some flexibility for existing facilities built before the guidelines came into force. Individual risk of up to $10x10^{-6}$ per year may be tolerable provided attempts are made to mitigate the risk towards reducing it to $1x10^{-6}$ p.a. While the existing risk may satisfy the criteria of up to $10x10^{-6}$ p.a. in the wool store land, the risk becomes unacceptable with the new residential dwellings in the proposed development.

The risk guidelines also allow some flexibility in societal risk in that if the incremental cumulative risk still falls entirely within the ALARP region, economic and social benefits considerations may be applied. In this instance, the existing societal risk itself partly falls in the intolerable region and the risk with the proposed development extends further into this region. The study concluded that the proposed residential, commercial and open space development at the Wickham woolshed stores site does not comply with the quantitative risk criteria for both individual risk and societal risk in HIPAP No.10 (4), even allowing for a higher level of risk to be tolerable for existing facilities.

1 INTRODUCTION

1.1 Background

Ampol Ltd (Ampol), formerly Caltex Australia, operates a refined petroleum products storage and distribution terminal at the corner of Annie and Arthur Streets, Wickham, NSW. The facility is in the Local Government Area of the City of Newcastle. The terminal receives petroleum products (gasoline, diesel) via the Sydney-Newcastle Pipeline (SNP) from the Ampol Banksmeadow terminal in Sydney and distributes the products through road tankers.

The Wickham Terminal was originally constructed in 1929 and operated by Golden Fleece Ltd. Initially the Terminal consisted of 3 tanks with products imported from overseas. The facility was acquired by Caltex from Golden Fleece Ltd in 1981, one year before the SNP pipeline was commissioned (1982). Since then the Terminal has been progressively upgraded and increased in capacity to handle the product transported through the SNP.

The SNP runs underground along the Avenue up to the western boundary of the Terminal, rising to above ground at the southern boundary of the site.

A site location diagram is shown in Figure 1.

Figure 1: Ampol Newcastle Terminal Site Location

The Ampol Terminal is surrounded by light industrial developments. Entrance to the Terminal is from Hannell Street on the east.

There are currently woolsheds on the corner of Annie Street and Milford Street, to the southwest of the Ampol Terminal. These are used as self-storages.

Residential properties are currently located on the eastern side of Hannell Street and Throsby Creek lies to the east of these properties.

Investec Australia Loans Management Pty Ltd (Investec) has lodged a Development Application (1) to develop the Wool Stores at Wickham (the Wickham Wool Stores) and another building adjacent to the east of these Wool Stores (building 4) as well as to build a new structure (building 5) adjacent to the north.

Concerns have been raised about the risks from the Ampol Terminal on the proposed development in the submissions to the Council of the City of Newcastle (The Council), especially by Ampol (5) and SafeWork NSW [(6), (7)].

Investec has submitted reports on the hazard and risk assessment from the Ampol terminal and pipeline on the proposed development [(8), (9)] in support of the DA, but the reports are based on public data and assumptions, and not on data obtained from Ampol, and hence the results are subject to uncertainties.

Based on the SafeWork submission, Ampol commissioned a compliance review with AS-1940-2017 (10) with respect to separation distances and identified improvements (11).

The Council sought an independent hazard and risk assessment (HRA) study of the Ampol Terminal, with data provided by Ampol. The Report was required to allow the consent authority to make an informed determination of the DA. Arriscar Pty Ltd (Arriscar) was commissioned by Council to conduct the study.

This report summarised details of the HRA of the Ampol Newcastle Terminal and risk impacts on the Wool Stores development.

1.2 Applicable Regulations and Guidelines

The regulations and guidelines applicable to the study are:

- Newcastle Local Environmental Plan (NLEP) 2012 (12)
- State Environmental Planning Policy No.33, Hazardous and Offensive Developments (13)
- Applying SEPP 33 (14)
- Hazardous Industry Planning Advisory Paper (HIPAP) No.6, Hazard Analysis (2)
- Hazardous Industry Planning Advisory Paper (HIPAP) No.10, Land Use Safety Planning (4)
- AS 1940-2017, The storage and handling of flammable and combustible liquids (10)

1.3 Scope of Systems Covered

The systems covered in this study include:

- Petroleum product storage tanks and bunds
- Product receival pipeline (SNP)
- Pumps and pipework within Terminal
- Road tanker loading bays and tanker loading operations
- Vapour recovery unit (VRU)
- Utilities and fire protection system
- Safety systems

1.4 Scope of study

The study scope covers the following:

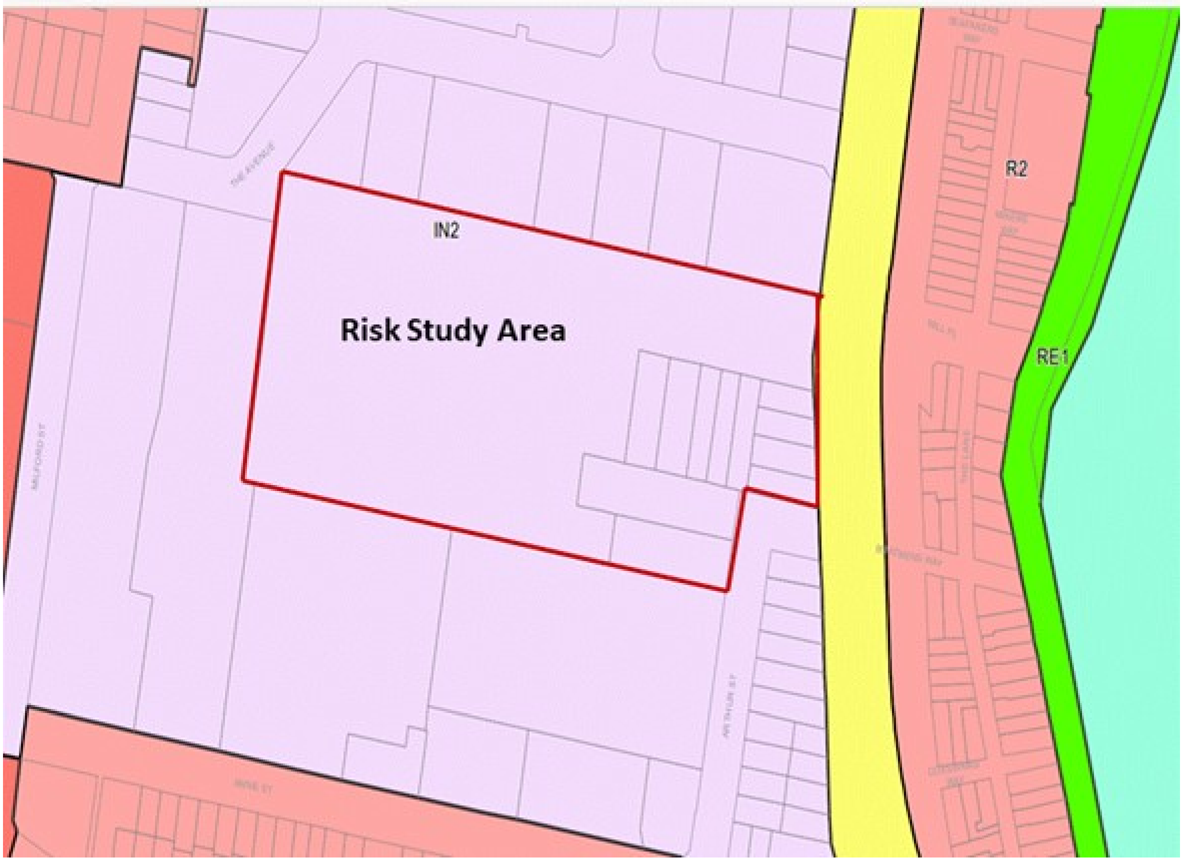
- A compliance review overview with AS 1940-2017 (10), with respect to separation distances
- Requirements of SEPP 33 as applied to the Ampol Terminal [(13), (14)]
- NLEP 2012 (12) requirements as applied to the proposed development
- Hazard analysis, including quantitative risk assessment (QRA) of the hydrocarbon storage and handling facilities
- Hazard analysis, including quantitative risk assessment (QRA) of the SNP pipeline (selected segment relevant to the local area)
- Compliance with risk criteria in HIPAP No.10 (4)
- Impact of existing potential hazardous facility on proposed development as specified by HIPAP No.10 (4)

2 REGULATORY REQUIREMENTS

2.1 NLEP 2012

The subject land (Ampol Terminal and the land subject to the proposed DA) is zone IN2 (Light Industrial) under the Newcastle Local Environment Plan (NELP) 2012 (12). A land use zoning map is shown in Figure 2.

Figure 2: Land Use Zoning Map of Study Area



Ref: Newcastle LEP 2012 – Land map sheet type: LZN_0004FA; Map Identification No. 5900_COM_LZN_004FA_005_20140509.

The current zoning of land in the study area with respect to the proposed wool stores development is summarised in Table 1. The study area consists of three Development Plans (DP).

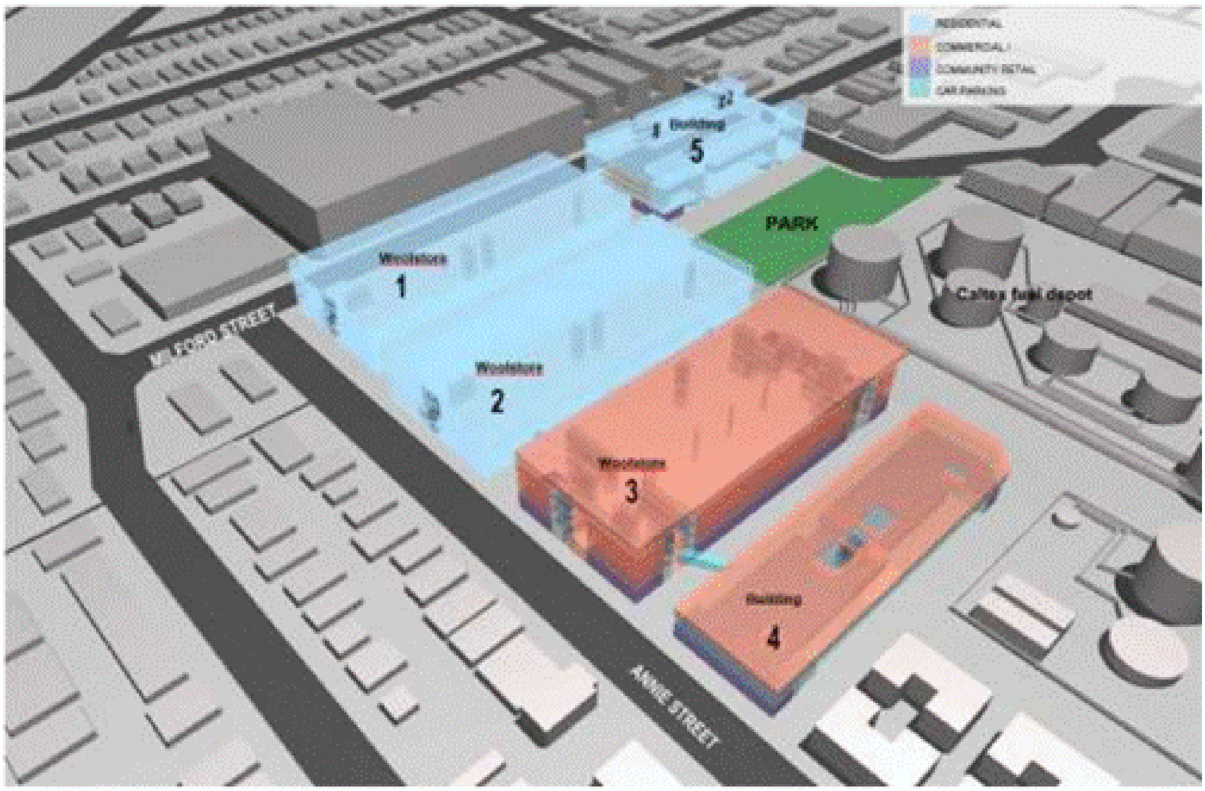
Table 1: Zoning Status of Subject Site

DP No.	Lot	Current Zoning	Address	Current Occupancy	Permissible
715007	1	IN2 Light Industrial	156 Hannell St, Wickham	Ampol Terminal	Yes
80877	1	IN2 Light Industrial	156 Hannell St, Wickham	Ampol Terminal	Yes
830026	13	IN2 Light Industrial	33 Annie St, Wickham	Wickham Self-storage	Yes

DP No.	Lot	Current Zoning	Address	Current Occupancy	Permissible
346352	1	IN2 Light Industrial	57 Annie St, Wickham	Wool store	Yes
346352	2	IN2 Light Industrial	49 Annie St, Wickham	Wool store	Yes
346352	3	IN2 Light Industrial	41 Annie St, Wickham	Wool store	Yes

The proposed development consists of 5 buildings and a park, as shown in Figure 3 (15).

Figure 3: Proposed Development



The zoning compatibility of proposed development is summarised in Table 2.

Table 2: Zoning Compatibility Status of Proposed Development

DP No.	Lot	Current Zoning	Address	Proposed Occupancy	Permissible
346352	1	IN2 Light Industrial	57 Annie St, Wickham	Building 1 - Residential	No*
346352	2	IN2 Light Industrial	49 Annie St, Wickham	Building 2 - Residential	No*
346352	3	IN2 Light Industrial	41 Annie St, Wickham	Building 3 – Commercial, retail	No*

DP No.	Lot	Current Zoning	Address	Proposed Occupancy	Permissible
830026	13	IN2 Light Industrial	33 Annie St, Wickham	Building 4 – Commercial, retail, car park	No*
		IN2 Light Industrial	Milford Street	Building 5 - New residential	No*

*The proposed development is not permissible in Zone IN2. However, the proposed development land has been listed as 'heritage' area in the NELP Drawing HER_004_FA. Under the Conservation Incentives in Clause 5.10 (10) of NLEP,

> *"The consent authority may grant consent to development for any purpose of a building that is a heritage item or of the land on which such building is erected, or for any purpose on an Aboriginal place of heritage significance, even though development for that purpose would otherwise not be allowed by this Plan, if the consent authority is satisfied…"*

5 sub-clauses are listed in Clause 5.10 (10) that need to be complied with.

2.2 SEPP 33

The State Environmental Planning Policy (SEPP) No.33 (13) defines potentially hazardous industries and potentially offensive industries, based on a facility storing and/or processing above a threshold of Dangerous Goods (DGs).

Part 3, Clause 11(2) of SEPP 33 states:

> *This Part does not apply to development the subject of a development application made before the date on which this Policy takes effect.*

One might therefore conclude that SEPP 33 does not apply to the Wickham Terminal unless a future DA proposes changes to the site and its operations. This does not mean that the Terminal is not a 'potentially hazardous industry'.

In relation to a future development on the Ampol site, Clause 13 of SEPP 33 applies, which states that:

> *In determining an application to carry out development to which this Part applies, the consent authority must consider:*
>
> *(a) current circulars or guidelines published by the Department of Planning relating to hazardous or offensive development, and*
>
> *(e) any likely future use of the land surrounding the development.*

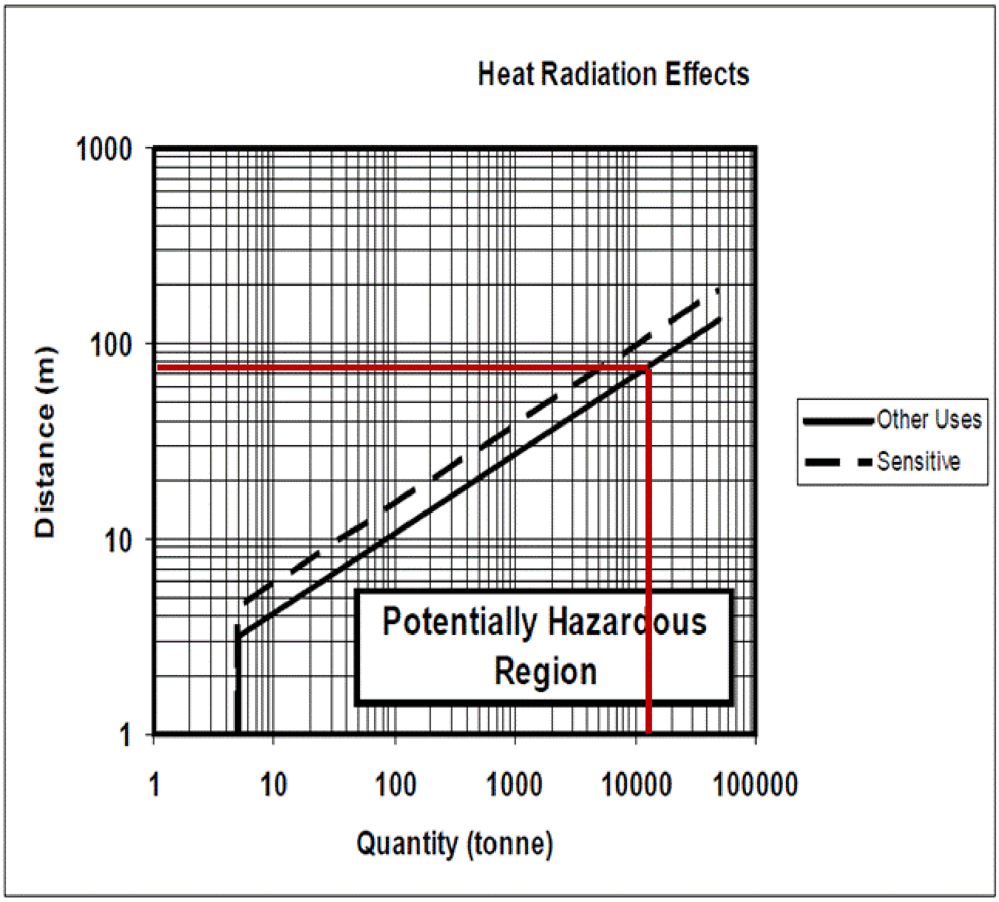
HIPAP 10 has been published subsequent to SEPP 33 and hence as a current guideline, it would apply to a potentially hazardous development.

HIPAP No.10 requires a Preliminary Hazard Analysis (PHA) to be undertaken for a development in the vicinity of a potentially hazardous development (section 4.2.2, Note 2).

In order to determine whether or not a PHA is required for the Wickham Terminal with respect to the proposed Woodstore development, one must apply a screening method to determine if the Wickham Terminal is a potentially hazardous industry. Applying SEPP 33 (14) is such a screening tool.

The Ampol Terminal has more than 12,000 tonnes of flammable storage (jet fuel and gasoline). Based on the separation distances table in (14), reproduced in Figure 4, the threshold distance for SEPP 33 applicability is 75m from the site boundary.

Figure 4: SEPP3 Threshold Distances for Flammable Liquids (Packing Group II and III)



The existing developments in the study area in Figure 1 are within 75m distance from the Ampol Terminal boundary, and therefore, the Ampol site is a ‘Potentially Hazardous Industry’.

While SEPP 33 does not strictly apply to the Wickham Terminal unless and until a new DA is raised for changes in the Terminal, the fact that the screening has established that it would be ‘potentially hazardous industry’ raises three issues:

1. If Ampol were to make changes to the site operations, then in accordance with SEPP 33, a Hazard Analysis as per HIPAP No.6 (2) would be required to demonstrate that the risks to surrounding land uses satisfy the criteria.
2. In this instance, the development proposed is on land adjacent to the Ampol Terminal. A Hazard Analysis would still be required to demonstrate that the risk to the proposed development complies with the risk criteria in HIPAP No.10 (4), in accordance with Clause 13 (e) of SEPP 33.
3. The intent of Clause 13 (e) is to assess the impact on future use of land surrounding the terminal (i.e. woolstore re-development), and also not to constraint any future changes to the Terminal itself.

Therefore, Applying SEPP 33 (14) as a screening tool and applying the requirements of HIPAP No.10 (Section 4.2.2, Note 2), a hazard and risk assessment was deemed necessary.

This report contains the Hazard Analysis and results.

2.3 Land Use Safety Guidelines

HIPAP No.10, Section 5.5 (4) outlines the risk criteria that must be satisfied by new developments in the vicinity of existing hazardous industries. The criteria are summarised in Table 3 (4).

2.3.1 Criteria for Risk of Fatality

Table 3: Individual Fatality Risk Criteria

Risk Levels (p.a.)	Land Uses
0.5×10^{-6}	Hospitals, child-care facilities and old age housing developments. Above the criteria level, no intensification of sensitive use development should take place.
1×10^{-6}	Residential developments and places of continuous public occupancy such as hotels, motels and tourist resorts. Above the criteria level, no intensification of residential development should take place
5×10^{-6}	Commercial developments, including offices, retail centres, warehouses, showrooms, restaurants and entertainment centres. Where the criterion is initially exceeded, commercial land development may be appropriate where mitigating measures can be implemented to reduce risk exposure to less than the target individual fatality risk level.
10×10^{-6}	Sporting complexes and active open space areas. Where the criterion is initially exceeded, commercial land development may be appropriate where mitigating measures can be implemented to reduce risk exposure to less than the target individual fatality risk level.
50×10^{-6}	Industrial sites. This risk level to be kept within the site boundary, where applicable. Where this criterion is initially exceeded, industrial land development may be appropriate where mitigating measures can be implemented to reduce risk exposure to less than the target individual fatality risk level.

Of relevance to the current context is the land use for residential developments, with a fatality risk target of 1.0 in a million per year.

2.3.2 Risk from existing Facilities

For existing facilities, the following allowances have been made in HIPAP No.4 (3), Section 2.5.1.1:

- *residential intensification may be appropriate where mitigating measures can be implemented to reduce risk exposure to less than the one in a million per year individual fatality risk level, provided the pre-mitigation residual risk levels are below the 10 in a million per year individual fatality risk level; and* *no residential intensification should take place where pre-mitigation residual risk levels are in excess of the 10 in a million per year individual fatality risk level.* The risk assessed in this study has been evaluated with respect to the above criteria.

2.3.3 Criteria for Risk of Injury

The risk of injury can arise from exposure to thermal radiation from fires, blast overpressure from explosions or toxic gases, including toxic combustion products from fires. The following criteria apply for injury risk (4).

Table 4: Risk Criteria for Injury for Residential and Sensitive Land Uses

Risk Levels (p.a.)	Exposure Level for Injury
50×10^{-6}	Thermal radiation at levels exceeding 4.7 kW/m^2. This level of heat radiation would cause injury after 30 seconds' exposure.
50×10^{-6}	Explosion overpressure at levels exceeding 7 kPa. This level of overpressure would cause injury either by direct exposure or indirectly through damage to property.
10×10^{-6}	Toxic concentrations should not exceed a level which would be seriously injurious to sensitive members of the community following a relatively short period of exposure.
50×10^{-6}	Toxic concentrations should not exceed a level which would cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community

2.4 Societal Risk

When there is a risk of multiple fatalities occurring in one event, DPIE has provisionally adopted indicative criteria as shown in Figure 5 (4) for addressing these societal concerns. The risk is represented as FN-curves (obtained by plotting the cumulative frequency at which such events might result in N or more fatalities, against N).

Figure 5: Indicative Societal Risk Criteria

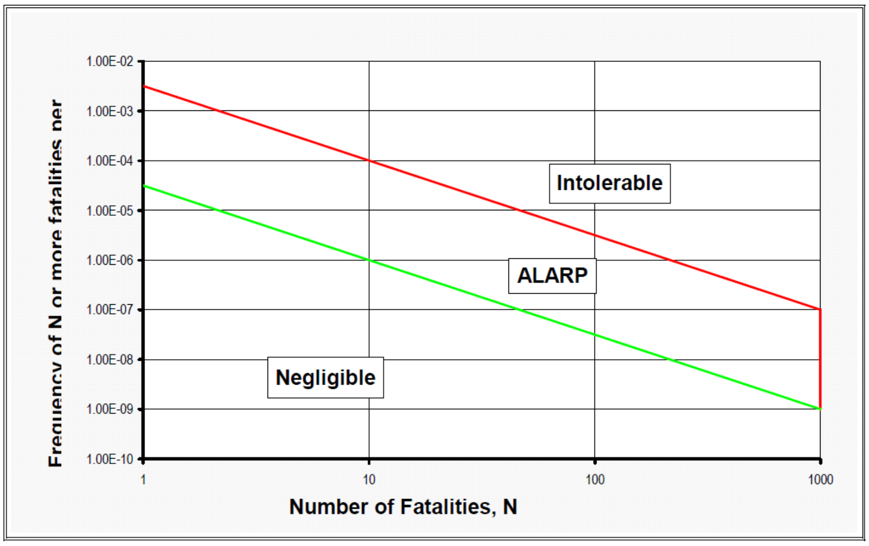


Figure 5 has three zones, the 'Negligible' zone, and 'ALARP' zone and the 'Intolerable' Zone. Above the intolerable zone, the development should not be permitted. If the risk is in the negligible zone, development may proceed, subject to other planning considerations. In the middle zone. The risk must be further reduced to a level considered 'As Low As Reasonably Practicable (ALARP)'. The maximum number of fatalities is limited to 1000 regardless of the frequency.

The application of societal risk criteria for case of a development in the vicinity of a potentially hazardous industry is described in HIPAP No.10. (4), Section 5.5.4.

> *where a development proposal involves a significant intensification of population in the vicinity of such a facility, the change in societal risk needs to be taken into account, even if individual risk criteria are met.*
>
> *In such instances, the incremental societal risk should be compared against the indicative criteria of Figure 12. Provided the incremental societal risk lies within the negligible region, development should not be precluded. If incremental risks lie within the ALARP region, options should be considered to relocate people away from the affected areas. If, after taking this step, there is still a significant portion of the societal risk plot within the ALARP region, the proposed development should only be approved if benefits clearly outweigh the risks.*

2.5 Governing Standard for Terminal AS 1940-2017

The main Australian Standard governing the storage and handling of flammable and combustible liquids is AS 1940-2017. A compliance review was undertaken by Sherpa Consulting (11) on behalf of Ampol on the tank farm, with respect to intertank separation distances, and mandatory controls. The study found that:

- All mandatory controls required under AS 1940-2017 (with the exception of separation distances) were found to be installed in the Terminal.

2.6 Governing Standard for Pipeline AS 2885-2008

Under the NSW Pipelines Act (1967) and Pipeline Regulations (2013), a pipeline operator must ensure the design, construction, operation and maintenance of a licensed pipeline is in accordance with the relevant provisions of Australian Standard AS 2885 (16) for gas and liquid petroleum pipelines.

A licensee must implement a pipeline management system that relates to the pipeline operated under the licence and is in accordance with the relevant provisions of AS 2885-2008.

Ampol has developed a management plan for the Sydney-Newcastle petroleum products pipeline (17).

2.7 Planning Considerations for Pipeline

The planning instrument relevant to the proposed development and adjacent Ampol pipeline is the State Environmental Planning Policy (Infrastructure) (SEPPI) (18), Subdivision 2 – Development adjacent to pipeline corridors.

Clause 66C of SEPPI (18) and Planning Circular PS 18-010 (19) require a risk assessment be carried out on the development from an adjacent pipeline.

Clause 66C (2) also states that:

Land is in a pipeline corridor for the purposes of this clause if the land is located—

(a) within the licence area of a pipeline for gas, or for petroleum or other liquid fuels, licensed under the Pipelines Act 1967, or

(b) within 20m of the centreline (measured radially) of a relevant pipeline, or

(c) within 20m of land the subject of an easement for a relevant pipeline.

The north-eastern property boundary of the proposed development is within 20m of the pipeline easement. Therefore, the risk assessment under SEPP 33 should also include the pipeline in the vicinity of the development, as per SEPPI.

3 BRIEF DESCRIPTION OF AMPOL TERMINAL

The terminal infrastructure consists of the following areas:

- Products pipeline (SNP) and receival station
- Fuel storage tank farm
- Pumps and piping network for product movement
- Road tanker loading bays (petroleum products)
- Ethanol receival (road tanker)
- Additives storage (flammable liquids)
- Utilities
- Fire protection system
- Monitoring and safety systems

A brief outline of the facility and operations is provided below.

3.1 Products Handled

The products handled at the terminal are:

- Gasoline (including PULP, SPULP)
- Jet fuel
- Diesel (including biodiesel)
- Ethanol (blended into gasoline in the road tanker for export)
- Additives (jet additive, Ultrazol, Lubrizol)
- Slops (generally treated as flammable as it contains gasoline)

Bulk fuel (gasoline, jet fuel and diesel) is received via the SNP. Ethanol is received in road tankers and transferred into the dedicated storage tank. Additives tanks are smaller in size and are generally filled from drums or from small solvent tankers.

3.2 Products Pipeline

The SNP carries the products to the Ampol Newcastle depot. Until the entry into the site, the pipeline runs underground. Within the site, it rises above ground at the isolation station. Thereafter, the pipeline manifolds into branch pipes, feeding the various tanks. The SNP pipeline operates 100% of the time. Flow rate varies, depending on the rate of fill and frequency of fill.

Ethanol is received by road tanker. Additives are received either by road tanker or drums.

Details of the underground section of SNP pipeline are summarised in Table 5. The pipeline route in the vicinity of the proposed development is shown in Figure 6. The pipeline enters above ground at the Terminal gate.

Figure 6: Sydney Newcastle Pipeline Route (Underground)

Table 5: Details of Fuel Supply Pipeline

Pipeline Owner	Ampol
Pipeline Name	Sydney-Newcastle Pipeline
Pipeline Origin and Destination	From Plympton to Wickham
In Use	Yes (50% of time)
Material/Product	Liquid Hydrocarbons: Gasoline, Diesel
Design Pressure	10,000 kPag
Maximum Allowable Operating Pressure (MAOP)	6,500 kPag (at Plympton pumping station)
Normal Operating Pressure	~ 1,000 kPag (approximate arrival pressure at Wickham Terminal)
Temperature	15-20 °C
Flowrate	450 m^3/ hour
Pipeline Material	API 5LX – X52
Pipeline Outside Diameter	324 mm
Wall Thickness	6.35 mm
Depth of Cover	AS 2885 requirement is 1.2m
Cathodic Protection	Yes (Impressed current)
External Coating	Extruded polyethylene
Leak Detection System/s	Via SCADA at Kurnell Control Room
Isolation System/s	Full remote control, including automated mainline valves at Hamilton and Wickham (1.78 km).
Inspections	Weekly ground patrols
Control Measures for pipeline integrity	Patrols, depth of cover, wall thickness, corrosion protection, SCADA monitoring, Dial-Before-You-Dig (DBYD) program
Pipeline inventory between isolation valves	134.48 kL

3.3 Tank Farm

The tank farm layout is shown in Figure 7. A summary of the tanks in the tank farm and products is provided in Table 6. Detailed equipment layout is shown in (20).

Figure 7: Ampol Terminal Tank Farm Layout

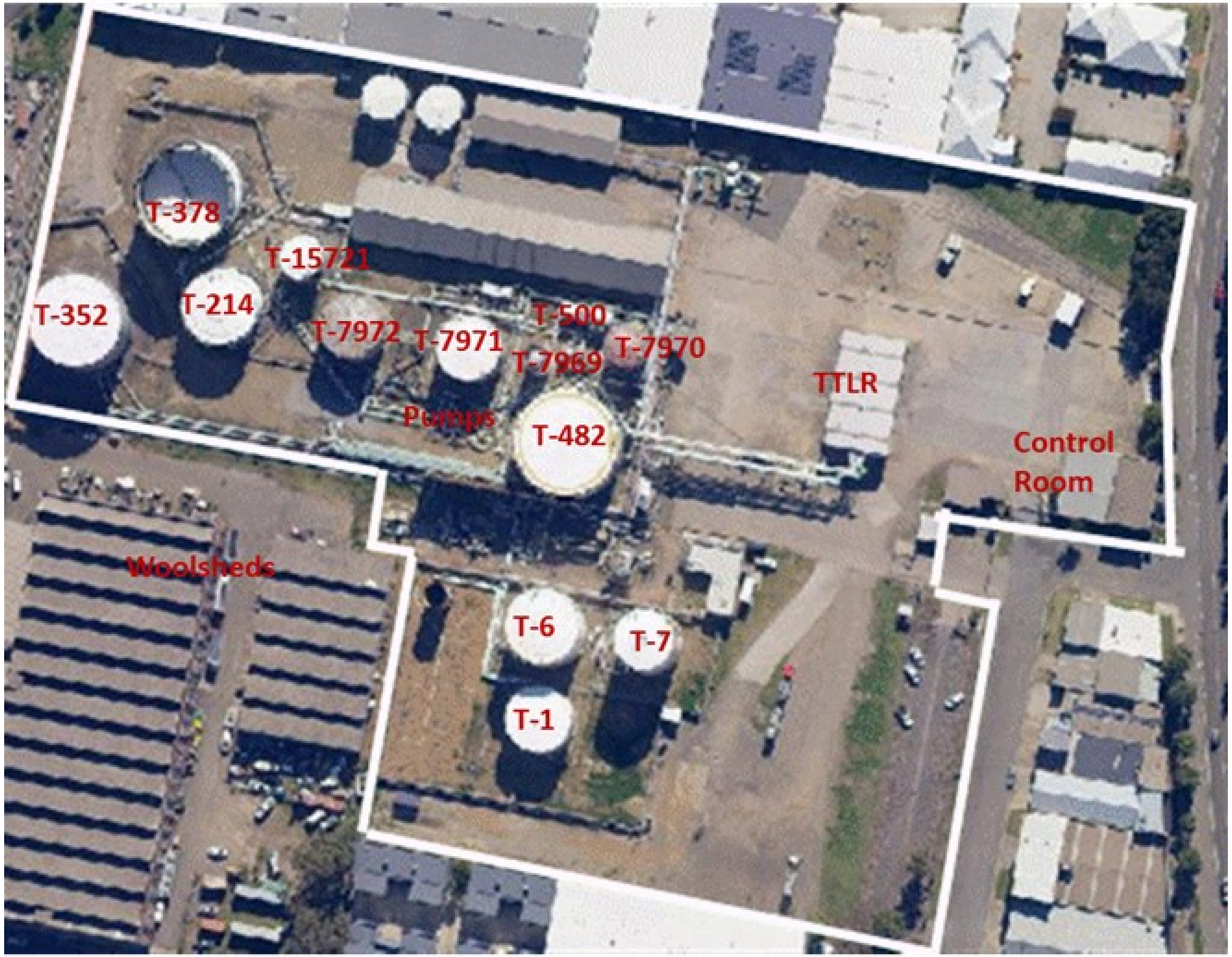


Figure 8: Ampol Terminal Equipment Layout

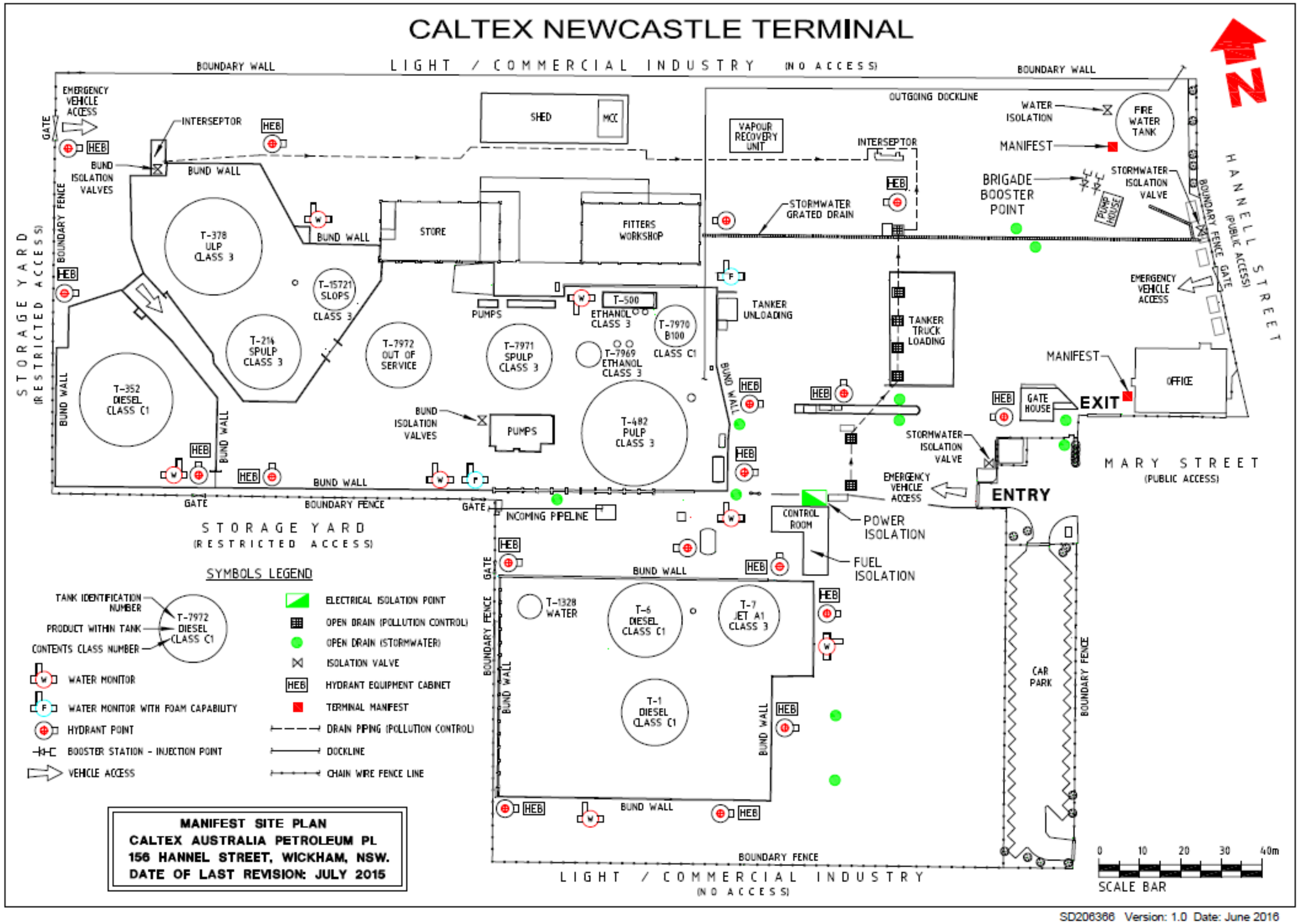


Table 6: Product Storage Tanks Summary

Tank	Product	Tank type	Capacity, kL	Dia., m	Height,m	DG Class
T-1	Diesel	Cone Roof	1663.3	16.4	8.84	C1
T-6	Diesel	Cone Roof	3748	18.2	14.64	C1
T-7	Jet fuel	Cone Roof	2631	14.8	16.5	3 PG III
T-16	AMP PET 200 (PULP additive)*	Horizontal	4.8			9
T-187A	Jet Additive ICINOL*	Cone Roof	4	1.3		Non-DG
T-187B	Jet Additive ICINOL*	Cone Roof	4	1.3		Non-DG
T-187C	Jet Additive Stadis*	Horizontal	0.205			Non-DG
T-1911	AMP PET 200 (Diesel Additive)*	Cone Roof	9.8			9
T-214	SPULP	IFR	2359	18.3	9.6	3 PG II
T-352	Diesel	Cone Roof	5905	23.0	14.5	C1
T-378	PULP	Floating Roof	7200	23.8	16.43	3 PG II
T-482	PULP	IFR	5450	25.9	10.9	3 PG II
T-500	Slops (Low Flash)	Horizontal	110	3.5		3 PG II
T-7969	Ethanol	IFR	233	6.1	8.76	3 PG II
T-7970	Biodiesel (B-100)	Cone Roof	671	10.2	9.13	C1
T-7971	Out of Service					
T-7972	Out of Service					
T-15721	Slops (treated as gasoline)	IFR	629	10.2	9.17	3 PG II

*Combustible liquid

Water draining is conducted from tanks approximately once a month. The drained water is pumped through an interceptor to recover any hydrocarbons and the effluent water is discharged to the sewer under an EPA licence.

3.4 Tanker Truck Loading Racks

There are four tanker truck loading racks (TTLR) for loading petroleum products in the Terminal. Bottom loading is carried out using loading arms. Up to a maximum of 4 loading arms can be used at a time (loading four compartments) in the loading bay. The displaced vapour from the tanker is connected to a vapour recovery unit (VRU). The recovered vapour is condensed and pumped back into a gasoline tank.

Approximate compartment size of the road tanker is 7000 Litres, and there can be up to 5 compartments in a tanker. Different products can be loaded in the compartments.

The tanker filing rate is 1800-2100 L/min.

Any spill is collected in a common underground tank (2,500 L capacity) fed by a sump below each loading bay. The collected spill is pumped to the gasoline tank. The loading bay area is bunded to contain spill that can be recovered through the sump.

Ethanol is received in road tankers and pumped into the ethanol storage tank (T-7969) in a dedicated unloading area (Rack No.5).

Loading and unloading is carried out by tanker drivers.

3.5 Product Exports

The TTLR operations are summarised in Table 7.

Table 7: TTLR Operations Summary

Rack No.	Product Handled	Transfer rate (L/min)	Average trucks/ week (B-doubles)
1	ULP, PLP, SULP, Diesel, Jet, B-100	3500 x 4	229
2	ULP, PLP, SULP, Diesel, Jet	3500 x 4	214
3	Diesel, B-100	3500 x 3	255
4	Jet fuel	3500	1
5	Ethanol (import only)	1300	1

Dedicated pumps pump the products from the tanks to the loading racks. Loading arms are used, with a short stainless-steel braided flexible line segment in each loading arm.

Product B-100 (Biodiesel) is received in bulk road tankers and exported. This product has not been handled in the last few years and is based on market conditions.

3.6 Product Imports

Products are received in batches in the SNP. Details are given in Table 8.

Table 8: Product Receival Rates

Tank No.	Product	Transfers / year	Transfer Rate (m3 / h)	Total On-line Time (h / year)
T-1	Diesel	40	450	150
T-6	Diesel	40	450	300
T-7	Jet fuel	3	450	20
T-214	SPULP	72	450	600
T-352	Diesel	40	450	500
T-378	ULP	204	450	2400
T-482	PULP	108	450	1300
T-7969	Ethanol (tanker)	231	120	120

3.7 Installed Safety Systems

Preventative and mitigative control measures are provided in the Terminal to control a hazardous incident. These include:

- Tank level monitoring (Enraf gauges) and alarm with operator intervention to stop fill
- Independent tank high high level protection system that shuts off inflow
- Hydrocarbon vapour detection in flammables tank farm bunds and alarm in control room
- Fire detection and alarm and automatic shutdown of both inlet and outline line valves on tanks containing flammables. UV/IR detectors installed.
- Foam injection provision in cone roof tanks of flammable tanks and in the rim of the floating roof tank
- Foam pouring provision in the tank farm bunds.
- Adequate bund volume to contain spills in accordance with AS 1940-2017
- Fire protection system (hydrant system)

The control room is manned 24/7.

3.8 Additives Tanks

Additives are added to petrol, diesel and jet fuel to improve performance. These are listed below:

Table 9: Additives Storage

Tank No.	Product	Capacity, m^3	Supplied
T-16	AMP PET 200 (PULP additive)	4.8	Filled from 1000 L IBCs
T-187A	Jet Additive ICINOL	4	Filled from 1000 L IBCs
T-187B	Jet Additive ICINOL	4	Filled from 1000 L IBCs
T-187C	Jet Additive Stadis	0.205	Single 205L drum
T-194	AMP PET 200 (Diesel Additive)	90.8	Filled from small tankers

These tanks are batch filled from 1000 L IBC containers using an air-driven pump.

Additives are injected into the corresponding fuel directly at the TTLR, pumped by small dedicated positive displacement pumps located near the additives tanks.

3.9 Additives Supply Container Storage

Additives are received into the site in 1000L intermediate bulk containers (IBCs), and stored in a shed next to the workshop. The IBCs can be stored 4 high in a bunded area.

Forklifts are used for IBC movements.

3.10 Tank Farm Bunds

There are two major bunds in which the tanks are located.

1. South Yard – Contains Tanks T-6, T-1 and T-7 (South Yard). Bund volume 4760 m^3.

2. North Yard – Contains Tanks T-378, T-214, T-352, T-482, T-7969, T-7970, T-7971, T-7972, and T15721. Bund volume 8032 m^3.

   T-352 (diesel tank) is located in an intermediate bund, but the bund volume is insufficient to hold the full contents of the tank. Therefore, T-352 is treated as part of the North Yard.

The bunds have compacted soil surfaces. The pipework within the bund consists of:

- Inlet lines to each tank with automatic remote isolation valve.
- Outlet line from each tank to export pump with remote automatic isolation valve at tank outlet. There are five pumps.

The export pumps from the tank farm to the TTLR are located within the North Yard bund.

3.11 Fire Protection

The Terminal fire protection system consists of the following:

- UV/IR fire detection in TTLR and automatic shutdown of TTLR
- 2x690 kL firewater tanks
- 2 diesel engine driven firewater pumps connected to both firewater tanks
- Dedicated foam storage and foam concentrate pump
- Direct foam injection into flammables storage tanks and in the rim of the floating roof tank
- Foam pouring provision in the bund using hydrants
- Classified hazardous areas and compatible electrical equipment
- Foam deluge in all 4 tanker loading racks and in the ethanol unloading rack.

4 Risk Assessment Methodology

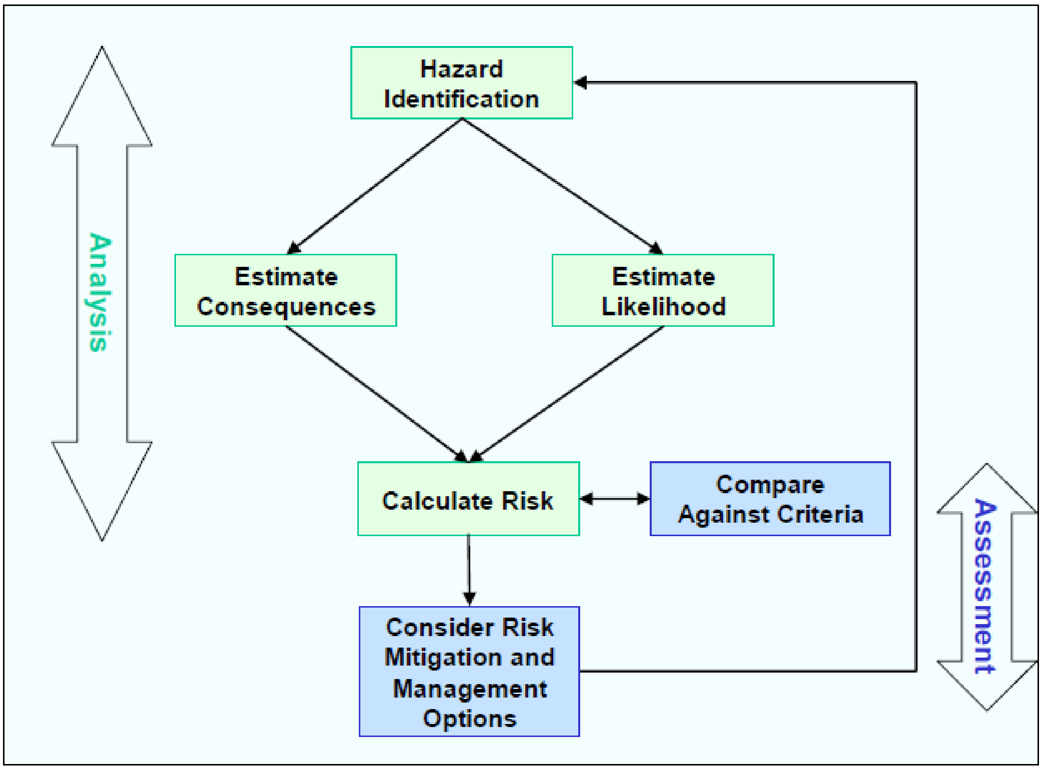
The requirements for the risk assessment for the Ampol terminal and high pressure fuel pipeline on the proposed development are listed in HIPAP No. 6 (2).

The risk assessment framework is depicted in Figure 9 (2). The principal steps are:

- Hazard identification
- Hazard consequence analysis
- Incident likelihood (frequency) assessment
- Calculation of risk on proposed development
- Comparison with applicable risk criteria
- Development of mitigation options to reduce risk, if applicable.

The above aspects have been addressed in this report.

Figure 9: Risk Assessment Methodology



1. Hazard identification:

   (a) Identify the hazards associated with a loss of containment of petroleum fuel from storage and the supply pipeline in the vicinity of the proposed development.

   (b) Selected a material representative of the fuel for risk assessment (gasoline, diesel, jet fuel). Gasoline poses a higher hazard than others and hence considered as a conservative measure for the pipeline part of the assessment.

   (c) Include the existing risk management measures by Ampol in assessing the loss of containment scenarios.

2. Estimate Consequences:

   (a) Identify all potential consequences of a loss of containment from the Terminal and pipeline.

   (b) List the assumptions made in the modelling of consequences. Justify the assumptions on the grounds of available literature data and/ or reasoned engineering judgement.

   (c) Use an industry/ regulator accepted software used for the consequence calculations. The DNVGL software SAFETI 8.23 is used for the analysis.

   (d) Use local meteorological data for the fuel vapour dispersion calculations.

3. Estimate Likelihood:

   (a) Use failure frequency data from an accepted database and applicable to the present context, for the risk assessment.

   (b) Ensure that the ignition probability value selected takes into account local conditions and potential ignition sources.

   (c) Adjust the fuel release frequency for the safeguards present in the pipeline design and operation, if appropriate to reflect local conditions. Provide appropriate justification provided for the assumption.

4. Calculate Risk:

   (a) Calculate the risks to the proposed development (location specific and societal), as required by the risk criteria in HIPAP No.10 (4).

5. Compare Against Risk Criteria:

   (a) Have any risk mitigation options been addressed? It must be noted that the Terminal and pipeline are existing approved facilities operated by Ampol with an established risk management system and any risk mitigation options may necessarily be on the part of the development.

   (b) Consider both qualitative and quantitative risk criteria, as required by HIPAP No.10 (4).

5 HAZARD IDENTIFICATION

5.1 Properties of Petroleum Fuels

The combustible or flammable liquids present in the Terminal are automotive fuels (e.g. Diesel, Gasoline) or aviation (jet) fuel. The additional flammable liquid stored in bulk is ethanol which is a gasoline additive.

Diesel fuel is a mixture of hydrocarbons (paraffinic, naphthenic, or aromatic hydrocarbons with carbon numbers predominantly between 10 and 22) and is modelled as Dodecane in the QRA.

Gasoline (i.e. unleaded petrol) is typically a mixture of hydrocarbons (paraffins, cycloparaffins, aromatic and olefinic hydrocarbons, with carbon numbers predominantly in the C4 to C12 range) and is modelled as Heptane in the QRA.

Jet Fuel is typically a mixture of hydrocarbons (paraffins, cycloparaffins, aromatic and olefinic hydrocarbons with carbon numbers predominantly in the C9 to C16 range) and is modelled as Decane in the QRA.

Physical properties of petroleum fuels are listed in Table 10.

Table 10: Physical Properties of Diesel, Gasoline and Jet Fuel

	DIESEL	GASOLINE	JET FUEL
Boiling Point	200 - 400 °C (c.f. 216.3 °C for Dodecane)	30 - 210 °C (c.f. 98.4 °C for Heptane)	150 - 300 °C (c.f. 174 °C for Decane)
Flash Point	> 61.5 °C (c.f. 73.8 °C for Dodecane)	-40 °C (c.f. -4.2 °C for Heptane)	38 - 55 °C (c.f. 46 °C for Decane)
Autoignition Temperature	> 250 °C (c.f. 203 °C for Dodecane)	370 °C (c.f. 204 °C for Heptane)	> 220 °C (c.f. 201 °C for Decane)
Relative Vapour Density (Air =1)	> 1 (c.f. 6.0 for Dodecane)	3.5 (c.f. 3.5 for Heptane)	> 5 (c.f. 4.9 for Decane)
Liquid density, 20C	850 kg/m^3	750 kg/m^3	800 kg/m^3
Lower Flammability Limit (vol. %)	0.6% (c.f. 0.6% for Dodecane)	1.4% (c.f. 1% for Heptane)	1% (c.f. 0.7% for Decane)
Upper Flammability (vol. %)	7.5% (c.f. 4.9% for Dodecane)	7.6% (c.f. 7% for Heptane)	6% (c.f. 5.4% for Decane)

Diesel, Gasoline and Jet Fuel are:

- Liquids at ambient conditions with vapour that is heavier than air;
- Combustible or Flammable; and
- Non-toxic with a characteristic hydrocarbon odour.

Properties of ethanol are listed in Table 11.

Table 11: Physical Properties of Ethanol

Property	Value
Boiling Point	200 - 400 °C
Flash Point	13 °C
Autoignition Temperature	393 °C

Property	Value
Relative Vapour Density (Air =1)	1.59
Lower Flammability Limit (vol. %)	3.5%
Upper Flammability (vol. %)	19.0%
Solubility in water	Soluble in all proportions

5.2 Additives

A summary of additives stored and handled are is provided in Table 9. The additives are naphthenic solvents of flash points > 61^{O}C. The additives are combustible, requiring a high energy ignition source to start a fire.

The additives are modelled as diesel (dodecane) for fire consequence analysis.

5.3 Hazards in Ampol Terminal

Fire and/or explosion are the principal hazards for bulk fuel facilities and may be realised due to loss of containment events during storage or transfer operations (including pipelines and road tanker loading bays).

If a leak occurs, then the potential consequences may include:

- Fire (jet fire, pool fire, tank top fire or flash fire);
- Explosion (vapour cloud explosion or an explosion in a confined space); and / or
- Toxic smoke generation (Carbon monoxide and carbon dioxide in smoke).

5.3.1 Fire

Combustion of flammable or combustible liquid released from an orifice (e.g. hole in a tank) may result in a pool fire. The size of the pool fire is dependent on the rate of release, burn rate and potential containment (e.g. bunding).

Tank top fires may also occur on bulk storage tanks roof tanks containing flammable or combustible liquids.

5.3.2 Explosion

Volatile vapours from released liquids may disperse downwind, forming a flammable vapour cloud. On ignition, a vapour cloud explosion may result, depending on the level of congestion in the area. A high degree of confinement and congestion is generally required to produce high flame speeds (i.e. > 100 m/s) in a flammable gas or vapour cloud. This may occur inside buildings and around buildings and other obstacles (e.g. process plant equipment, vehicles, etc.).

The explosion strength is lower with petroleum liquids, compared to LPG.

Under calm wind conditions, a release of flammable liquid (e.g. from a tank overfill incident) can form a very large vapour cloud. This can then result in a vapour cloud explosion, such as was observed at Buncefield in the UK in 2005 (21). The consequences of such events are severe and have been analysed in this report.

5.3.3 Toxic Smoke

Large quantities of smoke can be produced from hydrocarbon fires, especially flammable / combustible liquids such as Gasoline and Jet Fuel; however, this is rarely injurious for persons at ground level due to the buoyancy of the hot plume and its subsequent dispersion well above ground level. However, in multi-storey residential areas, there is potential for smoke ingress into buildings with consequent toxic effect, unless the exposed people are evacuated as part of the emergency response.

5.3.4 Tank Overflow, Vaporisation and Explosion

If a tank containing low flash point flammable liquid like gasoline is overfilled, fuel would be released from the top and flow down the side of the tank. The mechanism of the fuel release and drop from height leads to vapor release and by the time the release hits the ground under calm conditions, most of the vapor is formed. The turbulence of the release itself causes air entrainment. As the vapor rolls over the bund further entrainment is caused by onsite congestion. If ignited, the well mixed fuel-air vapor cloud will also have higher flame speeds caused by the turbulence thus further increasing the intensity of the explosion. This was the incident that occurred in Buncefield in the UK in 2005 and caused extensive damage and injuries (21).

This incident is credible in the Ampol Terminal for the tanks containing gasoline (T-214, T-378 and T-482).

5.3.5 Pipeline Incidents

Failure of the SNP in the underground section as the pipeline approaches the terminal would result in pool formation and a pool fire if ignited.

The leak would continue until the pipeline is isolated and the inventory in the isolated section is depleted.

5.4 Hazardous Scenarios Considered in the Terminal

5.4.1 Tank Farm Incidents

Loss of containment of products can occur from the following:

- Tank failure and leak of product into the bund.
- Tank farm piping failure and leak of product into the bund.
- Air ingress into the vapour space of cone roof tank (above liquid surface or above internal floating roof) and explosion/ tank top fire if ignited
- Vapour escape through seal of floating roof tank
- Pump seal leak in tank farm (restricted leak)
- Tank overfill and large release of flammable liquid resulting in ‘Buncefield’ type explosion under calm wind conditions
- Sinking of floating roof tank and exposure of flammable liquid surface to atmosphere

5.4.2 Tanker Truck Loading Rack Incidents

- Release in tanker loading bay from failure of tanker compartment
- Release from loading arm from fitting failure

5.4.3 Other Incidents

Other incidents are:

- Overfill of vapour recovery unit and release
- Fire in IBC storage shed (less likely as the additives are not flammable)

From SEPP 33 guidelines (14):

> *"If combustible liquids of class C1 are present on site and are stored in a separate bund or within a storage area where there are no flammable materials stored, they are not considered to be potentially hazardous. If, however, they are stored with other flammable liquids, that is, class 3PGI, II or III, then they are to be treated as class 3PGIII, because under these circumstances they may contribute fuel to a fire."*

On the above basis, fires in the additives IBC storage shed have not been carried forward into the risk assessment model.

5.5 Pipeline Failure Modes

Pipelines may leak due to various causes. The four principal failure modes that may result in a leak from an underground pipeline include (22):

- Mechanical failures, including material defects or design and construction faults;
- Corrosion, including both internal and external corrosion;
- Ground movement and other failure modes, including ground movement due to earthquakes, heavy rains/floods or operator error, and other natural hazards such as lightning, etc.; and
- Third Party Activity (TPA), including damage from heavy plant and machinery, damage from drills/boring machines and hot tapping, etc.

5.5.1 Mechanical Failure

Leaks due to mechanical failures are usually caused by a construction fault, a material fault / defect or design of the pipeline.

This failure mode is credible for the pipelines. Historical incident data for other pipelines (Refer to Appendix D, Table 44) indicates this is generally a low likelihood failure mode.

5.5.2 Corrosion

Leaks due to internal corrosion are generally a function of the material being transported, the wall thickness of the pipeline and the materials of construction.

Leaks due to external corrosion do not depend on the material being transported and are generally dependent on the soil type / conditions, pipeline coating and materials of construction, and the age of the pipeline.

This failure mode is credible for the SNP; however, historical incident data for other pipelines (Refer to Appendix D, Table 44) indicates this is a low likelihood failure mode, particularly for pipelines with a higher wall thickness (i.e. > 10 mm) and more recently manufactured pipelines (i.e. post 1980). The SNP wall thickness is < 10mm.

5.5.3 Ground Movement and Other Failure Modes

Pipeline leaks may occur due to ground movement (e.g. following a landslide or earthquake). The potential also exists for ground movement in the vicinity of water crossings (water erosion) or as a result of construction activities (new road infrastructure and buildings).

Other external events, such as lightning strikes, operational errors and erosion may also lead to a leak.

This failure mode is credible for the SNP.

5.5.4 Third Party Activity

Most leaks due to Third Party Activity (TPA) are caused by construction vehicles and equipment (drills, etc.) or by farm machinery in rural areas. The leak typically occurs immediately upon contact; however, it may be delayed (i.e. if the TPA only weakens the pipeline such that it fails at a later time).

Leaks due to TPA include those caused by horizontal directional drilling (HDD), which is commonly used to install utilities and services (communication cables, etc.).

Leaks due to TPA are particularly relevant when considering development in the vicinity of existing pipelines due to the potential for significant construction activities (e.g. new road infrastructure and buildings).

This failure mode is credible for the SNP.

5.6 Summary of Hazardous Scenarios Modelled

Table 12 lists a summary of hazardous scenarios (Major Incidents) modelled for the risk assessment.

Table 12: Hazardous Scenarios Summary

MI No.	Location	Description	Consequences modelled	Impact/s
MI-1	Tank farm South Yard	T-1 top fire	Elevated pool fire - diesel	Thermal radiation
MI-2		T-6 top fire	Elevated pool fire - diesel	Thermal radiation
MI-3		T-7 top fire	Elevated pool fire – Jet fuel	Thermal radiation
MI-4		South yard bund fire	Pool fire - diesel	Thermal radiation
MI-5		South yard bund fire	Pool fire – jet fuel	Thermal radiation
MI-6	Tank farm North Yard	Tank T-214, T-378, and T-482 overflow	Vapour cloud under nigh time calm conditions and ignition offsite	Vapour Cloud Explosion
MI-7	Tank farm North Yard	T-214 top fire	Elevated pool fire - SPULP	Thermal radiation
MI-8		T-352 top fire	Elevated pool fire - diesel	Thermal radiation
MI-9		T-378 top fire	Elevated pool fire - PULP	Thermal radiation

MI No.	Location	Description	Consequences modelled	Impact/s
MI-10		T-482 top fire	Elevated pool fire - PULP	Thermal radiation
MI-11		T-7969 top fire	Elevated pool fire - Ethanol	Thermal radiation
M-12		T-7970 top fire	Elevated pool fire - Biodiesel	Thermal radiation
MI-13		T-15721 top fire	Elevated pool fire – Slops	Thermal radiation
MI-14		North yard bund fire	Pool fire - gasoline	Thermal radiation, flash fire
MI-15		North yard bund fire	Pool fire - Ethanol	Thermal radiation, flash fire
M-16		North yard bund fire	Pool fire – combustible liquids	Thermal radiation
MI-17	TTLR 1-4	TTLR bund fire	Pool fire - gasoline	Thermal radiation, flash fire
MI-18		TTLR bund fire	Pool fire – jet fuel	Thermal radiation
MI-19		TTLR bund fire	Pool fire – combustible liquids	Thermal radiation, flash fire
MI-20	TTLR-5	Ethanol unloading rack bund fire	Pool fire - ethanol	Thermal radiation
MI-21	VRU	VRU fire	Pool fire - gasoline	Thermal radiation
MI-22	SNP - underground	Pipeline in the easement along site boundary	Pool fire – gasoline, jet fuel	Thermal radiation, flash fire
MI-23	Storage shed*	IBC storage fire	Non-hazardous combustible liquid	-

*Not carried forward for modelling – Non-hazardous storage.

6 HAZARD CONSEQUENCE ANALYSIS

6.1 Consequence Events and Modelling

The end events that result from the event tree analysis are:

- Pool fires
- Flash fires
- Buncefield Vapour Cloud Explosions (VCE)

The consequence modelling for each of these events were carried out by SAFETI 8.23.

6.2 Pool Fire

A pool fire event occurs when a flammable liquid spill is ignited. The heat radiation from a pool fire was modelled for a smoky hydrocarbon flame, taking into account the flame tilt by wind.

The probability of fatality resulting from a pool fire was determined in SAFETI using the probit method. The results are summarised in Appendix C, Table 30.

6.3 Flash Fire

The consequence area was determined by modelling the release conditions using the gas dispersion package in SAFETI 8.23. The distance to lower flammability limits were calculated for flammable vapour pool vaporisation. Assumptions made for the flash fire modelling can be found in Appendix A.

The resulting fatalities were taken as 100% for the area that the fire covers, i.e. 100% for the area of the cloud above the LFL.

Flash fire results are summarised in Appendix C, Table 31.

6.4 Buncefield Vapour Cloud Explosions

6.4.1 Background

On the 11th December 2005, a number of explosions occurred at Buncefield Oil Storage Depot, Hemel Hempstead, Hertfordshire, UK. The storage depots received petroleum products from the nearby refinery by pipelines.

At least one of the initial explosions was of massive proportions and there was a large fire, which engulfed a high proportion of the site. Over 40 people were injured; fortunately, there were no fatalities. Significant damage occurred to both commercial and residential properties in the vicinity and a large area around the site was evacuated. The fire burned for several days, destroying most of the site and emitting large clouds of black smoke into the atmosphere.

The UK Health and Safety Executive (HSE) and UK Environment Agency (EA) investigated the incident. The reasons for the incident were established as (21):

- The level monitoring sensor (automatic tank gauge or ATG) had failed and indicated a tank level lower than what it actually was, as the tank was being filled. Since the tank high level alarms were configured on the same sensor, the alarms did not activate either. No one noticed that the tank was being overfilled.

- The tank was also fitted with an independent high-level switch (IHLS) set at a higher level than the ATG alarms. This was intended to stop the filling process by automatically closing valves on any pipelines importing product, as well as sounding an audible alarm. The IHLS also failed to register the rising level of petrol (it was overridden), so the 'final alarm' did not sound and the automatic shutdown was not activated.
- The tank mimics on the screen showed a red 'stop' emergency shutdown button. Use of this was meant to close all tank side valves. Unbeknown to a number of the supervisors this was not working and had never been fitted into the system.
- The tank overflowed and continued to fill the bund.
- While the bund had the capacity to contain the fuel, it had shown failures at places, and had penetrations not fully sealed. This let the fuel leak out of the bund, created a large size pool of gasoline.
- The turbulence created by the overflow along the tank walls created a significant amount of flammable vapour.
- Above all of these, calm conditions prevailed in the winter night, preventing dispersion of the flammable vapour.
- Since there was no control of ignition outside the facility boundary (public spaces), the vapours ignited and resulted in the vapour cloud explosion and large fire.

What came as somewhat of a surprise was the size of vapour cloud that could be generated from a low flash point liquid, but above its boiling point. Until then, a major explosion from tank overflow was not an event foreseen. The fire hazards were well known.

While the Buncefield incident received much attention in the industry, two similar incidents have occurred in the industry since that time:

- Jaipur (India) IOC petroleum terminal explosion, 2009 (23)
- Puerto Rico (USA) Cataño oil refinery explosion, 2009 (24)

Both incidents occurred from a tank overflow, resulting in vaporised gasoline vapour and an explosion, similar to the incident at Buncefield.

It is now accepted in the oil industry and by process safety practitioners that tank overflow of gasoline can result in a Buncefield type explosion under certain conditions.

6.4.2 Applicability of the Buncefield Type Incident to Ampol Terminal

The previous risk assessment for the Wickham Terminal (8) did not quantify the risk from a Buncefield type incident at the Wickham Terminal on the basis that (a) the frequency of the incident was low and (b) the vapour cloud explosion effects were not significant. No justification had been provided for such assumptions.

The inquiry into Buncefield incident established a number of conditions under which an explosion could occur. Table 13 summarises the conditions and whether they could exist at the Wickham Terminal (5), (21).

Table 13: Conditions for a Buncefield Type Incident at Ampol Terminal

Conditions	What exists at Ampol Terminal	Is Buncefield type event credible?
Continuous transfer into the tank	Product is directly transferred by the Sydney-Newcastle pipeline	Yes
Transfer rates > 100 m^3/h	Transfer rates are 450 m^3/hour	Yes
Vertical tanks > 5m in height	All tanks are in the range 10-16m in height	Yes
'Calm' atmospheric conditions (taken as night time, nil wind conditions)	According to weather data (See Appendix A), calm conditions can prevail at night time up to 25% of the time, especially during winter.	Yes
Low flash point fuel transfer	Gasoline (ULP and SPULP) is transferred	Yes
Ignition sources	Good control of ignition sources inside the Terminal boundary (design and management). No control of ignition sources outside the site boundary (public space).	Yes
High level protection failure	1. ATG and flow monitoring and procedures to stop transfer when required level is reached (well below alarm level) 2. ATG high alarm. This is similar to Buncefield in that an ATG failure can disable the alarm as well. 3. Independent high high level switch and automatic shutdown of all tank inlet valves and the pipeline valve. 4. In addition, flammable vapour detector and alarm in the bund and operator intervention to shut off inflow. 5. A safety management system that ensure testing and maintenance of the above.	The likelihood is lower as there is also the vapour detection system as an additional layer of protection. However, the incident is still credible, and needs to be considered in the risk assessment.

6.4.3 Consequence Modelling

UK HSE has developed methodology since the Buncefield incident for calculating the explosion overpressures from a tank overflow incident.

It is not possible to model the HSE methodology directly in the SAFETI software. Therefore, these events were modelled using the HSE methodology separately on a spreadsheet and the explosion results were entered into the SAFETI software as 'standalone' incidents. The sources of calculations are:

- *Vapour cloud formation - Experiments and modelling*, UK HSE 2012 (25). This research report describes the experiments conducted to explore the mechanism of large vapour clouds formed by overflows from large atmospheric storage tanks in calm conditions and proposes a simple methodology for estimating the extent of the vapour cloud.

- *Dispersion & Explosion Characteristics of Large Vapour Clouds, Volume 1: Summary Report*, Steel Construction Institute 2014 (26). This document summarises the results of a Joint Industry Project, which included (25). A simple expression was derived which enables the maximum external overpressure to be estimated and is applicable to clouds with a radius ≥50 m.

Explosion overpressure distances for the various MIs are summarised in Appendix C, Table 32.

7 FREQUENCY AND LIKELIHOOD ANALYSIS

7.1 Likelihood of Representative Incidents

Based on the generic frequency data listed in Appendix D, the frequency of each MI was calculated for input to SAFETI 8.23.

7.1.1 Buncefield Type Incident Frequencies

The incident frequency data listed in Table 14 was used in the risk analysis.

Table 14: Frequency Data for Risk Analysis

MI No.	Location	Description	Material	Consequence	Frequency/ year
MI-1	Tank farm South Yard - Tanks	T-1 top fire	Diesel	Fire	9.00E-05
MI-2		T-6 top fire	Diesel	Fire	9.00E-05
MI-3		T-7 top fire	Jet fuel	Fire	9.00E-05
MI-4		South yard pool fire - T-1, T-6 leak - 150mm	Diesel	LOC	2.40E-06
MI-5	Tank farm South Yard - Bund	South yard pool fire - T-1, T-6 leak - 500mm	Diesel	LOC	2.40E-07
		South yard pool fire - T-1, T-6 leak - Catastrophic	Diesel	LOC	3.84E-08
		South yard pool fire - pipework leak - 25mm	Diesel	LOC	5.28E-08
		South yard pool fire - pipework leak - FBR	Diesel	LOC	5.76E-08
		South yard bund fire - tank overflow T1 and T6	Diesel	LOC	4.25E-07
		South yard pool fire - T-7 leak - 150mm	Jet fuel	LOC	1.50E-05
		South yard pool fire - T-7 leak - 500mm	Jet fuel	LOC	1.50E-06
		South yard pool fire - T-7 leak - Catastrophic	Jet fuel	LOC	2.40E-07
		South yard pool fire - T7 pipework leak	Jet fuel	LOC	2.77E-07
		South yard pool fire - T7 pipework leak -FBR	Jet fuel	LOC	1.95E-06
		South yard bund fire - T7 tank overflow	Jet fuel	LOC	1.03E-08

MI No.	Location	Description	Material	Consequence	Frequency/ year
MI-6	T-214	Buncefield type event	Gasoline	VCE	
	T-378	Buncefield type event	Gasoline	VCE	4.97E-06
	T-482	Buncefield type event	Gasoline	VCE	1.05E-05
MI-7	Tank farm North Yard Tanks	T-214 top fire	Gasoline	Fire	5.41E-06
MI-8		T-352 top fire	Diesel	Fire	2.48E-05
MI-9		T-378 top fire	Gasoline	Fire	9.00E-05
MI-10		T-482 top fire	Gasoline	Fire	9.00E-05
MI-11		T-7969 top fire	Ethanol	Fire	9.00E-05
M-12		T-7970 top fire	Diesel	Fire	9.00E-05
MI-13		T-15721 top fire	Gasoline	Fire	9.00E-05
MI-14	Tank farm North Yard – Diesel	North yard pool fire - T-352 leak - 225 mm	Diesel	Pool Fire	1.20E-06
		North yard pool fire - T-352 leak - 750mm	Diesel	Pool Fire	1.20E-07
		North yard pool fire - T-352 leak - Catastrophic	Diesel	Pool Fire	1.20E-06
		North yard pool fire -T352 pipework leak - 25mm	Diesel	Pool Fire	3.30E-07
		North yard pool fire -T352 pipework leak - FBR	Diesel	Pool Fire	3.60E-07
		North yard bund fire - T352 tank overflow	Diesel	Pool Fire	4.25E-07
MI-15	Tank farm North Yard - Flammables	North yard pool fire - T214 leak - 150mm	Gasoline	Pool Fire	1.50E-05
		North yard pool fire - T214 leak - 500mm	Gasoline	Pool Fire	1.50E-06
		North yard pool fire - T214 -Catastrophic	Gasoline	Pool Fire	2.40E-07
		North yard pool fire - 378 leak - 225 mm	Gasoline	Pool Fire	1.50E-05
		North yard pool fire - 378 leak - 750 mm	Gasoline	Pool Fire	1.50E-06
		North yard pool fire - 378 - Catastrophic	Gasoline	Pool Fire	2.40E-07

MI No.	Location	Description	Material	Consequence	Frequency/ year
		North yard pool fire - 482 leak - 750 mm	Gasoline	Pool Fire	1.50E-06
		North yard pool fire - 482 leak - 225 mm	Gasoline	Pool Fire	1.50E-05
		North yard pool fire - 482 - Catastrophic	Gasoline	Pool Fire	2.40E-07
		North yard pool fire - Gasoline pipework leak- 25mm	Gasoline	Pool Fire	1.11E-06
		North yard pool fire - Gasoline pipework leak- FBR	Gasoline	Pool Fire	3.75E-06
		North yard bund fire - T 214,378,482 tank overflow	Gasoline	Pool Fire	1.45E-06
		North yard pool fire - T7969 leak - 150mm	Ethanol	Pool Fire	1.50E-05
		North yard pool fire - T7969 leak - 500mm	Ethanol	Pool Fire	1.50E-06
M-16	North yard, smaller tanks	North yard pool fire - Smaller combustible tanks leak	Diesel	Pool Fire	2.54E-06
		North yard pool fire - Smaller flammable tanks leak	Gasoline	Pool Fire	5.19E-07
MI-17	TTLR-1 (Gasoline)	TTLR 1 (Compartment failure) - Gasoline	Gasoline	Pool Fire	1.01E-07
		TTLR1 - Pool fire - 15mm Gasoline	Gasoline	Pool Fire	1.80E-09
		TTLR1 - Pool fire - FBR - Gasoline	Gasoline	Pool Fire	1.97E-09
MI-18	TTLR-1 (Diesel)	TTLR 1 (Compartment failure) - Diesel	Diesel	Pool Fire	1.69E-09
		TTLR1 - Pool fire - 15mm Diesel	Diesel	Pool Fire	6.07E-11
		TTLR1 - Pool fire - FBR - Diesel	Diesel	Pool Fire	6.63E-11
M-19	TTLR-2 (Gasoline)	TTLR 2 (Compartment failure) - Gasoline	Gasoline	Pool Fire	4.73E-08

MI No.	Location	Description	Material	Consequence	Frequency/ year
		TTLR2 - Pool fire - 15mm Gasoline	Gasoline	Pool Fire	1.69E-09
		TTLR2 - Pool fire - FBR - Gasoline	Gasoline	Pool Fire	1.84E-09
M-20	TTLR-2 (Diesel)	TTLR 2 (Compartment failure) - Diesel	Diesel	Pool Fire	1.58E-09
		TTLR 2 (Compartment failure) - Diesel	Diesel	Pool Fire	5.67E-11
		TTLR 2 (Compartment failure) - Diesel	Diesel	Pool Fire	6.20E-11
M-21	TTLR-3 (Diesel)	TTLR 3 (Compartment failure) - Diesel	Diesel	Pool Fire	1.50E-08
		TTLR 3 - Pool fire - 15mm - Diesel	Diesel	Pool Fire	3.38E-11
		TTLR 3 - Pool fire - FBR - Diesel	Diesel	Pool Fire	3.69E-11
M-22	TTLR-4 (Jet fuel)	TTLR 4 (Compartment failure) - Jet Fuel	Jet Fuel	Pool fire	5.89E-10
		TTLR 4 - Pool fire - 15mm	Jet Fuel	Pool fire	1.06E-11
		TTLR 4 - Pool fire - FBR	Jet Fuel	Pool fire	1.15E-11
M-23	TTLR-5 (Ethanol)	TTLR-5 - Tanker failure - Ethanol	Ethanol	Pool Fire	1.04E-09
		TTLR 5 - Pool fire - 15mm - Ethanol	Ethanol	Pool Fire	1.88E-11
		TTLR 5 - Pool fire - FBR - Ethanol	Ethanol	Pool Fire	2.04E-11
MI-24	VRU	VRU release - Minor	Gasoline	Pool Fire	1.00E-03
		VRU release - Major	Gasoline	Pool Fire	1.00E-04
		VRU release - Catastrophic	Gasoline	Pool Fire	1.60E-05
MI-25	SNP - Pipeline in easement along site boundary	SNP release - 10 mm hole	Gasoline	Pool Fire	3.22E-05 /km
		SNP release - 25 mm hole	Gasoline	Pool Fire	2.2E-05 /km
		SNP release – 75 mm hole	Gasoline	Pool Fire	2.69E-05 /km
		SNP release - 110 mm hole	Gasoline	Pool Fire	2.35E-05 /km
		SNP release - FBR	Gasoline	Pool Fire	8.8E-06/km

7.2 Probability of Ignition

7.2.1 Onsite Ignition

The ignition probabilities adopted in the risk analysis were based on a review of relevant ignition probability data and ignition probability correlations. The primary source used in the risk analysis was the International Association of Oil and Gas Producers' (OGP), *Ignition Probabilities* (27).

Different ignition probabilities are used for flammables (gasoline, jet fuel, ethanol, slops and additives), and combustibles (diesel). The ignition probability is dependent on the release rates.

Details are given in Appendix A, Assumption 21.

7.2.2 Offsite Ignition

In tank overflow and Buncefield type incidents, the flammable vapour cloud is large and can reach a distance of 200 to 240m, depending on the tank. Since Ampol has no control over the ignition sources outside the site boundary, the on-site ignition probability data is not applicable for these events.

Estimation of ignition probability is associated with some uncertainty and all the analyst can do is to arrive on a cautious best estimate based on available data (ignition model and local conditions for ignition sources and source strengths).

The UK HSE ignition probability model has been used in this case. The model is expressed as (28):

$$P_{ign} = 1 - exp(-\mu A p)$$

where, P_{ign} = Ignition probability of vapour cloud

μ = Ignition source density per hectare. A value of 0.13 has been suggested in (28) for urban areas at night time

p = Ignition source strength. This varies depending on the population present within the flammable cloud.

TNO has developed a method to estimate the value of p, given the population.

$p = 1\text{-}0.99^N$ (29) where N is the number of persons within the flammable cloud area . Since value of N can be in excess of 500, p = 1. However, a value of N=200 was used for calculating p.

The calculated ignition probabilities for the tank overflows under calm nigh time conditions are summarised below:

Table 15: Buncefield Type Incident Ignition Probabilities

No.	Tank	Product	Cloud Radius, m	Cloud Area, ha	P_{ign}
1	T-214	SPULP	194	11.8	0.78
2	T-378	ULP	236	17.4	0.90
3	T-452	PULP	223	15.6	0.87

8 RISK ANALYSIS

8.1 Individual Risk of Fatality

Contours of constant risk (iso-risk) were generated from SAFETI 8.23 and superimposed on a map of the Ampol site and surroundings.

Contours were generated for risk levels of 1, 10 and 50 in a million per year. The risk contours for individual risk of fatality at various levels are shown in Figure 10.

Figure 10: Individual Fatality Risk Contours

The following observations can be made from the fatality risk contours:

- The risk of fatality at 50×10^{-6} per year is contained entirely within the Ampol site.
- The risk of fatality at 10×10^{-6} per year covers the proposed open space and all of the commercial areas of the proposed development site
- The risk of fatality at 1×10^{-6} per year covers the entirety of the residential areas of the proposed development site

8.2 Assessment of Compliance with Risk Criteria

The risk results for individual risk are compared with the criteria in Section 2.3.1 and 2.3.2 in Table 16.

Table 16: Individual Fatality Risk Criteria Compliance

Category	Risk Levels (p.a.)	Notes	Criteria Met?
Industrial Sites	50×10^{-6}	Individual fatality risk levels for industrial sites at levels of 50 in a million per year (50×10^{-6} per year)	Yes. The 50×10^{-6} per year contour lies

Category	Risk Levels (p.a.)	Notes	Criteria Met?
		should, as a target, be contained within the boundaries of the site where applicable.	entirely within the Terminal boundary.
Sporting complexes and active open space areas	$<10 \times 10^{-6}$	Should not be exposed to individual fatality risk levels in excess of ten in a million per year (10×10^{-6} per year).	No. The proposed open space to the west of the Terminal lies within the 10×10^{-6} per year contour.
Commercial developments including retail centres, offices and entertainment centres	$<5 \times 10^{-6}$	Should not be exposed to individual fatality risk levels in excess of five in a million per year (5×10^{-6} per year).	No. The proposed commercial development to the west of the Terminal exceeds the 5×10^{-6} p.a. contour and lies within the 10×10^{-6} per year contour.
Residential, hotels, motels, tourist resorts	$<1 \times 10^{-6}$	Should not be exposed to individual fatality risk levels in excess of one in a million per year (1×10^{-6} per year). This criterion assumes that residents will be at their place of residence and exposed to the risk 100% of the time throughout the year.	No. The entire residential complex in the proposed development lies within the 1×10^{-6} contour.
Hospitals, schools, child-care facilities and old age housing development.	$<0.5 \times 10^{-6}$	Should not be exposed to individual fatality risk levels in excess of half in a million per year (0.5×10^{-6} per year)	There are no sensitive land uses in the proposed development.

8.3 Risk of Property Damage and Accident Propagation

The cumulative risk of property damage and accident propagation (Overpressure exceeding 14 kPa) does not reach 50×10^{-6} per annum.

8.4 Risk of Property Damage and Accident Propagation (Exceeding 23 kW/m^2)

The cumulative risk of property damage and accident propagation (Heat radiation exceeding 23 kW/m^2) at 50 in a million per year is shown in Figure 11.

Figure 11: Injury Risk Contour for 23 kW/m2 heat radiation

The 50 in a million per risk of exceeding 23 kW/m^2 is not generated in the tank farm, and is based around the VRY, and falls entirely within the site.

8.5 Risk of Injury (Exceeding 7 kPa)

The cumulative risk of injury (Overpressure exceeding 7 kPa) does not reach 50 x 10^{-6} per annum, and no corresponding risk contour was generated.

8.6 Risk of Injury (Exceeding 4.7 kW/m^2)

The risk contour for injury from heat radiation exceeding 4.7 kW/m^2 at 50 x 10^{-6} per annum is shown in Figure 12.

Figure 12: Injury Risk Contour for 4.7 kW/m2 heat radiation

The contour marginally extends into the proposed development, but does not impact on a residential building. There is no significant contribution from the SNP to this risk at 50 in a million per year.

8.7 Societal Risk

It is possible that an incident at a hazardous facility may affect more than a single individual off-site, especially in the case of large releases of hazardous materials.

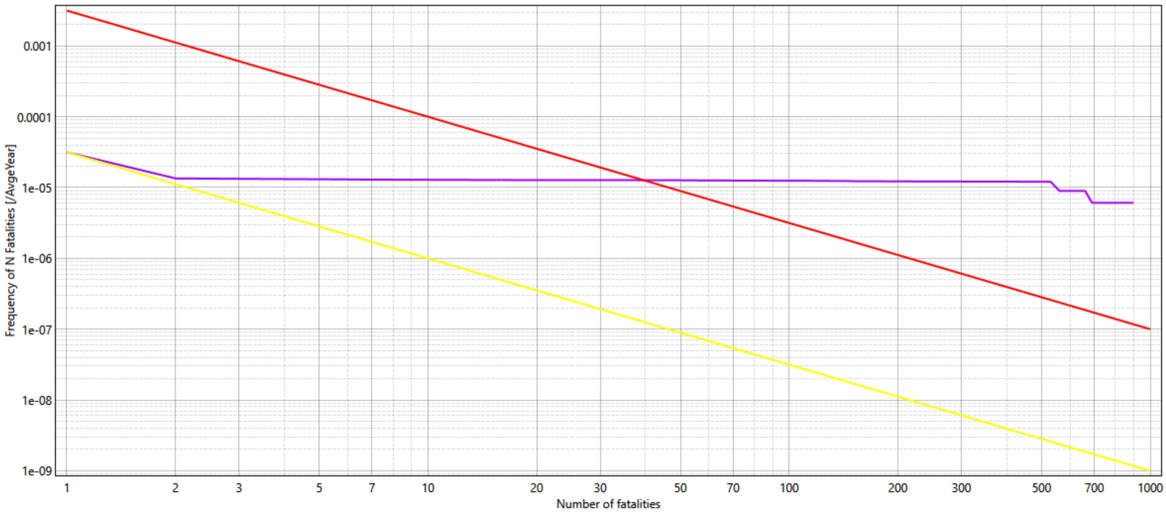
The societal risk concept evolved from the concept of 'risk aversion', i.e. society is prepared to tolerate incidents that cause single fatalities at a more frequent interval (e.g. motor vehicle accidents) than for incidents causing multiple fatalities (e.g. an aircraft accident).

Two parameters are required to define societal risk: (a) Number of fatalities that may result from an incident; and (b) the frequency (likelihood) of occurrence of the incident.

Societal risk can be represented by F-N curves, which are plots of the cumulative frequency (F) of various accident scenarios against the number (N) of casualties associated with the modelled incidents. In other words, 'F' represents the frequency of exceedance of number of fatalities, N.

The F-N plot is cumulative in the sense that, for each frequency on the plot, N is the number of fatalities that could be equalled ***or exceeded***, and F is the frequency of exceedance of the specified number of fatalities. The FN Curve for the proposed development is shown in Figure 13.

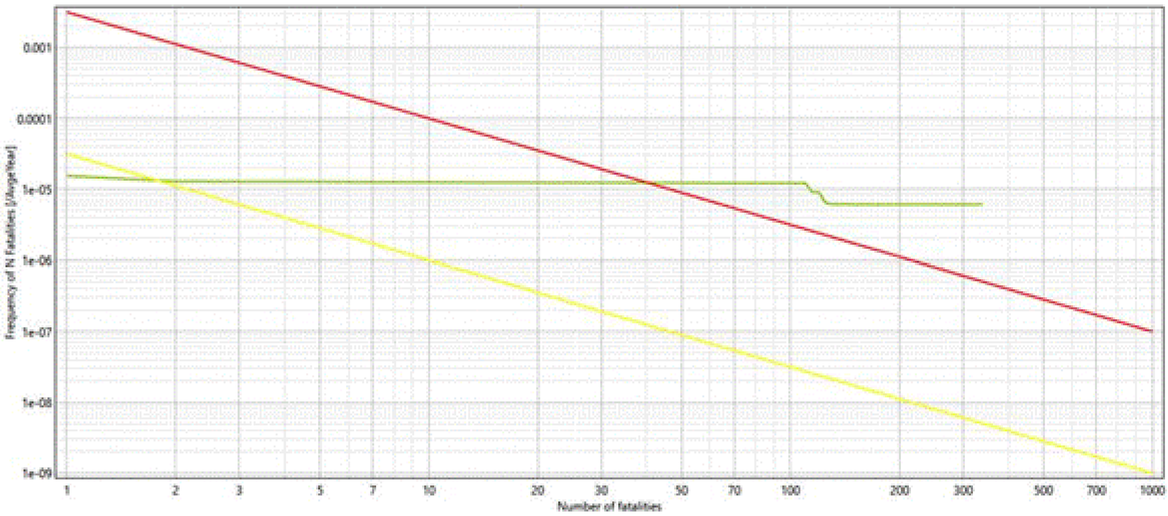
Figure 13: Societal Risk F-N Curve (Including Proposed Development)



- The curve remains flat at approximately 1x10^{-5} per year, as the major contributors to societal risk are the Buncefield type incidents.
- The curve stays in the ALARP region for N=35 or less.
- For N>35, the curve exceeds the upper limit criteria and falls in the 'intolerable' region.
- The maximum number of fatalities could be up to 900.
- The societal risk criterion is not satisfied.

The existing societal risk without the proposed development was also calculated to compare the incremental increase in risk due to the proposed development. The curve is shown in Figure 14.

Figure 14: Societal Risk F-N Curve (Existing)



- The F-N curve for existing risk (without the proposed development) also remains flat at approximately $1x10^{-5}$ per year, as the major contributors to societal risk are the Buncefield type incidents.
- The curve stays in the ALARP region for N=35 or less, similar to the 'post development' risk.
- For N>35, the curve exceeds the upper limit criteria and falls in the 'intolerable' region, and the maximum number of fatalities could be up to 340.
- The societal risk criterion is not satisfied in the current situation even without the population increase with the proposed development.

8.8 Societal Risk Evaluation

There are three societal risk criteria to be satisfied according to HIPAP No.10.

(1) F-N curve not to exceed the upper limit boundary;

(2) Total N not to exceed 1000; and

(3) Reduce the risk level to As Low As Reasonably Practicable (ALARP).

Criterion (1) is not satisfied.

Criterion (2) is satisfied as the maximum N is less than 1000.

For Criterion (3), if all reasonably practicable measures have been implemented in the Terminal, and the costs of any additional measures are estimated to be grossly disproportionate to the benefits gained, then ALARP is said to be achieved. This is an elaborate process. It is Arriscar's understanding that Ampol does not have to demonstrate this under existing conditions, as they are not the proponent.

If ALARP has been achieved and the risk is still 'intolerable' (above the upper line of criteria), HIPAP No.10 states that population intensification should be restricted.

In HIPAP 10 (4), the following is reported regarding the F-N criteria:

If a development proposal involves an intensification of population in the vicinity of a potential source of risk, then the incremental change in societal risk needs to be taken into *account, even if individual risk criteria are met [Ref.* (4)*, Section 5.5.4]. The incremental societal risk should be compared against the indicative societal risk criteria in Section 5.4.2 of HIPAP No. 10. If the incremental societal risk lies within the 'Negligible' region, then the development should not be precluded and if it lies within the 'Tolerable if ALARP' region, then options should be considered to relocate people away from the affected areas [Ref.* (4)*, Section 5.5.4]. If, after taking this step, there is still a significant portion of the societal risk plot within the 'Tolerable if ALARP' region, the proposed development should only be approved if benefits clearly outweigh the risks [Ref.* (4)*, Section 5.5.4].*

In the present context, the Terminal risk exceeds the risk criteria for societal risk, as part of the curve falls in the intolerable region. The question of '*approved if benefits clearly outweigh the risks'* arises only if the F-N curve falls within the ALARP region. Since the risk would only increase further due to proposed additional population increase in the vicinity of the Terminal, such population intensification is not desirable.

Therefore, from a societal risk consideration also, the proposed development is considered inappropriate at the proposed location.

8.9 Risk Evaluation for Existing Facilities

8.9.1 Individual Risk

For existing facilities that were constructed prior to the introduction of HIPAP guidelines and risk criteria, the guidelines provide the following considerations:

For existing hazardous facilities, Clause 2.5.2.1 of HIPAP 4 (30) states:

> *"residential intensification may be appropriate where mitigating measures can be implemented to reduce risk exposure to less than the one in a million per year individual fatality risk level, provided the pre-mitigation residual risk levels are below the 10 in a million per year individual fatality risk level; and residential intensification should take place where pre-mitigation residual risk levels are in excess of the 10 in a million per year individual fatality risk level."*

For the Wickham Terminal, the proposed development falls in the 10 in a million risk contour and hence the allowances given for existing facilities do not apply.

8.9.2 Societal Risk

Clause 2.5.4 of HIPAP 4 states that:

> *Provided the incremental societal risk lies within the negligible region, development should not be precluded. If incremental risks lie within the ALARP region, options should be considered to relocate people away from the affected areas. If, after taking this step, there is still a significant portion of the societal risk plot within the ALARP region, the proposed development should only be approved if benefits clearly outweigh the risks.*

The term 'incremental risk' has not been defined in the HIPAP, and therefore has been subject to different interpretations in the past.

Two possible interpretations are discussed here:

Interpretation 1:

Calculate the risk to the proposed development with the proposed population only, and call it 'incremental risk'. Such an approach has been taken in the Planager report (8), and the F-N curve is reported to fall partially in the ALARP region. It is referred to as 'incremental risk', but it is in fact the absolute risk arising from the terminal on the proposed development.

The above interpretation has a few shortcomings.

(a) The risk assessed is the absolute societal risk from the Terminal on the proposed development, and not incremental risk over and above the existing background risk without the proposed development.

(b) If Interpretation 1 is accepted, then for every future development in the region, the F-N curve for that development alone can be shown to be in the negligible region, and there could be an overall population creep to an unacceptable level in the area.

Interpretation 2:

Calculate the societal risk from the Terminal with the existing population. Then calculate the same F-N curve with the increased population in the proposed development. The difference between the two curves would be incremental risk to the cumulative risk.

The second interpretation has been adopted here.

The existing F-N curve for the area partly falls in the intermediate or 'ALARP' region and partly exceeds the criteria. The updated F-N curve with the new development population encroaches more into the 'intolerable region'.

Section 5.1.2 of HIPAP No. 10 (4) that:

> *Because of the uncertainties in the numerical outputs from a risk analysis, there needs to the degree of flexibility in the implementation and interpretation of probabilistic risk criteria. However, while quantitative risk criteria should not be used as absolute numbers, where risk levels exceed established criteria, the acceptability of the risk at or from a facility will need to be carefully considered in the light of the economic or social benefits provided by the development.*

The above statement offers discretion to the consent authority to consider a development in the light of economic and social benefits. However, there are a few other considerations:

- The Section 5.1.2 statement in HIPAP No.4 is contradicted by Sections 2.5.2.1 and 2.5.4 of HIPAP 4 (3).
- It is not clear that where both individual and societal risk criteria are not met, even after applying the allowances provided for existing hazardous facilities, economic and social benefits alone should influence the determination, exposing the population to an unacceptable level of risk.
- Finally, if the residential population density is increased in the vicinity of the Terminal, any future changes by Ampol on the Terminal may be constrained as SEPP 33 will apply and the residential area risk criteria may not be met even after ALARP.

9 COMPARISON BETWEEN PLANAGER REPORT [(8), (9)], AND THE PRESENT REPORT

This section provides a brief summary of the differences between the Planager reports submitted by the proponent in support of the DA [(8), (9)] and the present report.

Table 17: Comparison between Planager Reports and Arriscar Report

Parameter	Planager Report	Arriscar Report
Assumptions	Details not listed. Claims assumptions are conservative based on HRA practice. Cannot verify.	Transparent, traceable and verifiable. Assumptions based on cautious best estimates, when based on engineering judgement. Literature sources quoted.
Terminal information	All data taken from publicly available information, and from Ref. (11). Operational information not available for assessment.	Full information on design and operation of the Terminal including P&IDs, flowrates, product receival and tanker loading information provided by Ampol for the study.
Hazard identification	Restricted to worst credible scenarios that could affect the proposed development.	Full range of incidents from all potential sources (tanks, piping, pumps, tankers) including operational incidents (e.g. overfilling), as data was made available by Ampol.
Buncefield type incident	Overfilling frequency at full rate has been used as 1.9×10^{-6} p.a. based on OGP generic data. Does not appear to reflect overfill protection in the Terminal and operational data (number of fills and shutdown duration). This frequency combined with a low ignition probability (OGP database Table 8 applicable to LPG) estimates the overflow risk to be very low and does not reflect in the risk contours. Buncefield incident was not assessed as the largest risk contributor. Consequences of overflow incidents were treated as 'flash fires' based on vapour cloud dispersion.	Fault tree analysis was conducted based on actual protection provided and fill procedure provided by Ampol. The overall overflow frequency is one order of magnitude higher than using generic data. Since the vapour cloud would go offsite to the proposed development, ignition probability is based on population density using the TNO model, as OGP database was not found to be more suitable for offsite ignition in residential areas (29), (31). This value is an order of magnitude higher than the generic data in the OGP model which applies to on-site ignition sources. Consequences of vapour cloud explosions were assessed using the HSL methodology (25) as side-on overpressures at various distances. The consequence distances are larger than the flashfire distances. Buncefield type incident was assessed as the largest risk contributor.

Parameter	Planager Report	Arriscar Report
Failure frequencies -	Pumps – OGP data used. Tanks and surface fires – OGP data used Pipework – OGP data used	Pumps (single mechanical seal) – UK HSE data used. Values reported are 3 to 10 times higher. UK HSE data used. Very similar values. Pipework – UK HSE data used. Very similar values.
Ignition probabilities	OGP data used (onsite)	OGP data used (onsite). No difference.
Pipeline	Done in a separate report (9). Risks not integrated. Cumulative contribution not known.	Integrated risk assessment including Terminal and pipeline.
Individual risk contours	Smaller contours with Buncefield incidents. Assessed frequencies were one to two orders of magnitude lower.	Larger contours (higher frequency of overfill from fault trees and higher ignition probability offsite). This is one fundamental difference between the two reports.
Societal risk	Only the proposed development population was assessed representative of 'incremental risk', and shown to satisfy the risk criteria. Incremental risk is interpreted as the increase in cumulative risk between existing levels of societal risk without the proposed development and the new risk including the proposed increase in population. This has not been done. Further, since the Buncefield incidents were represented with lower consequence distances and lower frequencies, their contribution to societal risk is assessed as low.	Societal risk assessment consisted of: 1. Current levels of risk without the proposed development 2. Revised levels of risk with the proposed development 3. Incremental increase in cumulative risk was to increase the total potential fatalities from 340 to 900. The results contradict the Planager report results as it does not include existing population, besides underestimating Buncefield consequences, due to lack of data.

10 FINDINGS

The following findings were made from the risk assessment:

- The proposed development does not comply with the risk criteria in HIPAP 10 (4) for new residential developments.
- The proposed development does not comply with the risk criteria in HIPAP 10 (4) for commercial developments.
- The proposed development does not comply with the risk criteria in HIPAP 10 (4) for open space development.
- The population increase and consequent increase in societal risk from the proposed development does not comply with the F-N criteria in HIPAP 10 (4).
- The risk of injury exceeding a side on overpressure of 7 kPa at 50 in a million per year is not generated, indicating that this criterion is complied with.
- The risk of injury exceeding a thermal radiation of 23 kW/m^2 at 50 in a million per year falls entirely within the site and does not reach other industrial sites. The risk criterion for injury at adjacent industrial sites is complied with.
- The risk of injury exceeding a thermal radiation of 4.7 kW/m^2 at 50 in a million per year does not reach residential developments (including existing and proposed). The risk criterion for injury at residential areas is complied with.
- The major contribution to risk of fatality at the proposed development is from vapour cloud explosions arising from flammables tank overfill and Buncefield type incident.
- The societal risk criterion is not complied with as there is a significant increase in cumulative incremental risk ad a significant part of the F-N curve (high fatality area) falls in the 'Intolerable' region.
- The contribution to societal risk arises from Buncefield type incidents as well as Sydney-Newcastle fuel pipeline incidents in the vicinity of the Terminal.
- On a consequence basis alone, a vapour cloud explosion can result in side-on overpressure exceeding 70 kPa on the proposed development. Mitigation against such blast load is not possible.
- The conclusion is that the proposed residential, commercial and open space development at the Wickham woolshed stores site is an inappropriate development given that the risk criteria for both individual risk and societal risk are not complied with.

11 REFERENCES

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Appendices

Appendix A Assumptions

It is necessary to make technical assumptions during a risk analysis. These assumptions typically relate to operational inputs (facility, operations data), specific data inputs (e.g. material properties, equipment failure rates, etc.) and modelling assumptions (e.g. release orientations, impairment criteria, etc.).

To comply with the general principles outlined in Section 2.2 of HIPAP No. 6, all steps taken in the risk analysis should be: "*traceable and the information gathered as part of the analysis should be well documented to permit an adequate technical review of the work to ensure reproducibility, understanding of the assumptions made and valid interpretation of the results*". Therefore, details of the key assumptions adopted for the risk analysis are provided in this Appendix.

Each assumption is numbered and detailed separately. The basis for each assumption is explained together with its potential impact on the risk results and the incidents potentially affected. Key references are also listed for each assumption, where relevant.

It is important that the assumptions be supported by:

- facility data provided by Ampol;
- experience based data in the literature, where available, for failure scenarios, failure rates of equipment and components;
- actual operating experience provided by Ampol;
- similar assumptions made by experts in the field and a consensus among risk analysts; and
- engineering judgement of the analyst.

The main objectives are to minimise uncertainty in the risk estimate as far as is possible, and to ensure that the assumptions result in a 'conservative best estimate' of the risk. Such an approach is consistent with the following extract from Section 5 of HIPAP No. 6: "*In the consequence analysis and throughout the hazard analysis, the analyst must be conscious of the uncertainties associated with the assumptions made. Assumptions should usually be made on a 'conservative best estimate' basis. That is, wherever possible the assumptions should closely reflect reality. However, where there is a substantial degree of uncertainty, assumptions should be made which err on the side of conservatism.*"

Table 18: List of Assumptions by Subject

Subject	No.	Assumption
Operational Data	1	Operating Conditions
Locational Data	2	Representative Wind Speeds, Wind Directions and Stability Classes
	3	Ambient Conditions
	4	Surface Roughness
	5	Total Population (Day and Night)
	6	Indoor / Outdoor Population Distribution (Day and Night)
Consequence Analysis	7	Representative Materials
	8	Release Modelling
	9	Representative Hole Sizes for Hazardous Materials Releases
	10	Representative Hole Diameters for Pipeline Releases
	11	Height of Release
	12	Direction of Release
	13	Flammable Liquid
	14	Shape of Liquid Pools
	15	Maximum Extent of Flash Fire
	16	3D Explosion Model Parameters
	17	Maximum Mass Released
	18	Large Atmospheric Storage Tank Vapour Cloud Analysis
Likelihood Analysis	19	Failure Rate Data
	20	Likelihood of Tank Overfill Leading to a Large Vapour Cloud and Explosion
	21	Ignition Probability
	22	Ignition Probability for Buncefield Type Incident
	23	Human error probability
Vulnerability Parameters	24	Exposure to Flash Fire
	25	Exposure to Explosion Overpressure (Indoor or Outdoor)

A.1 Operational Data

Assumption No. 1: Operating Conditions
Subject: Operational Data
Assumption/s: • All operating conditions (pressure, temperature, flow rates etc.) are as provided by Ampol.
Justification and Impact/s of Assumption/s: • All operational data for the facilities was provided by the facility Operator (Ampol). • Operating conditions are required to undertake the release and dispersion modelling.
Incidents Affected: • All.
Reference/s: • Information provided by Ampol.

A.2 Locational Data

Assumption No. 2: Representative Wind Speeds, Wind Directions and Stability Classes
Subject: Locational Data
Assumption/s: • There are two weather stations closest to the site (a) Nobbys Station IDN 061055, 3.6 km from the site; (b) Williamtown RAAF met station IDN 060801 in Salt Ash at a distance of 18 km. • Nobby's station is located 40m above sea level and subject to high wind conditions and not representative of the Ampol Terminal site. Therefore, Williamtown RAAF Base weather station data was used. • The probabilistic distribution of wind speed and wind direction for the representative stability classes is based on the Bureau of Meteorology (BoM) meteorological data for Williamtown RAAF (Station ID: 060801). The daytime and night time distributions are provided in Table 19 and Table 20. • Note: For the BoM meteorological data, night is defined as being the hour before dusk to the hour after sunrise. This varies depending on time of year; however, the average night time and day time duration were taken as 14 hours/day and 10 hours/day, respectively, allowing for twilight.
Justification and Impact/s of Assumption/s: • The BoM meteorological data was processed in accordance with the methodology provided by the Victorian EPA. • The population data for Wickham in the vicinity of the Terminal varies significantly for day time and night time. Therefore, the representative wind speed, stability class and wind direction data was determined for both daytime and night time (Refer to Table 19 and Table 20). This is to ensure that the corresponding conditions and populations are accounted for when estimating the societal risk. • Wind speed typically has minimal impact on jet fires as the jet velocity is much higher than the wind speed. However, higher wind speeds may cause the 'tilting' of the flame from a pool fire. An allowance for flame tilt is included in the SAFETI model. • The downwind concentrations, and hence the hazard ranges for dispersion of flammable gas or vapour, vary with wind speed and Pasquil stability class. Therefore, multiple representative wind speed and stability class categories are included in accordance with standard practice for undertaking a quantified risk analysis (QRA).
Incidents Affected: • All.
Reference/s: • Exemplary Energy manipulation of BoM data for Williamtown RAAF (Station ID: 060801). • Stability categories calculated as per VIC EPA publication 1459. Sunrise and Sunset times obtained from NASA Jet Propulsion Laboratories' "Horizons" Ephemeris program. • Bureau of Meteorology, http://www.bom.gov.au/climate/averages/tables/cw_60801.shtml.

Table 19: Day Time Probability of Representative Wind Speeds and Stability Classes

Modified PG class	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
DL	0.0073	0.0035	0.0040	0.0029	0.0035	0.0028	0.0025	0.0026	0.0029	0.0019	0.0022	0.0026	0.0064	0.0090	0.0075	0.0052	0.0665
DM	0.0154	0.0119	0.0215	0.0197	0.0282	0.0299	0.0304	0.0262	0.0283	0.0121	0.0108	0.0118	0.0300	0.0528	0.0370	0.0153	0.3813
DH	0.0007	0.0016	0.0111	0.0274	0.0298	0.0282	0.0315	0.0398	0.0556	0.0162	0.0084	0.0053	0.0279	0.0862	0.0188	0.0022	0.3907
B	0.0165	0.0105	0.0103	0.0069	0.0079	0.0087	0.0135	0.0092	0.0057	0.0027	0.0024	0.0037	0.0099	0.0164	0.0194	0.0177	0.1615
Total	0.0399	0.0276	0.0469	0.0568	0.0694	0.0695	0.0779	0.0777	0.0924	0.0330	0.0238	0.0233	0.0743	0.1644	0.0827	0.0405	1.00

Table 20: Night Time Probability Representative Wind Speeds and Stability Classes

Modified PG class	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
F	0.0239	0.0189	0.0193	0.0167	0.0151	0.0059	0.0061	0.0059	0.0072	0.0036	0.0042	0.0074	0.0207	0.0327	0.0284	0.0132	0.2292
E	0.0039	0.0050	0.0076	0.0056	0.0036	0.0013	0.0014	0.0011	0.0021	0.0009	0.0010	0.0017	0.0062	0.0150	0.0107	0.0028	0.0699
DL	0.0238	0.0172	0.0180	0.0161	0.0160	0.0068	0.0071	0.0076	0.0103	0.0050	0.0047	0.0073	0.0171	0.0274	0.0214	0.0110	0.2166
DM	0.0112	0.0184	0.0401	0.0243	0.0224	0.0131	0.0153	0.0151	0.0241	0.0113	0.0085	0.0151	0.0344	0.0617	0.0328	0.0081	0.3558
DH	0.0002	0.0009	0.0050	0.0041	0.0023	0.0029	0.0073	0.0109	0.0191	0.0070	0.0042	0.0039	0.0135	0.0405	0.0061	0.0007	0.1285
Total	0.0629	0.0605	0.0901	0.0668	0.0593	0.0300	0.0372	0.0405	0.0627	0.0278	0.0225	0.0353	0.0920	0.1773	0.0994	0.0357	1.00

Assumption No. 3: Ambient Conditions

Subject: Locational Data

Assumption/s:

- The typical ambient conditions (temperature, atmospheric pressure, solar radiation and relative humidity) are based on the Bureau of Meteorology (BoM) meteorological data for Williamtown RAAF Base weather station.
- The average temperature, atmospheric pressure and solar radiation for each daytime and night time representative stability class – wind speed category is listed in Table 21.

Table 21: Average Temperature, Atmospheric Pressure and Solar Radiation

Stability Class	Windspeed (m/s)	Average Temp (°C)	Average Solar Radiation (W/m^2)	Relative Humidity (%)
Daytime				
B	1.86	22.3	625.5	62
DH	8.20	21.3	345.0	56
DL	1.32	18.0	47.9	67
DM	4.20	19.9	174.5	81
Night time				
DH	7.98	15.7	0	71
DL	0.72	15.0	0	81
DM	3.90	16.2	0	91
E	3.10	14.3	0	83
F	0.58	13.9	0	89

Justification and Impact/s of Assumption/s:

- The BoM meteorological data for Williamtown RAAF weather station was processed in accordance with the methodology provided by the Victorian EPA.
- The average ambient temperature is a required input for the SAFETI model. The temperature of the material in each process facility equipment is within the upper and lower limits reported in Table 21. Therefore, the average ambient temperature does not have a significant impact on the consequence calculations.
- The average atmospheric pressure is a required input for the SAFETI model. The Wickham Terminal area is flat and essentially at sea level. Therefore, the average atmospheric pressure does not have a significant impact on the consequence calculations.
- The average solar radiation is a required input for the SAFETI model. More recent versions of the SAFETI software allow this to be entered for each representative stability class – wind speed rather than a single value for all conditions.

Assumption No. 3: Ambient Conditions
Incidents Affected: • All.
Reference/s: • Exemplary Energy manipulation of BoM data for Williamtown RAAF Base (Station ID: 060801). • Stability categories calculated as per VIC EPA publication 1459. Sunrise and Sunset times obtained from NASA Jet Propulsion Laboratories' "Horizons" Ephemeris program. • Bureau of Meteorology, http://www.bom.gov.au/climate/averages/tables/cw_60801.shtml.

Assumption No. 4: Surface Roughness Length
Subject: Locational Data

Assumption/s:

- The roughness length for different surface types, as listed in the SAFETI user manual, is shown below in Table 22.

Table 22: Surface Roughness Length

Description	Roughness Length (m)
Open water, at least 5 km	0.0002
Mud flats, snow, no vegetation, no obstacles	0.005
Open flat terrain, grass, few isolated objects	0.03
Low crops; occasional large obstacles, x/h > 20	0.1
High crops, scattered large obstacles, 15<x/h<20	0.25
Parkland, bushes, numerous obstacles, x/h<15	0.5
Regular large obstacle coverage (suburb, forest)	1
City centre with high- and low-rise buildings	3

- The terrain near the Wickham Terminal has regular large obstacles (tanks, plant structure, storage sheds and other industrial buildings). Therefore, a roughness length of 1 m is chosen as representative value for this location.

Justification and Impact/s of Assumption/s:

- The surface roughness affects the dispersion analysis. As the surface roughness increases, a release of gas or vapour will disperse more quickly with increasing distance from the source. Therefore, it is necessary in SAFETI to select a surface roughness length that is representative of the types of terrain and obstacles near the proposed site.
- It is not possible to define different surface roughness lengths for different locations (land and water) within a single SAFETI model. Only a single representative value can be defined for the entire study area.

Incidents Affected:

- Dispersion modelling for all relevant Incidents.

Reference/s:

- SAFETI software documentation.

Assumption No. 5: Total Population (Day and Night)
Subject: Locational Data
Assumption/s: • The societal risk analysis includes the estimated population within the Study Area and the immediate surrounds (See Appendix B). • **Sensitive Land Uses** – The nearest sensitive land uses are: - Little Beginnings, 65, the Avenue, Maryville – 140m away - KU Wickham Preschool, 18A, Albert Street, Wickham - 320m away • **Residential Areas** – The nearest residential area is currently at Annie Street, 70m from the southern boundary of the Terminal. The residential population in the vicinity of the Study Area (within the maximum estimated hazard range) is based on occupancy rates from the 2016 Census for the associated statistical zones as given in Appendix B • **Proposed Residential Apartment Population** – The population in each proposed residential apartment building is conservatively based on an occupancy rate of 1.9 persons per apartment, with 100, 99 and 69 apartments in WS1, WS2, and WS5 respectively. 40% of this population is assumed to be present during the day and 100% is present during the night. • **Open Spaces** – An open space immediately west of the site is planned for in the proposed development. • **Commercial Areas** – The commercial/retail population in WS3, WS4 and WS5 is based on 1 person 30 m^2 of GFA, with 100% present during day and 10% present during the night. WS3, WS4 and WS5 GFAs are 11302m^2, 4229m^2 and 181m^2 respectively. • **Industrial areas surrounding the Ampol Terminal** – a population density for the industrial land uses has been assumed to be 10 people per hectare.
Justification and Impact/s of Assumption/s: • The total population and the % of the total population present during the day and night is required for estimation of the societal risk. • The average number of people counted per apartment on Census night from the 2016 Census was 1.9. • According to the community profile for Maryvale and Wickham, the population density is 20.55 people per hectare. It is noted that part of this statistical area includes residential dwellings which are covered in the 2016 Census data for the location. The industrial areas of Mayfield West and Carrington have population densities of 7.99 people and 9.6 people per hectare. As such a population density of 10 people per hectare has been applied to the IN4 industrial lots in the subject area.
Incidents Affected: • All (Note: This assumption is only applicable to the calculation of societal risk).
Reference/s: • Amended Wickham Wool stores DA Master Plan Report - April 2020 (32) • https://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/2071.0~2016~Main%20Features~Apartment%20Living~20 • https://profile.id.com.au/Newcastle/about?WebID=160 • Australian Bureau of Statistics, 2016 Census data.

Assumption No. 6: Indoor / Outdoor Population Distribution (Day and Night)

Subject: Locational Data

Assumption/s:

- The % of people located indoors and outdoors during the day and night is dependent on the type of use, as follows:
  - **Sensitive Land Uses** – There are no sensitive uses (schools, hospitals, day care centres) within the Study Area or the maximum estimated hazard range.
  - **Residential Areas** – 90% of the population is indoors and 10% is outdoors.
  - **Open Spaces** – 100% of the population is outdoors.
  - **Commercial Areas** – 90% of the daytime population is indoors and 10% is outdoors. 90% of the night-time population is indoors and 10% is outdoors.
  - **Industrial Areas** – The % of people located indoors and outdoors during the day and night is assumed as follows: 90% of the daytime population is indoors and 10% is outdoors; and, 90% of the night-time population is indoors and 10% is outdoors.

Justification and Impact/s of Assumption/s:

- The default values recommended by the TNO [‘Purple Book’] for residential and industrial areas are tabulated below (31). These were used as a guide and adjusted for Australian conditions.

Table 23: Proportion of Population Indoor and Outdoor During Day and Night

Location	Day Time (8am to 6:30pm)	Night Time (6:30pm to 8am)
Indoor	93%	99%
Outdoor	7%	1%

- The proportion of people located indoors and outdoors will affect the societal risk analysis, as the vulnerability to fire, explosion, etc. varies depending on location.

Incidents Affected:

- All (Note: This assumption is only applicable to the calculation of societal risk).

Reference/s:

- TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition (31).

A.3 Consequence Analysis

Assumption No. 7: Representative Materials
Subject: Consequence Analysis

Assumption/s:
• Materials that are mixtures (e.g. gasoline) are included in the SAFETI risk model as a representative material. For example:
  • Gasoline is modelled as 100% heptane.
  • Jet Fuel is modelled as 100% decane.
  • Diesel is modelled as 100% dodecane.
  • Additives are modelled as combustible liquids (Diesel)

Justification and Impact/s of Assumption/s: • The composition and materials used affect the magnitude of the consequences. Materials containing multiple components are simplified for modelling purposes by choosing a representative component to best approximate the variable composition. Modelling a representative material rather than a multi-component material reduces complexity, limits the potential for inconsistencies and ultimately has a minimal effect on the results. • The additives Safety data Sheets (SDS) indicated that that all have flash points above 61^{O}C, and therefore not flammable, but combustible.
Incidents Affected: • All
Reference/s: • Information provided by Ampol.

Assumption No. 8: Release Modelling
Subject: Consequence Analysis
Assumption/s: • A release from a process equipment/ storage vessel is modelled at the operating pressure (static head in the case of atmospheric storage tanks). • A release from process pipework or pipelines is modelled at the pump discharge pressure, with maximum release rate limited to the pumping rate. • A release from a packaged container is limited to one package (IBC).
Justification and Impact/s of Assumption/s: • Release rate is dependent on pressure, and releases directly from storage vessels are modelled at the storage pressure. • For pipeline releases, the maximum rate of discharge would be limited to the pumping rate unless the hole size is controlling the release rate.
Incidents Affected: • All.
Reference/s: • Information provided by Ampol.

Assumption No. 9: Representative Hole Sizes for Hazardous Materials Releases
Subject: Consequence Analysis
Assumption: • One or more representative hole size is assumed for each identified release event, with each representative hole size representing a range of similar hole sizes. • The representative hole sizes, which typically represent small leaks through to full bore rupture events, coincide with the failure frequency data used in the study (i.e. The selection of representative hole sizes was made in conjunction with the selection of the failure frequencies).
Justification and Impact of Assumption: • The representative hole size may impact the calculated release rate, and corresponding consequence distance.
Release Events Affected: • All release events other than from pipelines (Refer to Assumption No. 10).
References: • UK HSE, 2019, *Failure Rate and Event Data for use within Risk Assessments* (33). • International Association of Oil & Gas Producers (OGP), March 2010, *Process release frequencies*, OGP, Report No. 434 – 1 (34).

Assumption No. 9: Representative Hole Sizes for Hazardous Materials Releases
• Purple Book [Guidelines for Quantitative Risk Assessment - Purple Book CPR 18E - Committee for the Prevention of Disasters, CPR 18E (31) • Spouge [Spouge, J., "New Generic Leak Frequencies for Process Equipment", Process Safety Progress, Vol. 24, No. 4, December 2005] (35).

Assumption No. 10: Representative Hole Diameters for Pipeline Releases

Subject: Consequence Analysis

Assumption/s:

- The following representative hole diameters were selected for the consequence modelling:

Table 24: Representative Hole Diameters Selected for Consequence Analysis

Pipeline/s	Pipeline Diameter (mm)	Representative Hole Diameter (mm)			
		Pinhole (≤ 25 mm)	Small Hole (> 25 mm to ≤ 75 mm)	Large Hole (> 75 mm to ≤ 110 mm)	Rupture (> 110 mm)
SNP	324	20	75	110	311

Justification and Impact/s of Assumption/s:

- The representative hole diameters were selected to align with the leak frequency data (22). The data includes four hole size categories: Pinhole (≤ 25 mm); Small Hole (> 25 mm to ≤ 75 mm), Large Hole (> 75 mm to ≤ 110 mm); and Rupture (> 110 mm). The representative hole diameter/s in each hole size category were selected based on a review of the available historical data:
  - Leaks from underground pipelines in the Pinhole size category tend to be larger for TPA incidents (i.e. typically c. 20 mm to 25 mm) than for the other failure modes (i.e. typically less than c. 10 mm). However, a 20 mm hole was selected as being conservative.
  - If a leak exceeds 50 to 75 mm for a 100 to 150 mm diameter underground pipeline (equivalent to c. 25% of the cross-sectional area of the pipe), then it tends to be a full-bore rupture. Therefore, the large hole and rupture categories were combined.
  - The representative hole diameters for the above ground pipelines were assumed to be the same as for the underground pipelines.

Incidents Affected:

- Pipeline release incidents

Reference/s:

- Department of Industry, Resources and Energy, New South Wales, *2017-18 Licensed Pipelines Performance Report*. This includes data for all licensed pipelines in NSW for the 5-year period: 2013/14 to 2017/18 (36); and
- UK Health and Safety Laboratory (HSL), 2015, *Update of Pipeline Failure Rates for Land Use Planning Assessments*, Research Report (RR) 1035 (22).
- British Standards Institute, 2013, *Pipeline Systems – Part 3: Steel Pipelines on Land – Guide to the Application of Pipeline Risk Assessment to Proposed Developments in the Vicinity of Major Accident Hazard Pipelines Containing Flammables* (37).
- US Department of Transportation (DoT), *Pipeline and Hazardous Materials Safety Administration (PHMSA), Accident Reports - Hazardous Liquid Pipeline Systems* (January 2010 to September 2018) (38).

Assumption No. 11: Height of Release
Subject: Consequence Analysis
Assumption/s: • All releases from process equipment and containers are modelled at a release height of 1 m above ground level. • All releases from underground (UG) pipelines are modelled at a release height of 0 m above ground level. • All releases from aboveground (AG) pipelines are modelled at a release height of 1 m above ground level.
Justification and Impact/s of Assumption/s: • The SAFETI software does not permit entry of a height of release below 0 m. • The default release height in the SAFETI software is 1 m.
Incidents Affected: • All.
Reference/s: • SAFETI software documentation.

Assumption No. 12: Direction of Release
Subject: Consequence Analysis
Assumption/s: • The direction of release is dependent on the failure mode and representative hole size. • For pipeline releases, all hole sizes are modelled as 50% at 45 degrees (not impinged on any surface) and 50% at horizontal (impinging on obstacles and losing momentum). • For releases from equipment, all releases are modelled as horizontal.
Justification and Impact/s of Assumption/s: • Impingement reduces the momentum of the release and the dispersion modelling is dominated by the representative wind conditions. Liquid releases will rain out at point of release if impinged. If not impinged, then air will be entrained into the jet and a liquid release may not rain out at the point of release. • The UK HSE [RR 1034] reports that some data from UKOPA includes the 'hole circumferential position' for releases from under pipelines. Based on the 71 recorded incidents (All pipelines and materials) and average crater dimensions, an unobstructed release (c. +/- 71° from vertical) was estimated to occur for 63% of the releases and an obstructed release was estimated to occur for the balance (37% of releases). The distribution is not reported for different failure modes.
Incidents Affected: • All pipeline incidents.
Reference/s: • Current configuration of SNP in the study area. • UK HSE, 2015, *Review of the Event Tree Structure and Ignition Probabilities used in HSE's Pipeline Risk Assessment Code MISHAP*, Research Report (RR) 1034 (39).

Assumption No. 13: Flammable Liquid Pool Evaporation
Subject: Consequence Modelling
Assumption: • The equilibrium pool diameter has been used for liquid release where no containment, such as bunding is provided. • The area of the pool in bunded areas have been limited to the bund areas (e.g. tank bunds). • The type of surface has been assumed to be concrete in the LTTR as the area is paved. In the tank farm, including the pumps area (pumps located within tank farm) the surface is compressed soil.
Justification and Impact of Assumption: • The surface type (concrete or dry sand) affects the pool thickness and, subsequently, the rate of evaporation. Pool evaporation is of particular concern in the process area where liquids are often above their boiling point and evaporation plays a significant role in terms of the outcome.
Incidents Affected: • All incidents involving liquids.
References: • Site layouts provided by Ampol.

Assumption No. 14: Shape of Liquid Pools
Subject: Consequence Analysis
Assumption/s: • All liquid releases (which rain out) forming a pool are assumed to be circular. • Pools in bunded areas were modelled as circles of equivalent area.
Justification and Impact/s of Assumption/s: • SAFETI can only model circular pools.
Incidents Affected: • All incidents where a liquid pool is formed.
Reference/s: • Current topography of Study Area.

Assumption No. 15: Maximum Extent of Flash Fire
Subject: Consequence Analysis
Assumption/s: • The maximum extent of a flash fire is defined by the downwind and crosswind distances from the release location to a concentration equal to the lower flammability limit (LFL) concentration.
Justification and Impact/s of Assumption/s: • The peak to mean concentration within the gas cloud is approximately 2:1, and hence, while the average concentration is ½ LFL, there may be gas pockets within the cloud where the concentration can be LFL, and hence ignition is possible. However, flash fire impact would be experienced only above the lower flammability limit.
Incidents Affected: • All incidents with a flash fire as a potential outcome.
Reference/s: • SAFETI software documentation (40).

Assumption No. 16: 3D Explosion Model Parameters

Subject: Consequence Analysis

Assumption/s:

- The maximum explosive mass in a flammable gas or vapour cloud is the maximum mass between the LFL and UFL concentration for that section of the cloud that overlaps a congested area.
- The peak side-on overpressure resulting from an explosion is estimated using the Extended Explosion Modelling option in the SAFETI software, with TNO Multi-energy curve numbers of 2 for open spaces and 4-5 for congested areas (see below).
- The blast overpressure is estimated based on the obstructed volume (%) and the potential obstructions in each congested area. The following congested areas are included in the QRA:

Table 25: Congested Areas in Study Area

Area/s	TNO ME Curve No.	Blockage Ratio (%)	Height (m)
Tanker loading bay	4	30	5
Existing ‘blast’ wall south of T- 482	5	80	5

- Only overpressure effects are included. Projectiles and whole-body displacement are not included.

Justification and Impact/s of Assumption/s:

- The explosive mass and blast strength are key parameters for modelling the overpressure from a VCE.
- The Ampol Terminal is not strictly a congested area. Therefore, TNO Model curve number 3 was assumed to apply in the Terminal.
- The 3D Obstructed Region Explosion Modelling option considers the interactions between the flammable cloud and obstructed regions that have been defined for the study area. This is more valid than simple models (e.g. TNT equivalence) which do not consider these interactions.

Incidents Affected:

- All incidents with a VCE as a potential outcome.

Reference/s:

- Centre for Chemical Process Safety, “Estimating the flammable mass of vapour clouds”, American Institute of Chemical Engineers, 1999 (41).
- TNO, VROM, ‘Yellow Book’ (42).
- SAFETI software documentation (40).

Assumption No. 17: Maximum Mass Released
Subject: Consequence Analysis
Assumption: • In some cases, the maximum mass released depends on whether detection and subsequent isolation occurs. If there is no detection and isolation, then the maximum inventory in the system may be released. • Detection and isolation may not be relevant if the steady state consequences have already been reached prior to the detection and isolation time. • The time for detection and isolation was taken as follows: - Release detection by vapour detection in the bund, alarm with manual isolation: 15 minutes
Justification and Impact of Assumption: • Overall, the isolation time (the time to detect and isolate) affects the duration of the release or fire event. For a flammable liquid release, the increased duration potentially increases the size of the pool, the resulting vapour cloud and the subsequent explosion event. • The detection methods available are vapour detectors in the bund area (following Buncefield recommendations in AS 1940-2017), UV/IR fire detectors, and personnel present in the field. For each of these methods, the occurrence of a loss of containment is more discernible the larger the release. This is captured in general by decreasing the time to detect as the release size increases. • The time to isolate a release (once detected) does not vary with release size because the decision to isolate and the action of isolation itself is generally the same for all release sizes. The assumed isolation time is conservative, but accounts for a single operator present during after-hours.
Release Events Affected: • All.
References: • TNO, 1999, *Guidelines for Quantitative Risk Assessment*, The Purple Book, Committee for the Prevention of Disasters, CPR 18E, Third Edition, The Hague (31).

Assumption No. 18: Large Atmospheric Storage Tank Vapour Cloud Analysis

Subject: Consequence Analysis

Assumption/s:

- The extent of a vapour cloud generated by overfilling a large atmospheric storage tank in calm, stable conditions has been determined using the methodology presented in the UK HSE Research Report RR 908.
- The distance to overpressure levels from the ignition of a large vapour cloud has been estimated using the equation:

$$P = 6.571\left(\frac{H}{\Delta R}\right)^{0.975}$$

Where: P is the overpressure, bar.

H is the cloud height, m. This is assumed to be 1 m, consistent with the VCA model assumption for ignition radius.

ΔR is the radius of the cloud, m.

- Such large vapour clouds have only been modelled for DG Class 3 dangerous goods of packing groups I or II, stored in vertical, cylindrical, non-refrigerated, above ground storage tanks with side walls greater than 5 metres in height, and where the filling rate is greater than 100 cubic metres/hour.

Justification and Impact/s of Assumption/s:

- The UK HSE Vapour Cloud Analysis model (VCA Model) presented in RR908 was specifically prepared to develop a simplified model for the spread of large vapour clouds arising from an atmospheric storage tank overfill. The development included field tests.
- The equation for overpressure was obtained from the Steel Construction "Dispersion and Explosion Characteristics of Large Vapour Clouds" The project's ultimate objectives were to understand vapour cloud development following large losses of primary containment, the characteristics of explosions involving large flat flammable vapour clouds and the explosion mechanisms that can give rise to very high overpressures over a large area as observed in the Buncefield incident. This was done through large and medium scale experimental studies supplemented by numerical analysis.
- The limitation of tank size and dangerous goods classification is consistent with the classification of petrol, and the UK HSE's definition of Large Scale Petroleum Storage Sites, upon which special land use planning advice is provided in light of the potential for very large vapour clouds in calm and stable conditions.

Incidents Affected:

- Overfill of large vertical atmospheric storage tanks containing DG Class 3 dangerous goods of packing groups I or II.

Reference/s:

- UK HSE, RR908 - *Vapour cloud formation: Experiments and modelling* (43).
- Steel Construction Institute, *Dispersion & Explosion Characteristics of Large Vapour Clouds Volume 1: Summary Report*, 2014 (44).
- UK HSE Land use planning advice around large scale petrol storage sites, https://www.hse.gov.uk/foi/internalops/hid_circs/technical_general/spc_tech_gen_43/index.htm, accessed 29/02/2020.

A.4 Likelihood Analysis

Assumption No. 19: Failure Rate Data
Subject: Frequency Analysis
Assumption: • Generic industry data for equipment failures was selected for the QRA.
Justification and Impact of Assumption: • Generic industry data for equipment failures was selected as there is no specific failure data for the facilities in the study area. The use of generic industry data facilitates a comparison of the results of the risk assessment with other sites (i.e. benchmarking). • A review of several sources of failure data was made prior to selecting the failure frequencies for the parts count QRA (i.e. base line frequencies for the fabric failures). • The principal source of the data used in the QRA was UK HSE, 2019, *Failure Rate and Event Data for use within Risk Assessments*. Other sources were also considered (See below). • When different failure data for a specific component was referenced, a conservative selection was made.
Release Events Affected: • All release events.
References: • UK HSE, 2019, *Failure Rate and Event Data for use within Risk Assessments* (33). • International Association of Oil & Gas Producers (OGP), March 2010, *Process release frequencies*, OGP, Report No. 434 – 1 (34). • International Association of Oil & Gas Producers (OGP), March 2010, *Storage Failure Frequencies*, OGP, Report No. 434 – 3 (45).

Assumption No. 20: Likelihood of Tank Overfill Leading to a Large Vapour Cloud and Explosion
Subject: Likelihood Analysis
Assumption/s: • The likelihood of a tank overfill leading to a large vapour cloud and explosion (i.e. a 'Buncefield' type incident) is calculated by fault tree analysis.
Justification and Impact/s of Assumption/s: • The likelihood of tank overfill is dependent on the overfill protection system installed on the tank and the frequency of tank filling. The likelihood would vary as the demand varies with number of fills in each tank.
Incidents Affected: • All large atmospheric storage tanks storing flammable liquids (Tanks 214, 378 and 482). • Ethanol tank was excluded as it is filled from a road tanker and transfer does not occur if there is insufficient ullage in the tank. • Slops tank (T- 15721) was excluded as transfer to slops tank is at a much lower rate using Terminal pumps, and only small quantities are sent to slops. Further, operating practice maintains very low inventory in slops tank.
Reference/s: • Information provided by Ampol

Assumption No. 21: Ignition Probability
Subject: Likelihood Analysis
Assumption/s: • The probability of ignition for each representative release incident is dependent on the type of facility, material released, release rate and surrounding land uses. • The total ignition probability applied for each representative release incident is based on the ignition probability curves drawn from the UKOOA look-up correlations (As presented in OGP Report No. 434 – 6.1) (27).
Justification and Impact/s of Assumption/s: • The estimated probability of ignition is a critical and significant input for the risk analysis. The risk results are directly proportional to this input. • The total ignition probability curves in OGP Report No. 434 – 6.1 assume the immediate ignition probability is 0.001. The fraction of the total ignition probability for immediate ignition of flashing materials was assumed to be 0.3, which is the default value in the SAFETI software. • Scenario 13 in OGP Report 434-6.1 was used for ignition probability of flammable liquids representative of the Ampol facility, i.e. Flammable liquids that do not have a significant flash fraction (i.e.10% or less) if released from onshore outdoor storage area Tank farm (i.e. spill in a large bund containing 4 or fewer tanks, or any other bund less than 25000 m^2 in area). • Scenario 30 in OGP Report 434-6.1 was used for ignition probability of diesel, i.e. Releases of combustible liquids stored at ambient pressure and at temperatures below their flash point (e.g. most gas, oil, diesel and fuel oil storage tanks) from onshore outdoor storage area "tank farm". This look-up correlation can be applied to releases from tanks and low pressure transfer lines or pumps in the tank farm/ storage area. However, it should not be used for high-pressure systems (over a few barg).
Incidents Affected: • All.
Reference/s: • International Association of Oil & Gas Producers (OGP), March 2010, *Ignition Probabilities*, OGP, Report No. 434 – 6.1 (27).

Assumption No. 22: Ignition Probability for Buncefield Type Incident
Subject: Likelihood Analysis
Assumption/s: • The probability of ignition of a Buncefield type incident is estimated using the UK HSE ignition model for large vapour clouds
Justification and Impact/s of Assumption/s: • The vapour clouds generated in the tank overflow incidents would each offsite and hence onsite ignition probability models are not appropriate. The HSE ignition model covers offsite ignition sources (28). • The ignition probability is calculated as Pign = 1- exp(-µAp), where µ is the ignition density per hectare. For urban areas at night time, a value of 0.13 has been suggested. • A is the area of the flammable cloud in hectares, calculated from the methodology developed by the UK HSE (25). • p is the ignition strength. For residential areas, the strength is a function of number of persons covered by the flammable cloud area (N), estimated as $1\text{-}0.99^{N}$ (29).
Incidents Affected: • Tank overflow from T-214, T-378 and T-482 and Buncefield type incidents
Reference/s: • Health and Safety Laboratory, *Vapour cloud formation: Experiments and modelling* (25) • CCPS, *Guidelines for determining the probability of ignition of a released flammable mass* (29). • UK HSE CRR 203/1998 (28).

Assumption No. 23: Human Error Probability
Subject: Likelihood Analysis
Assumption/s: • The probability of operator error (failing to take action, taking incorrect action, delayed action etc) was taken as 0.001 (1 chance in 1000 tasks).
Justification and Impact/s of Assumption/s: • Human error probability significantly influences the Tank overfill incident and hence the value must be carefully selected. • Literature data (46) indicates that for Simple, familiar and frequent task skill-based or rule-based, for which procedures are available, a value of 4.0E-04 per task may be used. The range given is from 0.00014 to 0.0009 per task. • A value of 0.001 per task was selected as a conservative value. • Information provided by Ampol indicated that no tank high level alarms have been raised in over 400 pipeline transfer to tanks per year, in the last 10 years. Such alarms are recorded and reported.
Incidents Affected: • All.
Reference/s: • Ref. (46) • Information provided by Ampol

A.5 Vulnerability Parameters

Assumption No. 24: Exposure to Flash Fire
Subject: Vulnerability Parameters
Assumption/s: • For calculation of location-specific individual risk, the probability for fatality = 1 for any individual located within the flammable cloud (Distance to LFL concentration). • For calculation of societal risk: • The probability for fatality for any individual located within the flammable cloud (Distance to LFL concentration) is 1 (outdoor) or 0.1 (indoors for buildings).
Justification and Impact/s of Assumption/s: • The assumed probabilities are not consistent with the guidance in the TNO 'Purple Book' and the default values in the SAFETI software. In both cases, the probability of fatality is set at 1 for all individuals (outdoor or indoor). This was considered too conservative for the types of buildings in the study area (primarily industrial and commercial buildings). The probability of fatality indoors was set at 0.1 to take account of the possibility of open doors / windows and/or failure to evacuate.
Incidents Affected: • All incidents with a flash fire as a potential outcome.
Reference/s: • SAFETI software documentation (40). • TNO, VROM, *Guidelines for Quantitative Risk Assessment*, 'Purple Book', CPR18E, 3rd Edition (31).

Assumption No. 25: Exposure to Explosion Overpressure (Indoor or Outdoor)

Subject: Vulnerability Parameters

Assumption/s:

- The probability of fatality from exposure to the peak side-on overpressure from an explosion is as shown in Table 26 (Person located outdoors) and Table 27 (Person located indoors).

Table 26: Probability of Fatality from Exposure to Peak Side on-Overpressure (Outdoor)

Overpressure (kPa)	Probability of Fatality	Source
7	0	HIPAP No. 4 (30)
35	0.15	HIPAP No. 4
50	0.5	OGP 434-14 (47)
70	1.0	HIPAP No. 4

Table 27: Probability of Fatality from Exposure to Peak Side on-Overpressure (Indoor)

Overpressure (kPa)	Probability of Fatality	Source
7	0	HIPAP No. 4
10	0.01	CIA (Building Type 2 *) (48)
30	0.6	CIA (Building Type 2 *)
60	0.9	CIA (Building Type 2 *)
100	1.0	CIA (Building Type 2 *)

* Typical office block: four storeys, concrete frame and roof, brick block wall panels

- Exposure to a peak side-on overpressure of 7 kPa (or greater) is potentially injurious for an individual located outdoors.
- For the calculation of societal risk:
  - The probability of fatality for individuals located outdoors is as listed in Table 26.
  - The probability of fatality indoors (buildings) is as listed in Table 27.

Assumption No. 25: Exposure to Explosion Overpressure (Indoor or Outdoor)
Justification and Impact/s of Assumption/s: • When calculating location-specific individual injury or fatality risk contours, all individuals must be considered to be located outdoors for 100% of the time since this is the underlying basis for the NSW DPIE's individual risk criteria. Vulnerability parameters for individuals located indoors are only applicable for the calculation of societal risk. • The probability of fatality is higher for an individual located in a conventional building than when outdoors due to the higher chance of harm from collapse of the structure. • The NSW DPIE's injury/damage risk criterion for explosion overpressure is as follows: "Incident explosion overpressure at residential and sensitive use areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year".
Incidents Affected: • All incidents with a VCE as a potential outcome.
Reference/s: • NSW Department of Planning and Infrastructure, Jan 2011, Hazardous Industry Planning Advisory Paper (HIPAP) No. 4, Risk Criteria for Land Use Safety Planning (30). • Oil & Gas Producers Association (OGP), Risk Assessment Data Directory, Report No. 434-14.1, Vulnerability to Humans, March 2010 (47). • Chemical Industries Association (CIA), 2003, *Guidance for the location and design of occupied buildings on chemical manufacturing sites*, 2nd. Ed (48).

Appendix B Population Data

B.1 Residential and Industrial Areas (Based on 2016 Census Data)

Estimates of the residential population in the surrounding suburbs have been made using 2016 census data (Statistical Areas 1 Usual Place of Residence for residential populations) as shown in Table 28.

Table 28: Residential Populations by Area

Statistical Area 1 7-digit identifier	Population 2016
1122420	167
1122424	369
1123501	285
1123502	615
1123505	365
1123507	472
1123508	352
1123510	400
1123511	526
1123512	470
1123514	443
1123515	285
1123516	651
1123517	395
1123519	467

Table 29: Industrial Populations

Statistical Area 1 7-digit identifier	Estimated working population, day	Estimated working population, night
1123510	80	8
1123519	17	1.7
Wool store - Industrial	30	3

Appendix C Consequence Analysis Results

C.1 Consequence Analysis Results for Representative Release Scenarios

The hazard ranges for the release cases modelled are provided in Table 30 and Table 31. The examples provided are for the D 4.1 daytime weather condition for the following consequences:

- Pool Fires
- Flash Fires
- Jet Fires

The VCE consequence distances which occur as a result of a flammable liquid overfill are given in Table 32 with associated overpressure contours in **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 30: Pool Fire Consequence Analysis Results

No.	Description	Material	Pool Diameter (m)	Distance (m) to 4.7 kW/m^2	Distance (m) to 12.5 kW/m^2	Distance (m) to 21 kW/m^2	Distance (m) to 35 kW/m^2
MI_1	T-1 Tank Top	Diesel	16.4	-	-	-	-
MI_2	T-6 Tank Top	Diesel	18.2	-	-	-	-
MI_3	T-7 Tank Top	Jet Fuel	14.8	-	-	-	-
MI_4	South Yard Bund	Diesel	66	85	45	-	-
MI_5	South Yard Bund	Jet Fuel	66	89	45	-	-
MI_7	T-214 Tank Top	Gasoline	18.3	37	-	-	-
MI_8	T-352 Tank Top	Diesel	23	-	-	-	-
MI_9	T-378 Tank Top	Gasoline	23.8	-	-	-	-
MI_10	T-482 Tank Top	Gasoline	25.9	40	-	-	-
MI_11	T-7969 Tank Top	Ethanol	6.1	-	-	-	-
MI_12	T-7970 Tank Top	Diesel	10.2	24	-	-	-
MI_13	T-15721 Tank Top	Gasoline	10.2	30	-	-	-
MI_14	North Yard Bund	Diesel	60*	79	42	-	-
MI_15	North Yard Bund	Gasoline	60*	89	42	-	-
		Ethanol	60*	109	78	63	54
MI_16	Small Tank	Diesel	60*	89	42	-	-
		Gasoline	60*	109	78	63	54
MI_17	TTLR_1	Gasoline	23.8	50	25	15	-
MI_18	TTLR_1	Diesel	23.8	42	25	15	-
MI_19	TTLR_2	Gasoline	23.8	50	25	15	-
MI_20	TTLR_2	Diesel	23.8	42	25	15	-
MI_21	TTLR_3	Diesel	23.8	42	25	15	-
MI_22	TTLR_4	Jet Fuel	23.8	45	25	15	-

No.	Description	Material	Pool Diameter (m)	Distance (m) to 4.7 kW/m^2	Distance (m) to 12.5 kW/m^2	Distance (m) to 21 kW/m^2	Distance (m) to 35 kW/m^2
MI_23	TTLR_5	Ethanol	23.8	35	25	21	15
MI_24	VRU Minor	Gasoline	18.9	43	20	10	-
	VRU Major	Gasoline	18.9	43	20	10	-
MI_25	10mm MID	Gasoline	4.9	22	16	13	9
	25mm MID	Gasoline	13	38	25	14	10
	75mm MID	Gasoline	39	65	30	-	-
	110mm MID	Gasoline	39	65	30	-	-
	FBR MID	Gasoline	58	86	40	-	-

Table 31: Flash Fire and Jet Fire Consequence Analysis Results

Scenario			Flash Fire		Jet Fire				
No.	Description	Size	Release Rate (kg/s)	Distance to LFL (m)	Flame Length (m)	Distance (m) to 4.7 kW/m^2	Distance (m) to 14 kW/m^2	Distance (m) to 21 kW/m^2	Distance (m) to 35 kW/m^2
MI_15	Pump Seal	79	45	25	28	60	46	41	36
	Pump Casing	150	163	38	37	82	63	54	49
MI_24	VRU - Vessel Minor	150	163	-	15	20	12	10	9
MI_25	Pipeline_25 TOP	25	11.7	-	21	52	33	26	21
	Pipeline_75 TOP	75	105	-	54	121	78	60	46
	Pipeline_110 TOP	110	105	-	54	121	78	60	46
	Pipeline_FBR TOP	FBR	105	-	54	121	78	60	46

Table 32: VCE Consequence Analysis Results

Description	Distance (m) to overpressure level (bar)								
	Material	0.07	0.1	0.3	0.35	0.5	0.6	0.7	1.0
T-214 Buncefield VCE	SPULP	299	267	218	214	208	206	204	201
T-378 Buncefield VCE	ULP	341	309	259	256	250	247	246	243
T-482 Buncefield VCE	PULP	329	296	247	243	237	235	233	230

Figure 15: T-214 Overfill VCE

Figure 16: T-378 Overfill VCE

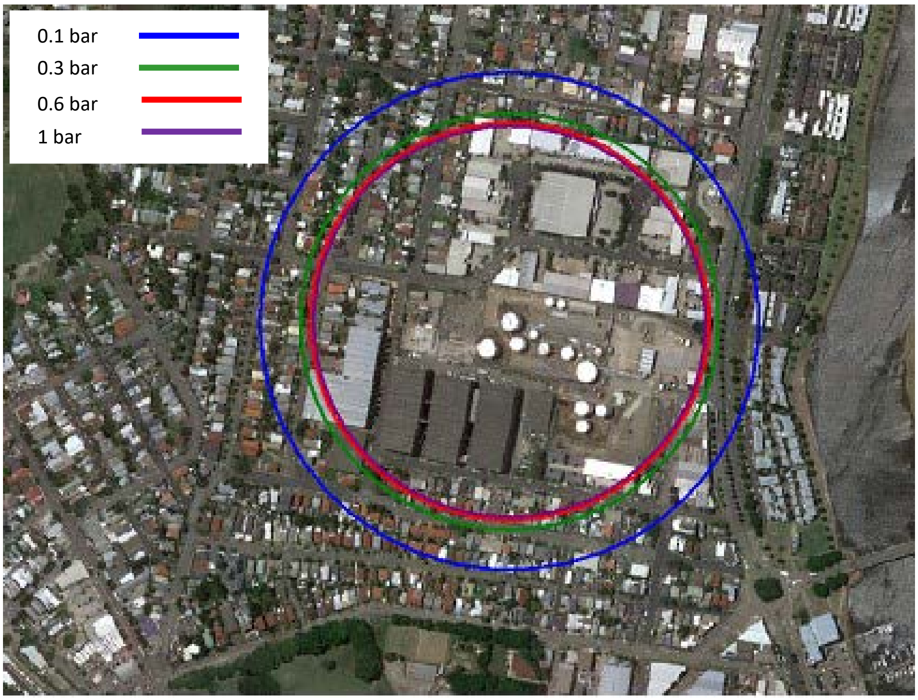
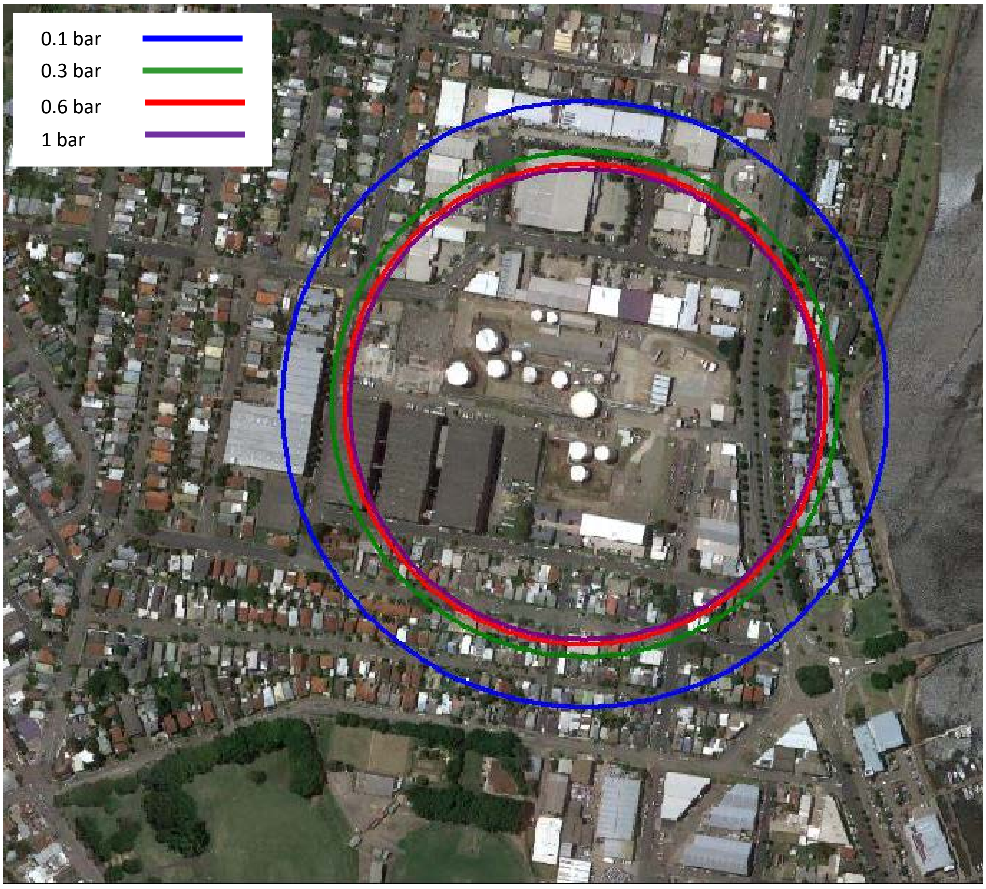


Figure 17: T- 482 Overfill VCE



Appendix D Frequency Analysis

The failure rate data used in the hazard and risk assessment is summarised in this Appendix. Generic industry data for equipment failures was selected as there is no specific failure data for the facilities in the study area. The use of generic industry data facilitates a comparison of the results of the risk assessment with other sites (i.e. benchmarking).

A review of several sources of failure data was made prior to selecting the failure frequencies for the parts count QRA (i.e. base line frequencies for the fabric failures).

The principal source of the data used in the QRA was UK HSE, 2019, *Failure Rate and Event Data for use within Risk Assessments*. Other sources were also considered (See below).

When different failure data for a specific component was referenced, a conservative selection was made.

The sources of the data are:

- UK HSE, 2019, *Failure Rate and Event Data for use within Risk Assessments* (33).
- International Association of Oil & Gas Producers (OGP) 2010, *Process release frequencies*, Report No. 434 – 1 (34).
- International Association of Oil & Gas Producers (OGP) 2010, *Storage Failure Frequencies*, OGP, Report No. 434 – 3 (45).
- Health and safety Laboratory. Research Report RR 1035 - Update of pipeline failure rates for land use planning assessments, 2015 (49).

Table 33: Primary Source: Failure Rate and Event Data

Category	ID #	Description
Tanks	1	Large Atmospheric Vessels (33), Item FR 1.1
	2	Small and Medium Atmospheric Tanks (33), Item FR 1.1.1.2)
	3	Atmospheric Storage Tank Fire Frequencies (45)
Process Piping and Fittings	4	Pipework (33), Item FR 1.3)
	5	Valves (33), Item FR 1.2.1)
	6	Flanges and Gaskets (33), Item FR 1.2.5)
	7	Instrument Connections (34)
Other Equipment	8	Pumps (33), Item FR 1.2.2)
Road Tanker Transfers	9	Hoses and Couplings (Road Tanker Transfers) (33), Item FR 1.2.3)
	10	Hard Arms (Road Tanker Transfers) (33), Item FR 1.1.3.1)
	11	Underground (Onshore) Gasoline Pipelines (22), Table 81)

Table 34: Large Atmospheric Storage Tanks (33), Item FR 1.1

Type of Release	Failure Rate [per vessel yr]
Catastrophic	5.00E-06
Major	1.00E-04
Minor	2.50E-03
Roof	2.00E-03

	Hole Diameters [mm] for Tank Volumes [m^3]		
Category	>12000 m^3	4000 to 12000 m^3	450 to 4000 m^3
Major	1000	750	500
Minor	300	225	150

Notes: The failure rates apply to fixed position, single walled vessels with a capacity greater than 450m^3, which operate at ambient temperature and pressure. Roof failures includes all failures of the roof and does not include liquid pooling on the ground. Most atmospheric storage tanks are specifically designed so that the roof wall seam will preferentially fail hopefully mitigating the effects of an incident.

Table 35: Large Atmospheric Storage Tanks (33), Item FR 1.1.1.2

Type of Release	Failure Rate [per vessel yr]	
	Non-Flammable Contents	Flammable Contents
Catastrophic	8.00E-06	1.60E-05
Major	5.00E-05	1.00E-04
Minor	5.00E-04	1.00E-03

Notes: Small releases are defined as smaller or much slower loss of contents e.g. through a small leak over 30 minutes. Large releases are defined as a rapid loss of most or all contents e.g. large hole in a vessel leaking over several minutes. Small releases are defined as smaller or much slower loss of contents e.g. through a small leak over 30 minutes. FR117_2 defines hole sizes for tanks of unknown size (large holes are defined as 250 mm diameter and small holes as 75 mm diameter). When the size of the tank is known, assume that a large hole would empty the tank in 5 minutes and a small hole would empty the tank in 30 minutes.

Table 36: Atmospheric Storage Tank Fire Frequencies (45)

Type of Fire	Floating Roof Tank	Fixed Roof Tank	Fixed plus Internal Floating Roof Tank
Rim seal fire	1.6E-03		1.6E-03
Full surface fire on roof	1.2E-04		
Internal explosion & full surface fire		9.0E-05	9.0E-05
Internal explosion without fire		2.5E-05	2.5E-05
Vent fire		9.0E-05	

Table 37: Pipework (33) Item FR 1.3 (per metre-year)

CODE	Hole size	0 - 49 mm	50 - 149 mm
PIPE-3	3 mm diameter	1.00E-05	2.00E-06
PIPE-4	4 mm diameter	-	-
PIPE-25	25 mm diameter	5.00E-06	1.00E-06
PIPE-1/3	1/3 pipework diameter	-	-
PIPE-FBR	Full Bore Rupture	1.00E-06	5.00E-07

Table 38: Valves (33) **Item FR 1.2.1**

Type of Event	Failure Rate [per demand]
Failure to close	1.00E-04
Failure to close	3.00E-02
Failure to close	1.00E-02
Failure to operate	1.30E-02
Failure to operate	1.30E-01

Table 39: Flanges and Gaskets (33) **Item FR 1.2.5**

Type of event	Frequency [per year per joint]
Failure of one segment of a gasket	5.00E-06
Failure of Spiral Wound Gasket	1.00E-07

Table 40: Instrument Connections (34)

CODE	Hole diameter range	Frequency [per instrument year]	
		All Releases	Full Releases
INST(1-3)	1 to 3 mm	3.5E-04	1.8E-04
INST(3-10)	3 to 10 mm	1.5E-04	6.8E-05
INST(10-50)	10 to 50 mm	6.5E-05	2.5E-05

Table 41: Pumps (33)**, Item FR 1.2.2**

CODE	Type of event	Frequency [per pump per year]
PUMP-CASING	Failure of casing	3.00E-05

CODE	Spray Release	Frequency [per pump per year]	Effective length of crack
PUMP-SS-SPRAY	Pump single seal	5.00E-04	Shaft circumference
PUMP-DS-SPRAY	Pump double seal	5.00E-05	Shaft circumference

Shaft Diameter [m]	Circumference [m]
0.025	0.079
0.05	0.157
0.075	0.236
0.1	0.314
0.125	0.393
0.15	0.471

Table 42: Hoses and Couplings (Road Tanker Transfers) (33), Item FR 1.2.3

CODE	Facility	Failure Rate [per operation]			
		Guillotine failure	15 mm diameter hole	5 mm diameter hole	Total
HOSE-BASIC	Basic facilities	4.00E-05	1.00E-06	1.30E-05	5.40E-05
HOSE-AVG	Average facilities	4.00E-06	4.00E-07	6.00E-06	1.04E-05
HOSE-MULTI	Multi safety system facilities	2.00E-07	4.00E-07	6.00E-06	6.60E-06

Table 43: Hard Arms (Road Tanker Transfers) (33)**, Item FR 1.1.3.1**

CODE	Type of Release	Probability of Failure [per transfer]
HA-GF	Guillotine failure	2.00E-07
HA-15	15 mm diameter hole	4.00E-07
HA-5	5 mm diameter hole	6.00E-06

Table 44: Underground Gasoline Pipeline Failure (22)

Failure Mode	Pipeline Diameter [mm]	Pinhole [≤ 25 mm]	Small Hole [> 25 mm to ≤ 75 mm]
Mechanical Failure	All	8.20E-06	1.00E-05
Corrosion	All	1.20E-05	1.20E-05
Ground Movement / Other	All	1.20E-05	2.50E-06
TPA	All	2.20E-05	2.40E-06
		5.42E-05	2.69E-05

Road Tanker Vessels

Road tanker vessels are treated as single walled atmospheric tanks. The following frequencies per compartment are recommended by Bevi (50).

Table 45: Road Tanker Compartment Failure (50)

Type of Release	Probability of Failure [per year]
Instantaneous release of entire contents	5.00E-06
Release of entire contents in 10 min. in a continuous and constant stream	5.00E-06
Continuous release from a hole with an effective diameter of 10 mm	1.00E-04

Tank Overflow Frequency

Tank overflow frequency was calculated using fault tree analysis.

The overflow protection provided are:

a) Tank gauging, high level alarm and operator intervention to change receiving tank

b) Independent high level trip to close the tank inlet valve automatically to shut inflow

c) Flammable vapour detector in the bund to detect leaks and overflows and alarm, with operator intervention to shut off inflow

All the three layers of protection must fail, in order for tank overflow to occur. Fault Trees were constructed using the Isograph software FaultTree+ V.14, and shown in Figure 18 to Figure 22.

The following failure rate data applies to the protection functions:

Table 46: Tank Overfill Protection Instrumentation Failure Rates

No.	Component	Make	Failure rate x 1.0E6 /hour	Function test interval, hours	Probability of failure on demand (PFD)	Data Source
1	Level Transmitter	Vega	1.948	730*	7.11E-04	(51)
2	Surge protector	Pepperl & Fuchs	0.051	8760	2.23E-04	(51)
3	Signal conditioner	Vega	0.74	8760	3.24E-03	(51)
4	Safety Relay	Pilz	0.5	8760	2.19E-03	(52)
5	Digital I/O	Siemens	0.552	8760	2.42E-03	(51)
6	Operator error (Routine skilled action)	Routine, relatively frequent task, requiring knowledge based performance based on established procedures.			0.001	(46)
7	Level Transmitter	Drexelbrook	1.059	8760	4.64E-03	(51)
8	PLC	Siemens 1oo2D		8760	1.88E-05	(51)
9	Solenoid	ASCO	0.213	8760	9.33E-04	(51)
10	Inlet valve actuator	Motivact	4.5	8760	1.97E-02	(51)
11	Inlet Valve (Butterfly)		2.98	8760	1.31E-02	(53) 6.4.3
12	Quick exhaust valve	Swagelok	9.00E-01	8760	3.94E-03	(51)
13	Flammable vapour detector**		5.3	8760	2.32E-02	(53) 1.2.1
14	Analogue input	Siemens	2.076	730*	7.58E-04	(53) 4.1.16

*Tank dipping carried out monthly and compared against level sensor output. This is reflected in the test interval. Calibration and alarm testing done annually.

**Multiple detectors in bund, all of which must fail for the system to fail. A 10% ß- factor is used.

Figure 18: Fault Tree for Tank 378 Overflow

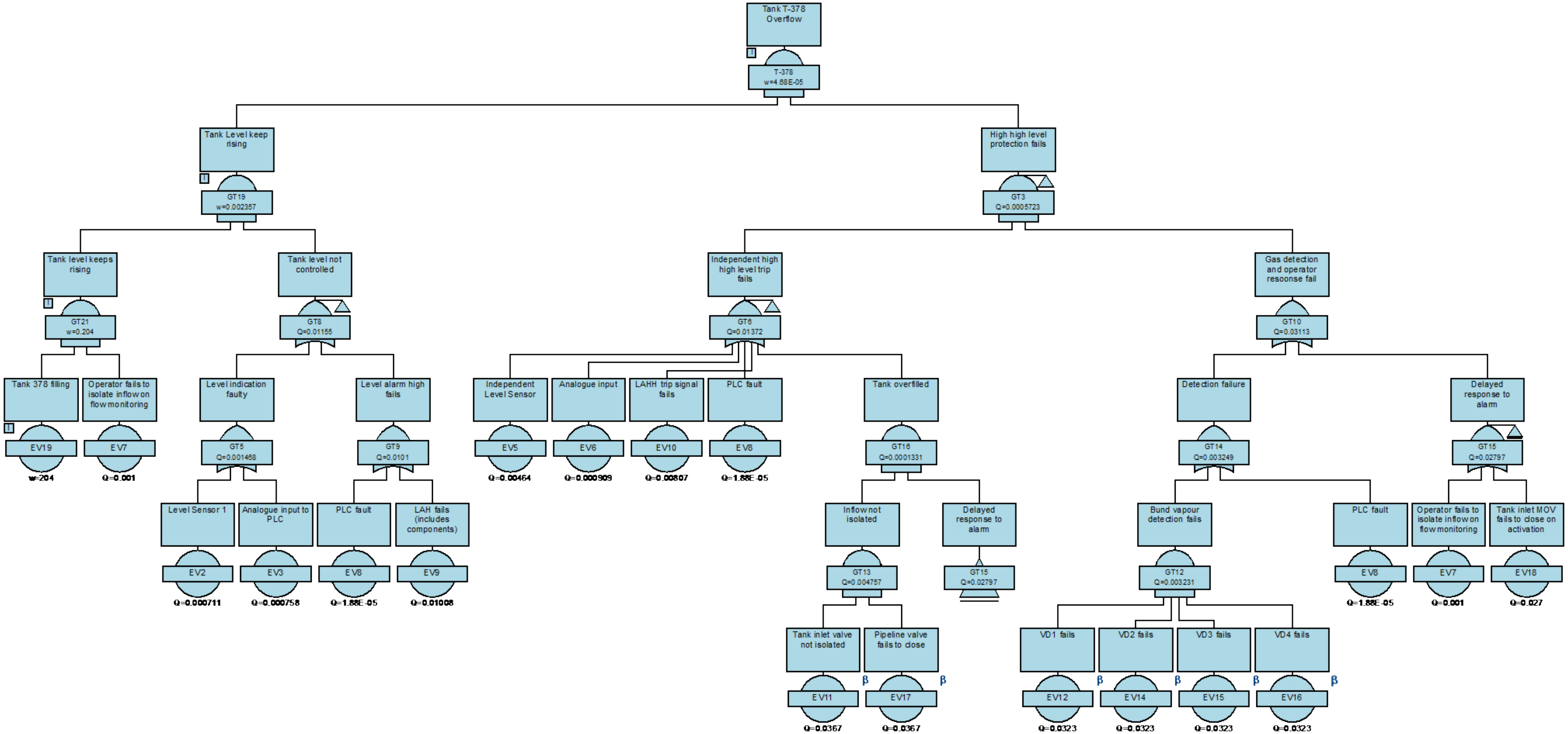


Figure 19: Fault Tree for Tank 482 Overflow

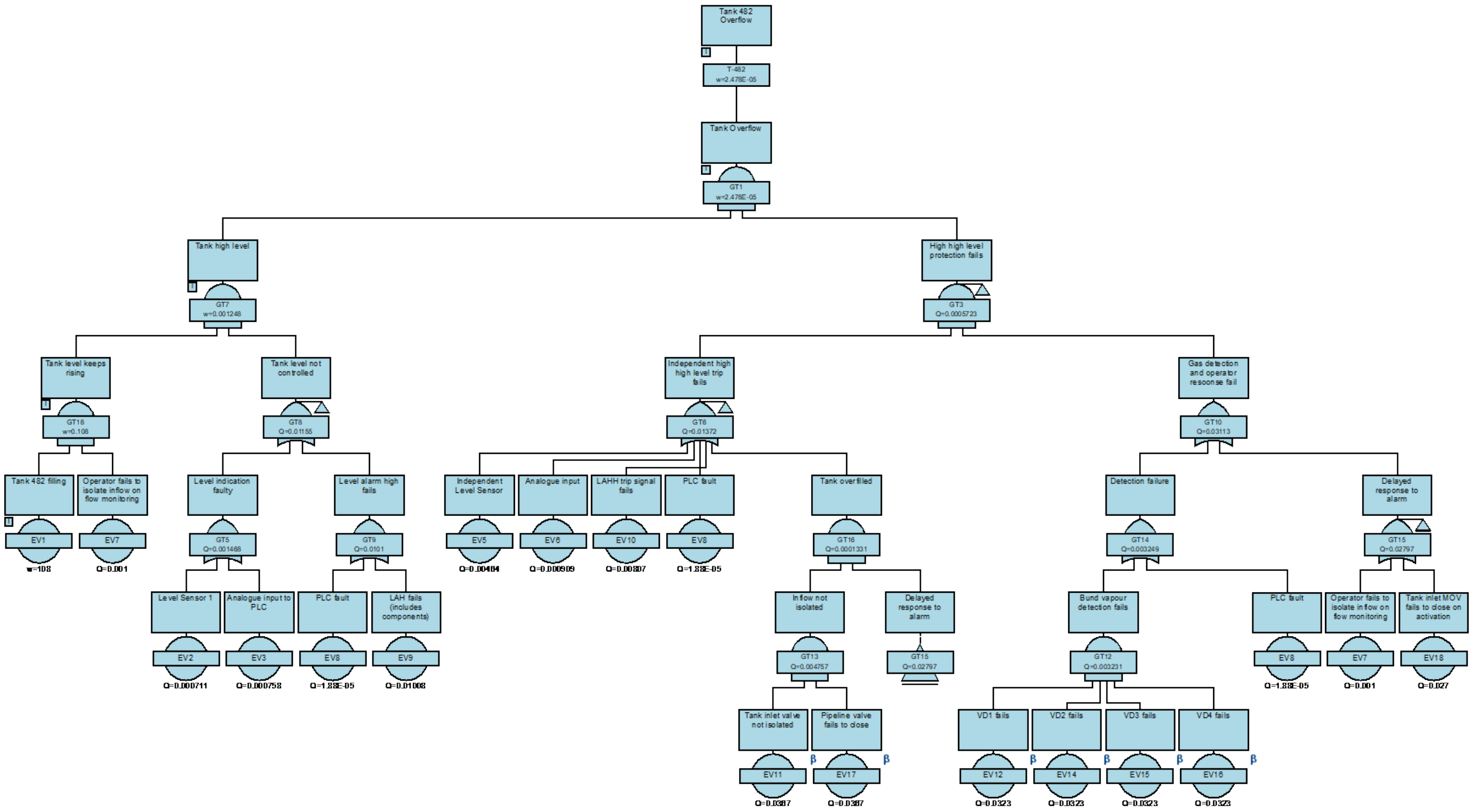


Figure 20: Fault Tree for Tank 214 Overflow

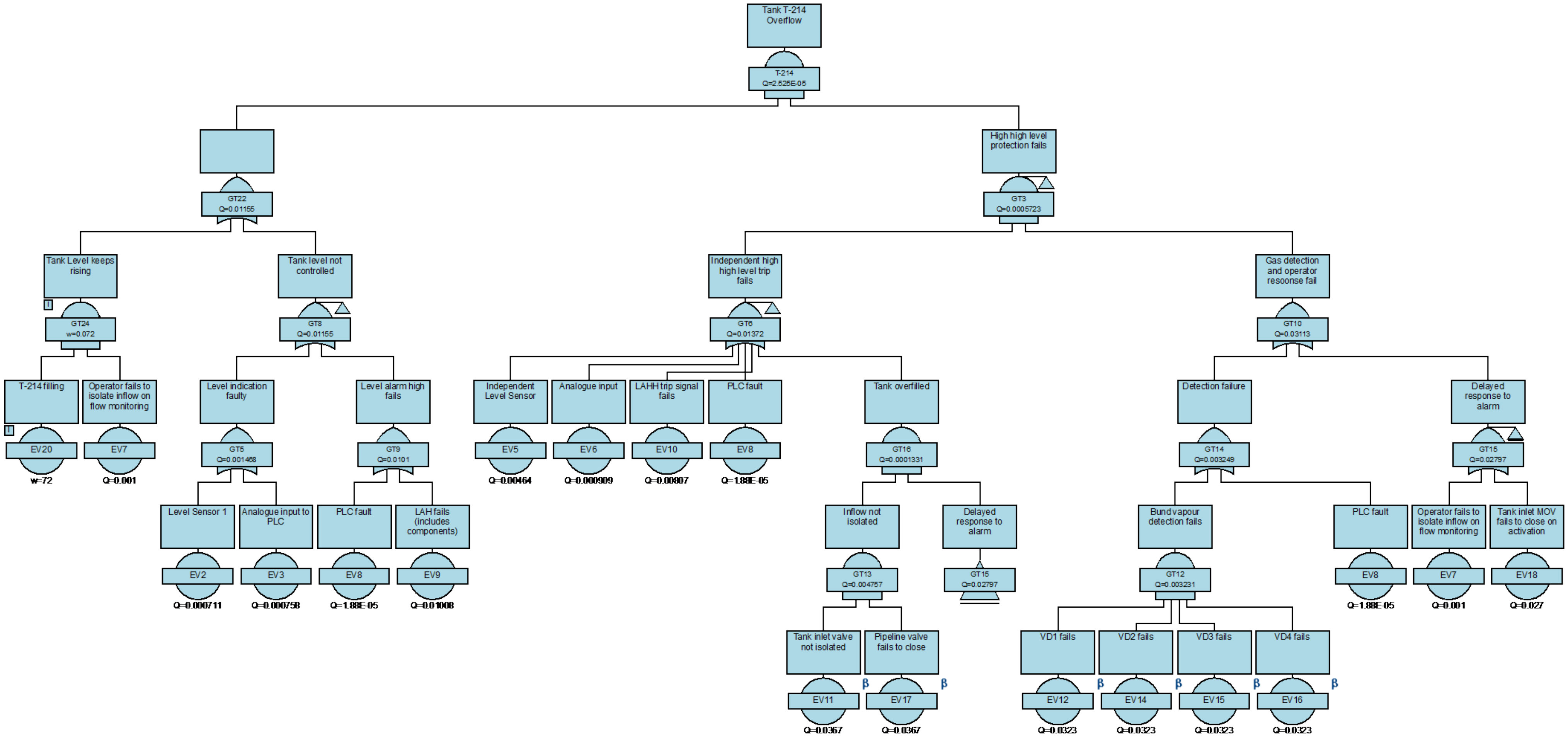


Figure 21: Fault Tree for Tank 1, 6 or 352 Overflow

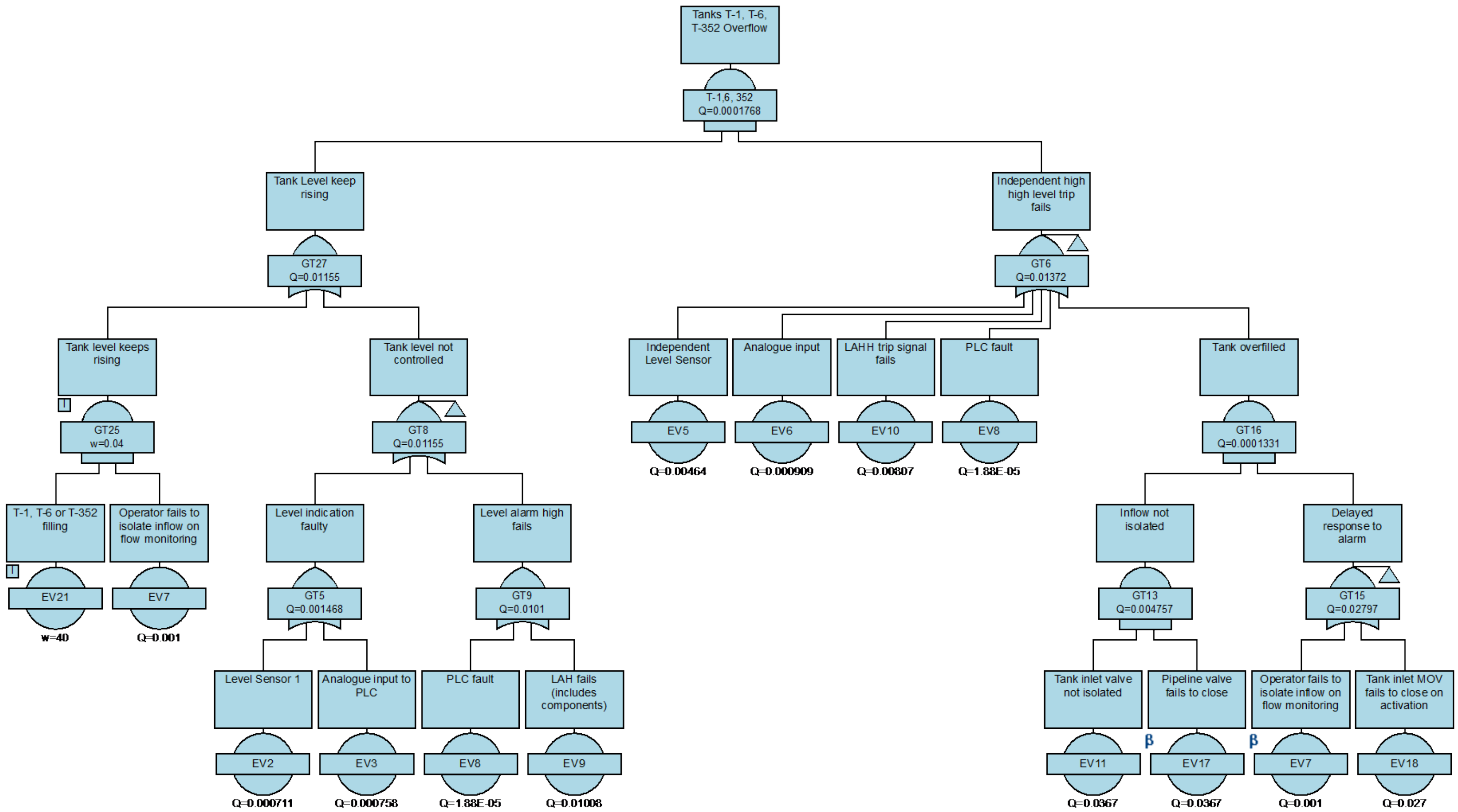


Figure 22: Fault Tree for Tank 7 Overflow