LANDCORP

KEMERTON INDUSTRIAL PARK

QUANTITATIVE RISK ASSESSMENT

DOCUMENT NO. : J91676_KEMERTON_QRA

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DATE : 24 September 2010

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			Malik		

Title **LANDCORP** **KEMERTON INDUSTRIAL PARK** **QUANTITATIVE RISK ASSESSMENT**	**QA Verified**	L. Malik	Malik
	Date	24/09/10	

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ABBREVIATIONS & DEFINITIONS

ABS	Australian Bureau of Statistics
Ag	Silver
Al	Aluminium
Al_2O_3	Alumina
$Al(OH)_3$	Aluminium hydroxide
$Al_2(SO_4)_3$	Aluminium sulphate
ALARP	As Low as Reasonably Practicable
AN	Ammonium nitrate
AQ	Anthrahydroquinone
AS/NZS	Australian / New Zealand Standards
AVGAS	Aviation gasoline
barg	Bar gauge
BLEVE	Boiling Liquid Expanding Vapour Explosion
C	Carbon
°C	Degrees Celsius
CaO	Calcium oxide
$Ca(OH)_2$	Calcium hydroxide
CH_2O	Formaldehyde
CH_3OH	Methanol
Cl_2	Chlorine
Co	Cobalt
CO	Carbon monoxide
CO_2	Carbon dioxide
CONCAWE	Conservation of Clean Air and Water in Europe
CS_2	Carbon disulphide
CuS	Copper sulphide
C_6H_{12}	Cyclohexane
DEC	Department of Environment and Conservation
DG	Dangerous Goods
DMP	Western Australian Government Department of Mines and Petroleum
DOIR	former Western Australian Government Department of Industry and Resources (now DMP)
DRI	Direct Reduced Iron
DSD	Department of State Development
e.g.	For example
EGIG	European Gas Pipeline Incident Data Group
EPA	Environmental Protection Authority of Western Australia
ERS	Environmental Risk Solutions Pty Ltd
ESD	Emergency Shutdown
ETA	Event Tree Analysis

Fe_2O_3	Iron (III) oxide
FTA	Fault Tree Analysis
h	Hour(s)
H_2	Hydrogen
H_2O_2	Hydrogen peroxide
H_2S	Hydrogen sulphide
H_2SO_4	Sulphuric acid
ha	Hectares
HCl	Hydrogen chloride
HCN	Hydrogen cyanide
HF	Hydrogen fluoride
HNO_3	Nitric acid
HSE	Health and Safety Executive (United Kingdom)
HV	High Voltage
IDEA	Intermittently Decanted Extended Aeration
IDLH	Immediately Dangerous to Life or Health
IRPA	Individual Risk Per Annum
ISO	International Organisation for Standardisation
KF	Potassium fluoride
kg	Kilogram(s)
KIE	Kwinana Industrial Estate
KIP	Kemerton Industrial Park
kL	Kilolitre
km	Kilometre(s)
kPa	Kilopascal(s)
LEL	Lower explosive limit
LFL	Lower Flammability Limit
Li	Lithium
Li_2CO_3	Lithium carbonate
Li_2SO_4	Lithium sulphate
LOC	Loss of Containment
LOC / 1000 km-y	Loss of Containment for 1000 kilometre years
LPG	Liquefied Petroleum Gas
LPGITA	Liquefied Petroleum Gas Industry Technical Association
m	Metre
m	Mass discharge rate, kg/s
m^2	Square metres
m^3	Cubic metres
m^3 / h	Cubic metres per hour
m^3 / pa	Cubic meters per annum
m / s	Metres per second
Mg	Magnesium

mg / m^3	Milligrams per cubic metre
$MgCl_2$	Magnesium chloride
mg.min / m^3	Milligram minutes per cubic metre
MIE	Minimum ignition energy
mJ	MilliJoules
ml	Millilitre
mm	Millimetre
Mpa	Megapascals
MSHA	United States Department of Labour Mine Safety and Health Administration
N_2	Nitrogen
Na	Sodium
N / A	Not applicable
NaCl	Sodium chloride
NaCN	Sodium cyanide
Na_2CO_3	Sodium carbonate
NaOCl	Sodium hypochlorite
NaOH	Sodium hydroxide
Nb	Niobium
NG	Natural Gas
Ni	Nickel
NH_3	Ammonia
$(NH_4)_2SO_4$	Ammonium sulphate
NIOSH	The National Institute for Occupational Health and Safety
NZS	New Zealand Standard
O_2	Oxygen
OEL	Occupational Exposure Limit
OIE	Oakajee Industrial Estate
pa	Per Annum
P&ID	Piping and Instrumentation Diagram
PPE	Personal Protective Equipment
ppm	Parts per million
PSA	Pressure Swing Adsorption
Q	Anthraquinone
QRA	Quantitative Risk Assessment
Ref.	Reference
Risk	Means the likelihood of unwanted consequences, such as death, injury, damage to property or damage to the environment, from the realisation of specified hazards.
SG	Specific Gravity
S	Sulphur
SO_2	Sulphur dioxide
SO_3	Sulphur trioxide

SRD	Safety and Reliability Directorate
T	Time (seconds)
t	Tonnes
Ta	Tantalum
$TaCl_5$	Tantalum chloride
Ti	Titanium
$TiCl_4$	Titanium tetrachloride
TiO_2	Titanium dioxide
tph	Tonnes per hour
tpa	Tonnes per annum
tpd	Tonnes per day
TNO	The Netherlands Organisation for Applied Scientific Research
TWA	Time Weighted Average
UAN	Urea Ammonium Nitrate
UEL	Lower explosive limit
UFL	Upper Flammability Limit
ULP	Unleaded petroleum
UK	United Kingdom
UKOPA	United Kingdom On-Shore Pipeline Operators Association
VCE	Vapour Cloud Explosion
WA	Western Australia
w/w%	Weight by weight percentage
‘xx in a million’	The level of increase in level of risk of fatality to an individual due to hazards associated with activities in question; for the purposes of this study, industrial.
”	Inch
%	Percent

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1. SUMMARY

The Kemerton Industrial Park (KIP) is located approximately 140 km south of Perth, and 17 km northeast of Bunbury in the Shire of Harvey, Western Australia (WA). It was established primarily to accommodate heavy industry and was originally envisioned to include a port facility between Springhill Road and Buffalo Road. An expansion has long been intended for the KIP, and the latter's development is being sponsored by LandCorp, and will ultimately cater for uses related to the surrounding area's existing industry. An all important buffer zone extending 500 m from the boundary of the heavy industry core to that of the lighter supporting industry area acts to reduce levels of societal risk presented by the heavy industry core.

A Strategy Plan (Ref. 29) developed for the KIP, details the total area of the KIP as 7,453 hectares (ha) comprising 2,019 ha of Industry Core, 293 ha Support Industry Area and 5,231 ha of Buffer Areas. The Buffer Area is intended to ensure that the impacts of industries located in the Industry Core do not adversely impact on neighbours beyond the buffer boundary of the KIP.

As a result of the requirements of the Environmental Protection Authority of Western Australia (EPA) and in accordance with the Strategy Plan, LandCorp has commissioned ERS to conduct a Quantitative Risk Assessment (QRA) of the KIP. The QRA will serve to demonstrate the overall risk presented by a proposed suite of conceptual industries LandCorp deems as likely to locate to the KIP.

The QRA was categorised into a Base Case and a High Density Industrial Loading Case. This allowed for the risk associated with each case to be evaluated separately. The Base Case comprised an industrial layout similar to the Oakajee Industrial Estate (OIE), which ERS previously modelled in a QRA conducted for LandCorp. The High Density Case comprised a new suite of industries for consideration, in addition to those proposed in the Base Case.

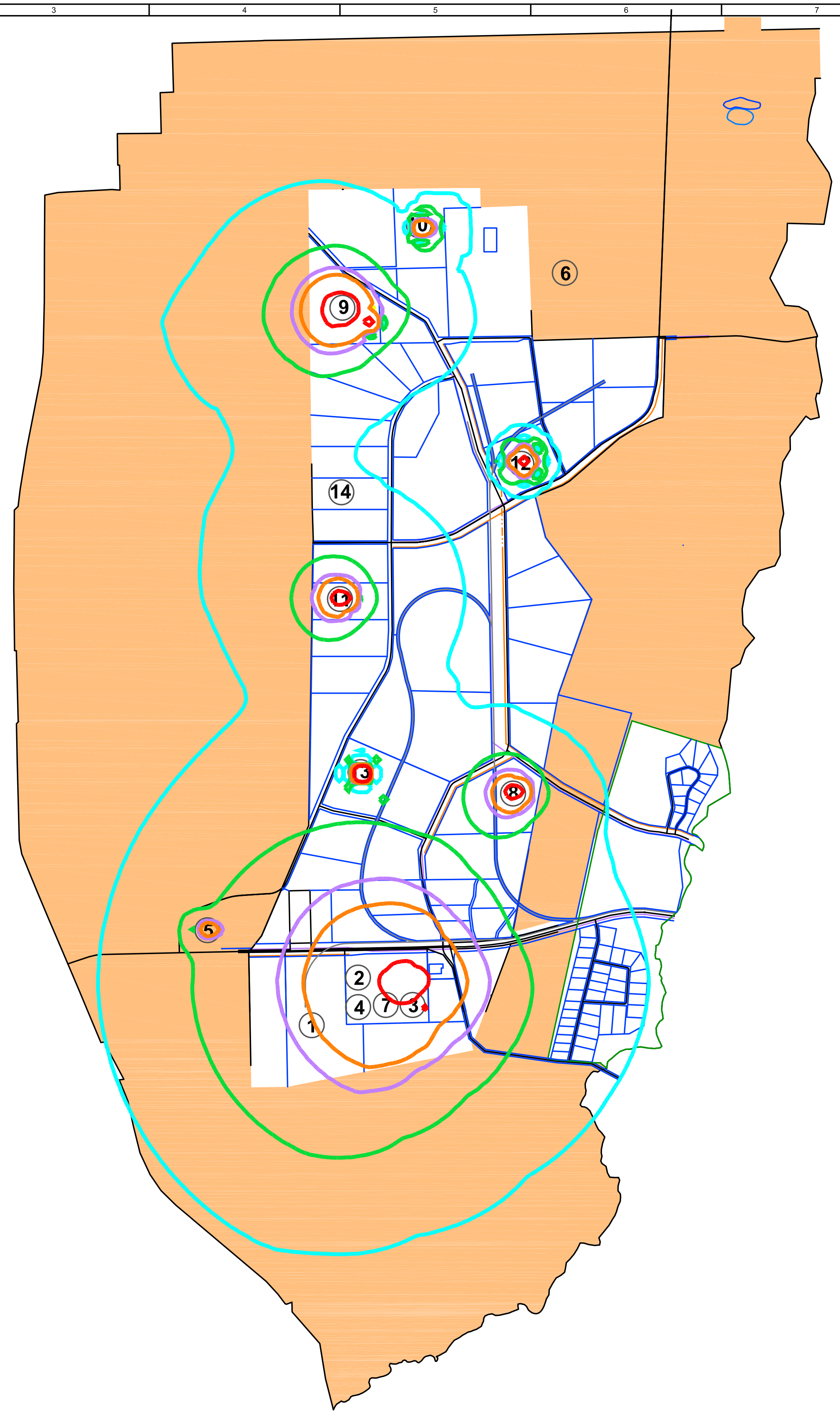
The QRA was performed based on conceptual industries detailed in **Section 5** that present a range of risk profiles. A systematic review of industry data sources, documentation, drawings and relevant information available was used to determine potential hazardous events and release scenarios related to each industry. The resultant data was then entered into specific QRA software programs *TNO Effects* and *Riskcurves* to generate risk contours associated with the proposed industrial layouts.

Generally, for both the Base and High Density Cases, EPA criteria for boundaries and buffer zones, is met. Where industries are in breach of EPA site boundary criteria, such as the conceptual Nickel Refinery, Oil Refinery and Fertiliser Plant, location to bigger sites within the KIP in order to accommodate IRPA contours is possible, as the KIP layout is only proposed at this stage. Individual QRAs however, should be undertaken for each facility to ensure that risk levels associated with these plants do not result in non-compliance with the EPA criteria.

During the process of undertaking the QRA study, industry specific safety controls and risk mitigation measures which should be included as part of good design and operating practice for the various facilities, have not been considered, as this information was not available at this early stage of the Kemerton project. As such, the results of this QRA represent a conservative approach.

From the QRA results, the main recommendation to reduce risks to As Low As Reasonably Practicable (ALARP) is:

Notwithstanding the compliance recommendations within this report, each industry shall be required to undertake individual QRA studies to locate in the KIP, ensuring that the risk levels associated with each facility do not result in non-compliance with EPA risk criteria.



BASE CASE INDUSTRIES

①	Silicon Smelter (Simcoa Operations)*
②	Pigment Plant (Cristal Global)*
③	Chlor-Alkali Plant (Nufarm - Coogee)*
④	Oxygen & Nitrogen Plant (BOC Gases)*
⑤	Water Treatment Plant (Water Corporation)*
⑥	Silica Sand Facility (Kemerton Silica Sands)*
⑦	Lime Hydration Plant (Cockburn Cement)*
⑧	Urea Plant
⑨	Nickel Refinery
⑩	Direct Reduced Iron (DRI) Plant
⑪	Sodium Cyanide Plant
⑫	Fuel Terminal
⑬	Titanium Metal Plant
⑭	Ammonium Nitrate Storage

* *Existing Facilities*

🟦	An increase in risk level of '1 in a million' (1×10^{-6}) - criterion for residential zones.
🟩	An increase in risk level of '10 in a million' (1×10^{-5}).
🟪	An increase in risk level of '50 in a million' (5×10^{-5}) - criterion for the site boundary.
🟧	An increase in risk level of '100 in a million' (1×10^{-4}) - criterion for the cumulative risk level imposed on an industry.
🟥	An increase in risk level of '1,000 in a million' (1×10^{-3}).

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Kilometres

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FIGURE 1-1
LANDCORP
KIP BASE CASE
RISK CONTOURS

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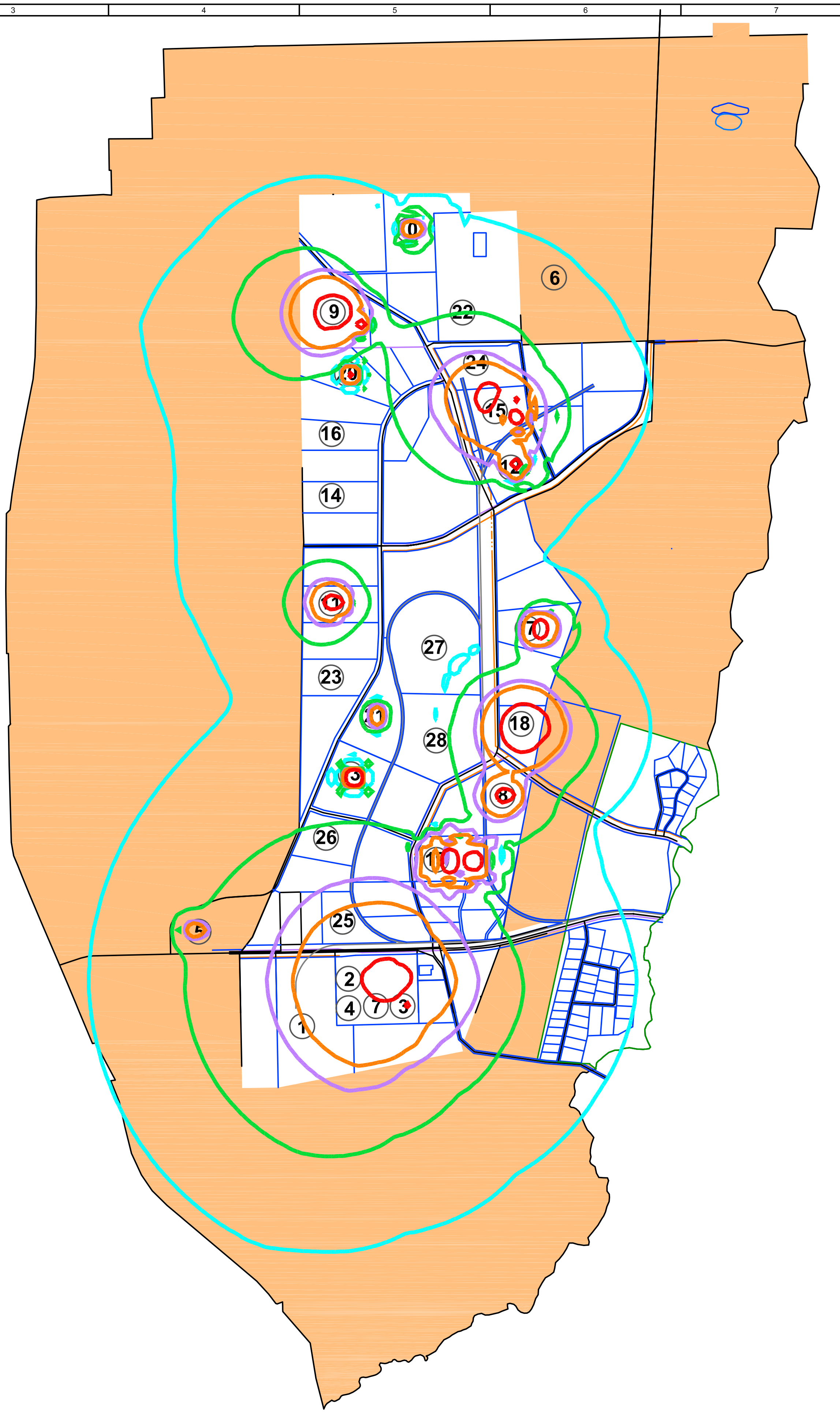

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Kilometres

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⑪	Sodium Cyanide Plant
⑫	Fuel Terminal
⑬	Titanium Metal Plant
⑭	Ammonium Nitrate Storage

* *Existing Facilities*

ADDITIONAL INDUSTRIES FOR HIGH DENSITY INDUSTRIAL LOADING CASE

⑮	Oil Refinery
⑯	Xanthate Plant
⑰	Ammonia Plant
⑱	Fertiliser Plant
⑲	LPG Facility
⑳	Hydrogen Peroxide Plant
㉑	Lithium Metal Facility
㉒	Timber Products Plant
㉓	Tantalum Refining Plant
㉔	Pulp and Paper Mill
㉕	Synthetic Rutile Plant
㉖	Vanadium Refining Plant
㉗	Aluminium Refinery
㉘	Aluminium Smelter

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FIGURE 1-2 LANDCORP
KIP HIGH DENSITY CASE
RISK CONTOURS

FILE TYPE	SIZE	SCALE	DRG NO	REV
AUTOCAD	A3	1:SCALE	KIP-QRA-003	1

2. INTRODUCTION

2.1 Background

The Kemerton Industrial Park (KIP) is located approximately 140 km south of Perth, and 17 km northeast of Bunbury in the Shire of Harvey, Western Australia (WA). It was established primarily to accommodate heavy industry and was originally envisioned to include a port facility between Springhill Road and Buffalo Road. An expansion has long been intended for the KIP, and the latter's development is being sponsored by LandCorp, and will ultimately cater for uses related to the surrounding area's existing industry. An all important buffer zone extending 500 m from the boundary of the heavy industry core to that of the lighter supporting industry area acts to reduce levels of societal risk presented by the heavy industry core.

A Strategy Plan was initially developed for the KIP in 1997 that took into consideration planning, environmental, economic and social issues related to the KIP. Further investigations and reviews have since been made, culminating in the current Strategy Plan (Ref. 29), that draws together the key elements of various studies and investigations prepared for the KIP over the years.

The Strategy Plan details the total area of the KIP as 7,453 hectares (ha) comprising 2,019 ha of Industry Core, 293 ha Support Industry Area and 5,231 ha of Buffer Areas. The Buffer Area is intended to ensure that the impacts of industries located in the Industry Core do not adversely impact on neighbours beyond the buffer boundary of the KIP.

As a result of the requirements of the Environmental Protection Authority of Western Australia (EPA) and in accordance with the Strategy Plan, LandCorp has commissioned ERS to conduct a Quantitative Risk Assessment (QRA) of the KIP. The QRA will serve to demonstrate the overall risk presented by a proposed suite of conceptual industries LandCorp deems as likely to locate to the KIP.

The QRA is categorised into a Base Case and a High Density Case. This allows for the risk associated with each case to be evaluated separately. The Base Case comprises an industrial layout similar to the Oakajee Industrial Estate (OIE), which ERS previously modelled in a QRA conducted for LandCorp. The High Density Case comprises a new suite of industries for consideration, in addition to those proposed in the Base Case.

Risk contours for the QRA will be generated using *The Netherlands Organisation (TNO) Effects and Riscurves* software. The results of the QRA will be compared to acceptable EPA criteria and will be used to support subsequent zoning of the estate for industrial use in line with the Structure Plan which will guide future development of the estate.

2.2 Objective

The overall objective of the risk modelling is to predict zones of risk impact from a mixture of industries with low, moderate and high risk impact profiles, so as to enable LandCorp to:

- determine adequacy or otherwise of the estate buffer to contain risk & hazard impacts within EPA criteria;
- assess, where pertinent, possible inter-industry impacts and attendant inter-industry buffers; and
- guide distribution of high, medium and low risk industries within the industrial core.

2.3 Scope

The scope of this QRA is a suite of conceptual industries that present a range of risk profiles. The scope was established in consultation with LandCorp and the Department of State Development (DSD) to represent a range of risk profiles sufficient to establish the capacity or otherwise of Kemerton to accommodate industries with such profiles.

The proposed suite of industries will be categorised into a Base Case and a High Density Case. The Base Case will consist of a suite of industries selected from the recent QRA conducted by ERS for LandCorp for the OIE with a layout effectively unchanged. The High Density Case will consist of a new suite of industries for consideration, in addition to those proposed in the Base Case. Sensitivity runs have been undertaken to determine the potential individual risk levels associated with the two different industrial loading cases, and the potential impact on the surrounding general industrial and buffer zones.

The QRA considers compliance with current individual risk guidelines as established by the EPA, and if required, suggests options to minimise the levels of individual risk that could be imposed on facilities outside the Strategic Industrial Zone.

This scope was established in consultation with LandCorp after the finalisation of the current proposed users.

Note: this QRA is not intended to be definitive for each potential user and for the KIP. Actual industries which will locate to the KIP, their specific designs and their locations have yet to be determined, hence a number of assumptions have been made during the study, which are detailed in this report.

3. METHODOLOGY

3.1 General

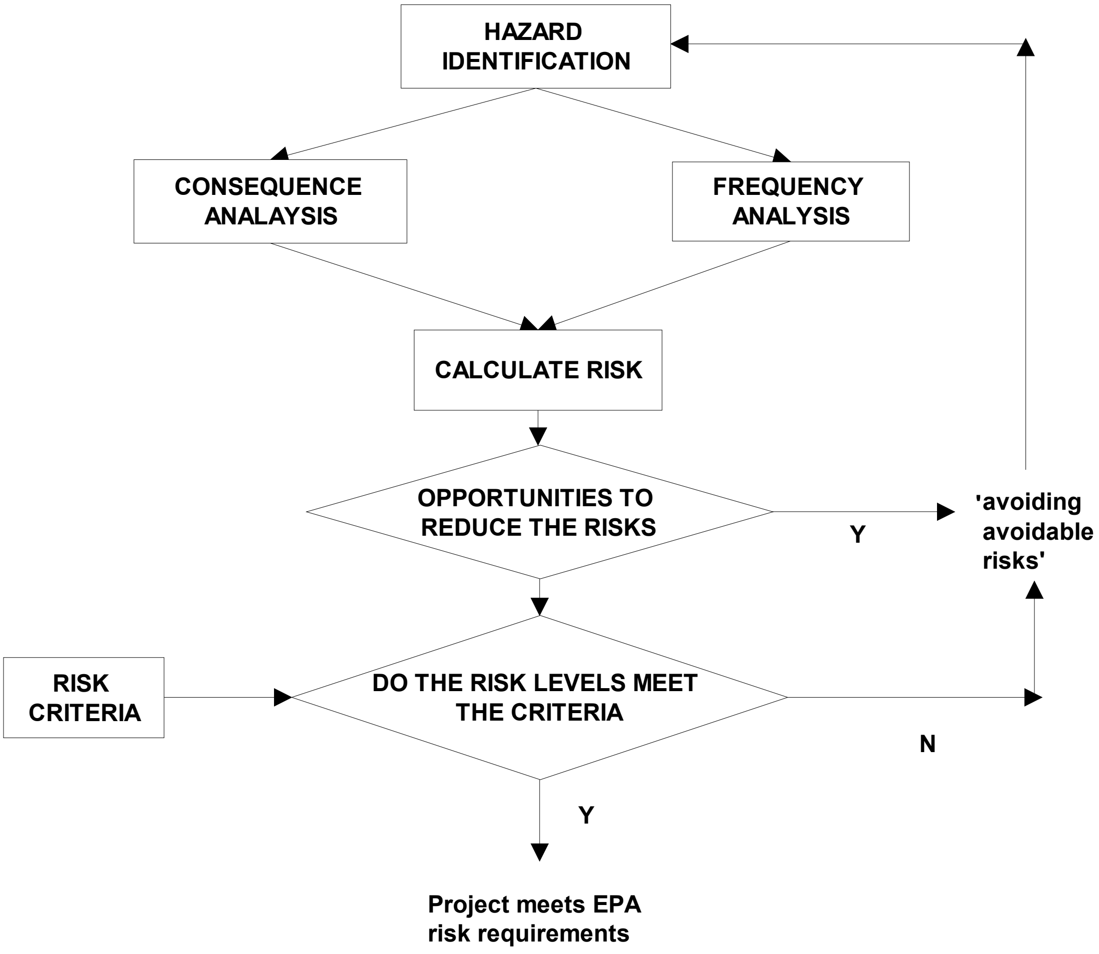
The QRA methodology used in this QRA will be similar to that used in the 1997 Woodward-Clyde KIP Expansion Study, Core / Buffer Definition Study document A3300107/006 and that employed for the QRA recently provided to LandCorp for the OIE. This approach provides consistency with past studies of this nature and is consistent with the requirements of AS/NZS ISO 31000:2009 “Risk Management-Principles and Guidelines” (Ref. 1), and the guidelines provided by the Department of Energy and Conservation (DEC) and the Western Australia Government Department of Mines and Petroleum (DMP).

The QRA includes the following steps, which is consistent with AS / NZS ISO 31000:2009 “Risk Management-Principles and Guidelines,” namely:

- Hazard identification process – to identify credible accident scenarios. This includes a review of previous Hazard Analysis studies, review of design documentation and review of piping layout drawings, inventories, mass flow rates and operating conditions within isolatable sections;
- Frequency analysis – to determine failure frequencies associated with each of the identified accident scenarios;
- Consequence assessment – to determine the impact associated with each of the identified accident scenarios;
- Risk modelling – to determine individual risk contours;
- Comparison of risk levels to EPA criteria – to determine the tolerability of the estimated risk levels;
- As Low As Reasonably Practicable (ALARP) review – to assess whether the current and proposed risk reduction measures reduce the level of risk to ALARP; and
- Report results.

Figure 3.1 (below) shows the basic steps in undertaking a QRA.

Figure 3.1 Risk Assessment Process



3.2 Industry loading

The proposed suite of industries will be categorised into a Base Case and a High Density Case. This allows for the risk associated with each case to be evaluated separately. The Base Case involves a suite of industries selected from the recent QRA conducted by ERS for LandCorp for the OIE and a layout effectively unchanged. The High Density Case involves a new suite of industries for consideration, in addition to those proposed in the Base Case. Modelling will be carried out using the QRA software program *TNO Effects and Riscurves.*

Sensitivity runs will be undertaken to determine the potential individual risk levels associated with the two different industrial loading cases, and the potential impact on the surrounding areas.

3.3 Individual Fatality Risk

Individual fatality risk relates to the increase (above that to which a person may already be exposed) in the level of risk of fatality directly from the hazards associated with the location of the proposed industries at the KIP. The value is site specific and relates to the increased level of risk at a particular location.

Table 3.1 reproduces the EPA individual fatality risk criteria that are detailed in their publication 'Guidance for Risk Assessment and Management: Offsite Individual Risk from Hazardous Industrial Plant' (Ref. 2). This guidance note adds to the criteria given in EPA Bulletins 611, 627 & 730 'Criteria for the Assessment of Risk From Industry', 'Criteria for the Assessment of Risk From Industry – Expanded Discussion' and 'Risk Criteria – On-Site Risk Generation for Sensitive Developments, Modifications to Sensitive Development Criterion – On-Site Risk, respectively (Refs. 3, 4 & 5).

EPA Bulletin 611 (Ref. 3) also states that:

> "There is a public expectation and corporate responsibility that where possible, regardless of calculated risk levels and criteria, 'avoidable risks should be avoided'".

The EPA reinforces the above requirement with the following statement:

> "In addition to industry best practice, there is a corporate responsibility that wherever possible, regardless of calculated risk levels and criteria, risk should be reduced to as low as reasonably practicable (ALARP)".

Table 3.1 EPA Individual Fatality Risk Criteria

a) A risk level in residential zones of one in a million per year or less, is so small as to be acceptable to the Environmental Protection Authority.

b) A risk level in "sensitive developments", such as hospitals, schools, child care facilities and aged care housing developments of between one half and one in a million per year is so small as to be acceptable to the Environmental Protection Authority.

> In the case of risk generators within the grounds of the "sensitive development" necessary for the amenity of the residents, the risk level can exceed the risk level of one half in a million per year up to a maximum of one in a million per year, for areas that are intermittently occupied, such as garden areas and car parks.
>
> c) Risk levels from industrial facilities should not exceed a target of fifty in a million per year at the site boundary for each individual industry, and the cumulative risk level imposed upon an industry should not exceed a target of one hundred in a million per year.
>
> d) A risk level for any non-industrial activity located in buffer zones between industrial facilities and residential zones of ten in a million per year or lower, is so small as to be acceptable to the Environmental Protection Authority.
>
> e) A risk level for commercial developments, including offices, retail centres and showrooms located in buffer zones between industrial facilities and residential zones, of five in a million per year or less, is so small as to be acceptable to the Environmental Protection Authority."

3.4 Societal Risk

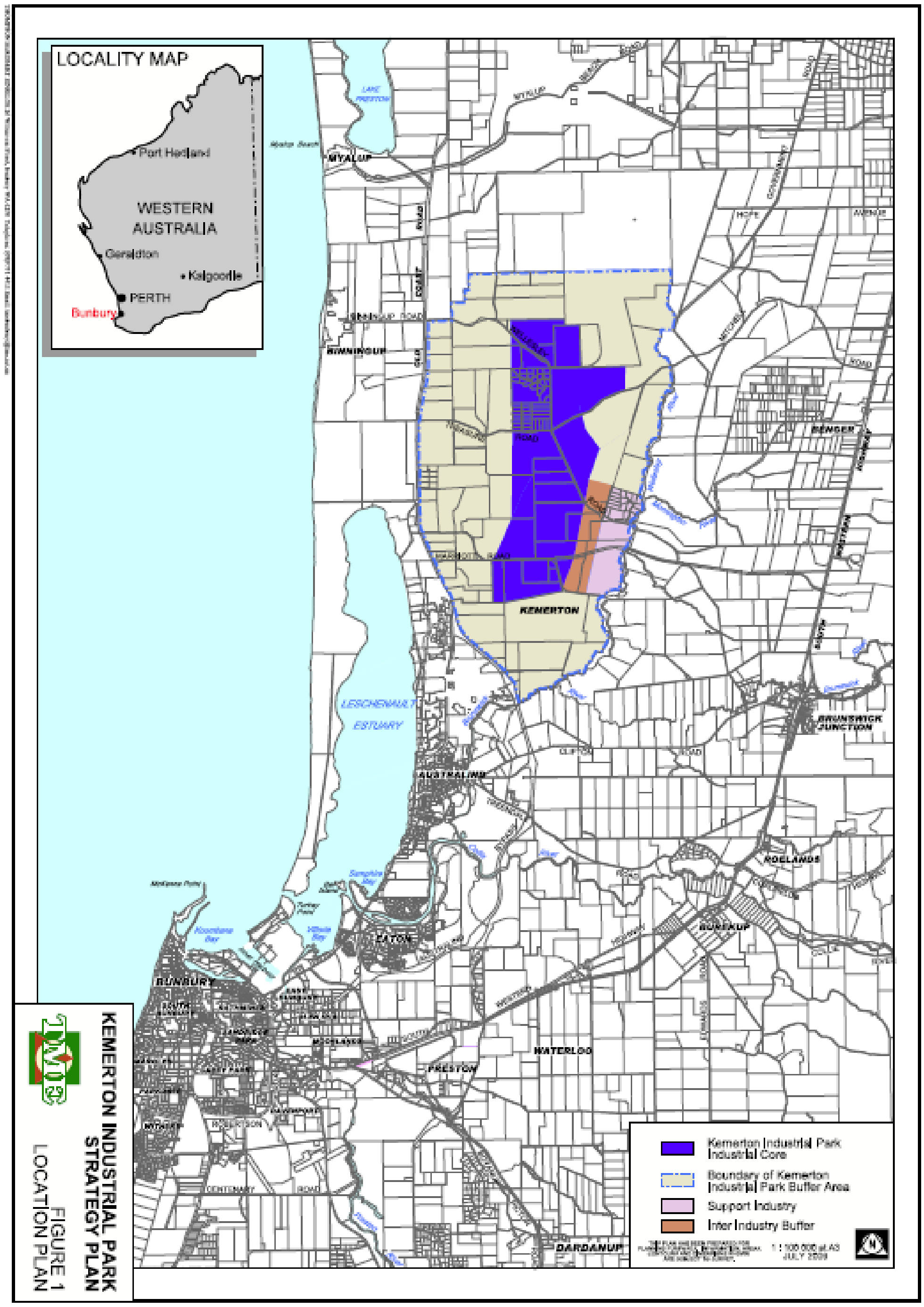
Consideration of Societal Risk is not included in this scope.

4. PROJECT DESCRIPTION

4.1 Plant Location

The KIP is located approximately 17 km from the City of Bunbury. The total area of the KIP is 7,543 hectares (ha) comprising 2,019 ha of Industrial Core, 293 ha of Support Industry area and 5,231 ha of Buffer areas. A map indicating the location of the park is shown below in **Figure 4-1.**

Figure 4.1 Kemerton Industrial Park Location



Source: Kemerton Industrial Park Strategy Plan (November 2009), (Ref. 29)

4.2 Natural Environment and Surrounding Land Use

The KIP has relatively flat terrain, with a water table that occurs close to the surface, all year round. The area comprises a mixture of cleared grazing land, areas of native vegetation and wetlands and pockets of plantation forestry with associated fauna.

The KIP's Buffer Area contains the Public Purposes area, regional open space, conservation, rural uses (including agriculture and quarrying), plantations and landfill sites. The Buffer Area is not intended to accommodate industry but instead to ensure that the impacts of industries located in the Industry Core do not adversely impact on neighbours beyond the buffer boundary of the KIP (Ref. 29).

A Water Treatment Plant is located in the Public Purposes area of the Buffer zone on the western side of the Industry Core. An abattoir and piggery are also located within the Buffer Area on the western side of the Industrial Core. In the north eastern section of the Buffer Area, Kemerton Silica Sands operates a Silica Sand mine. There is also an active sand quarry in the north western section of the Industry Core, whilst two landfill sites are located in the southern end of the Buffer Area.

A Kemerton Support Industry Area exists to the south eastern side of the Industry Core and is separated by an Inter-Industry Buffer. No support industries are located here at present. Most of the Support Industry area comprises a mixture of cleared grazing land, areas of native vegetation and wetlands and pockets of plantation forestry.

4.3 Existing Industries

The following industries are located within the Industry Core of the KIP:

- Silicon Smelter – Simcoa Operations Pty Ltd;
- Pigment (Titanium dioxide) Plant – Cristal Global;
- Chlor-Alkali Plant for supply of sodium hydroxide and chlorine to Cristal Global – Nufarm-Coogee;
- Oxygen and Nitrogen facility for the supply of oxygen and nitrogen to Cristal Global – BOC Gases;
- Lime Hydration Plant – Cockburn Cement; and
- Transfield Power Station

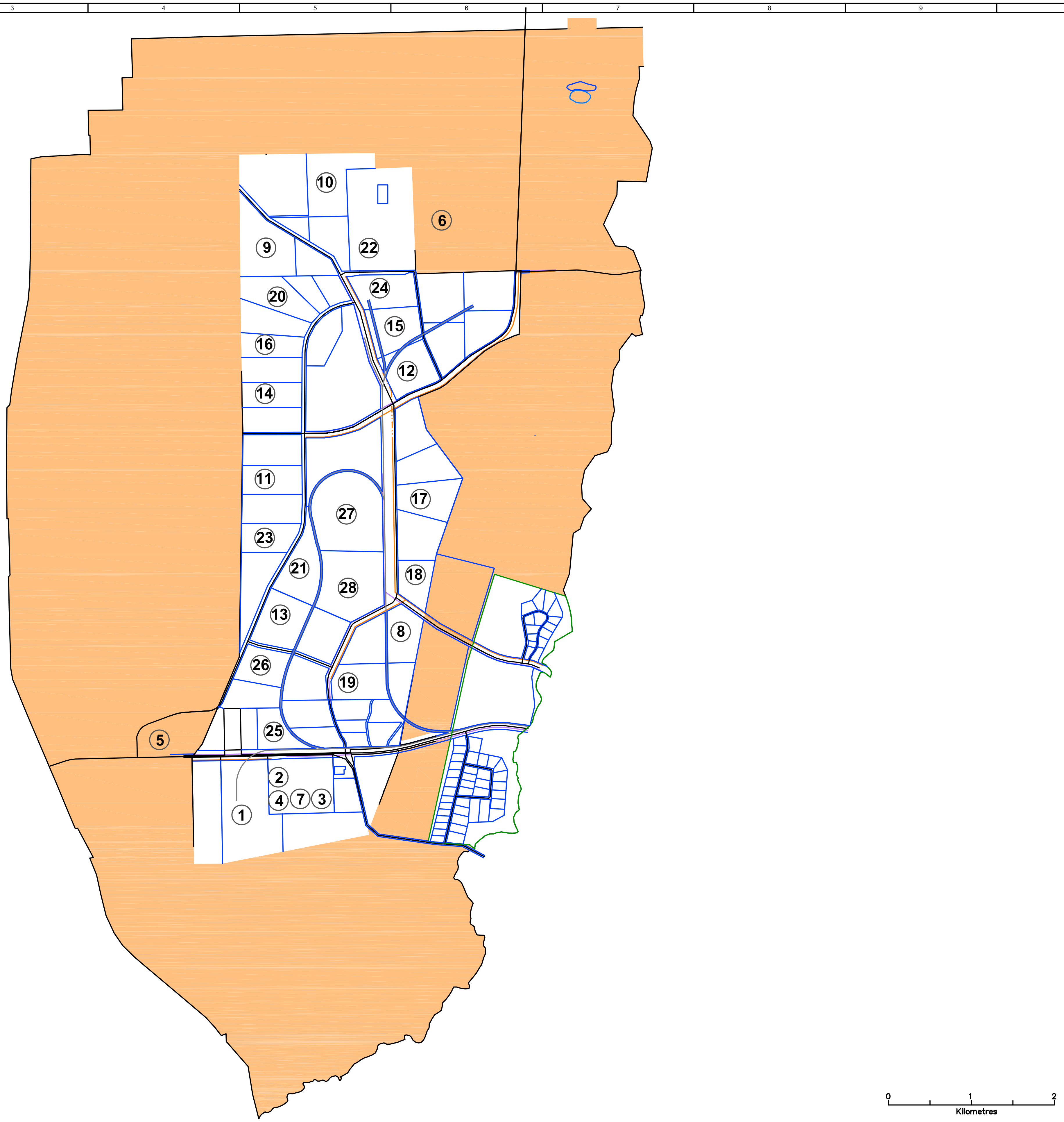
The following industries are located within the Buffer Area of the KIP:

- Silica Sand Facility – Kemerton Silica Sands; and
- Waste Water Treatment Plant – Water Corporation.

4.4 KIP Plant Locations

The KIP's proposed industrial layout, including existing facilities, is illustrated in **Figure 4.2**

Figure 4.2: Kemerton Industrial Park Proposed Layout



BASE CASE INDUSTRIES

①	Silicon Smelter (Simcoa Operations)*
②	Pigment Plant (Cristal Global)*
③	Chlor-Alkali Plant (Nufarm - Coogee)*
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⑮	Oil Refinery
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⑱	Fertiliser Plant
⑲	LPG Facility
⑳	Hydrogen Peroxide Plant
㉑	Lithium Metal Facility
㉒	Timber Products Plant
㉓	Tantalum Refining Plant
㉔	Pulp and Paper Mill
㉕	Synthetic Rutile Plant
㉖	Vanadium Refining Plant
㉗	Aluminium Refinery
㉘	Aluminium Smelter

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FIGURE 4-2 LANDCORP
KEMERTON INDUSTRIAL PARK
LAYOUT

FILE TYPE	SIZE	SCALE	DRG NO	REV
AUTOCAD	A3	1:SCALE	KIP-QRA-001	0

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4.5 Population Data

4.5.1 City of Bunbury

The Australian Bureau of Statistics (ABS), 2006 census figures indicate that 55,000 people are usually resident in The City of Bunbury, which is located approximately 17 km from the KIP.

4.5.2 Nearby Residential Areas

The KIP Industrial Core is located approximately 2 km from Leschenault, the nearest residential area. The ABS 2006 census figures indicate a population of 2,850 people for Leschenault.

4.6 Infrastructure

4.6.1 Road Connections

The KIP is located close to two major highways. The Old Coast Road follows the western boundary of the Kemerton bufffer. The Old Coast Road is linked to the new Perth – Bunbury highway which links Bunbury directly to Perth. The South Western highway to the east of the KIP also links Bunbury to Perth.

4.6.2 Port of Bunbury

The Port of Bunbury is a deep water port, located approximately 20 km away from the KIP.

4.6.3 Gas Pipeline

Natural gas will be supplied to the park through the Dampier to Bunbury Natural Gas Pipeline, which is piped from the North West Shelf natural gas reserves. The pipeline passes through the KIP and runs just outside the boundary of the Industry Core.

4.7 Meteorological Data

4.7.1 Temperature and Relative Humidity

The KIP is located within the South West Region of Western Australia, which has a mild Mediterranean climate with hot / dry summers and mild / wet winters. Coastal areas within the South West region have mean annual temperatures ranging from 11 Degrees Celsius (^{o}C) to 23^{o}C. A mean annual temperature of 17 ^{o}C is used for this study. A mean annual relative humidity of 75% has also been used (Ref.27).

4.7.2 Modelling Data

The weather data used in this study is provided in **Appendix A**. This data is derived from statistics provided by Air Assessments for the year 1995. Weather data for the region is not expected to have changed drastically in the past fifteen years and therefore use of the 1995 weather data is considered acceptable.

In order to collate data into a suitable format for input into the *Riskcurves* modelling software package for the QRA, a number of parameters were recorded first, for a given time period. The wind speed, direction and atmospheric stabilities were recorded and were then used to determine the relative probabilities for winds blowing into each sector, with each sector representing a wind direction from 1 to 12 (as per a clock face). These relative probabilities were then derived for each of the Pasquill stability classes.

Pasquill stability classes are a measure of the degree of turbulence in the atmosphere, categorised into six stability classes ranging from A to F, with A being the most unstable and F being the most stable. The degree of atmospheric turbulence is dependent on the level of solar radiation and the wind speed. Atmospheric stability affects dispersion of released gases, as under unstable conditions, a released gas mixes more rapidly with the air around it than under stable conditions, thus diluting the pollutant further.

5. REPRESENTATIVE HAZARDOUS INDUSTRIES

5.1 General

5.1.1 Selection of Industries

Industries selected for the KIP are categorised into a Base Case and a High Density Case. The Base Case involves a suite of industries selected from the recent QRA conducted by ERS for LandCorp for the OIE and a layout effectively unchanged. The High Density Case involves a new suite of industries for consideration, in addition to those proposed in the Base Case. Apart from the existing industries, none of the others are proposed for Kemerton at this time, but they were chosen to reflect a range of high, medium and low risk profiles.

Table 5.1 and **Table 5.2** list the industries proposed for the Base Case and High Density Case.

Table 5.1 Base Case Industry Loading for KIP

Base Case Industry Loading	
1	*Silicon Smelter (Simcoa Operations)
2	*Pigment Plant (Cristal Global)
3	*Chlor-Alkali Plant (Nufarm-Coogee)
4	*Oxygen and Nitrogen Plant (BOC Gases)
5	*Water Treatment Plant (Water Corporation)
6	*Silica Sand Facility (Kemerton Silica Sands)
7	*Lime Hydration Plant (Cockburn Cement)
8	Urea Plant
9	Nickel Refinery
10	Direct Reduced Iron (DRI) Plant
11	Sodium Cyanide Plant
12	Fuel Terminal
13	Titanium Metal Plant
14	Ammonium Nitrate Storage

*Existing facility

Table 5.2 High Density Industry Loading for KIP

High Density Industry Loading	
1	*Silicon Smelter (Simcoa Operations)
2	*Pigment Plant (Cristal Global)
3	*Chlor-Alkali Plant (Nufarm-Coogee)
4	*Oxygen and Nitrogen Plant (BOC Gases)
5	*Water Treatment Plant (Water Corporation)
6	*Silica Sand Facility (Kemerton Silica Sands)
7	*Lime Hydration Plant (Cockburn Cement)
8	Urea Plant
9	Nickel Refinery
10	Direct Reduced Iron (DRI) Plant
11	Sodium Cyanide Plant
12	Fuel Terminal
13	Titanium Metal Plant
14	Ammonium Nitrate Storage
15	Oil Refinery
16	Xanthate Plant
17	Ammonia Plant
18	Fertiliser Plant
19	LPG Facility
20	Hydrogen Peroxide Plant
21	Lithium Metal Facility
22	Timber Products Plant
23	Tantalum Refining Plant
24	Pulp and Paper Mill
25	Synthetic Rutile Plant
26	Vanadium Refining Plant
27	Alumina Refinery
28	Aluminium Smelter

*Existing facility

Notes: Pipelines and transport routes were excluded from the modelling study as the contribution of risk from these hazards, based on the Kwinana Cumulative Risk Analysis, was not considered to be significant.

Table 5-3 lists potential hazardous materials and consequences associated with the proposed industries to be located at the KIP.

Table 5.3 Hazardous Industries at KIP

Industry	Description	Hazardous Materials and Consequences
Aluminium Smelter	Smelting is run in a large number of pots with the aluminium (Al) metal deposited at the bottom of the pots and periodically drained off.	Diesel – fire. Liquefied Petroleum Gas (LPG) - jet fire / explosion.
Alumina Refinery	The Bayer process is used to refine bauxite to produce alumina (Al_2O_3). Bauxite is digested with hot sodium hydroxide (NaOH) which is subsequently cooled and precipitated as aluminium hydroxide ($Al(OH)_3$). This is then calcined to form Al_2O_3.	NaOH – corrosive liquid.
Ammonia Plant	Ammonia (NH_3) is manufactured from natural gas (NG). The process involves high pressure reformation of NG in the presence of steam over a catalyst. Liquid anhydrous NH_3 would be stored in bulk at the site.	NH_3 – toxic gas. NG – jet fire.
Ammonium Nitrate Storage	Ammonium nitrate (AN) would be stored either in prills or granules. AN could be either fertilizer or explosive grade. Explosive grade AN is highly porous, making it sensitive to detonation. Fertiliser grade AN with a lower porosity does not absorb contaminants as readily and has a much greater resistance to detonation.	AN – explosive.
Chlor-Alkali Plant	Chlorine (Cl_2) and NaOH are formed by electrolysing sodium chloride (NaCl) in electrolysis cells. Cl_2 is transported via pipeline to the adjacent Titanium dioxide (TiO_2) plant.	Cl_2 – toxic gas. NaOH – corrosive liquid.
Direct Reduced Iron	The plant uses a Direct Reduced Iron (DRI) process to convert ore to iron. The DRI process uses a reactor. The fuel and associated reducing atmosphere for the reactor is produced from reforming natural gas. The reformer converts NG to carbon monoxide (CO), hydrogen (H_2) and water under operating high pressure and temperature conditions. A NG lateral would be constructed to supply the site. Liquefied Petroleum Gas (LPG) would also be stored at the plant.	LPG – jet fire / explosion. NG – jet fire. CO – fire and toxic gas. H_2 – jet fire / explosion.
Fertiliser Plant	The manufacture of AN involves the exothermic reaction between gaseous NH_3 and nitric acid (HNO_3) to form AN liquid, which is dried and used as both a fertiliser and an explosive.	NH_3 – toxic gas. AN – explosive.

Industry	Description	Hazardous Materials and Consequences
Fuel Terminal	The Fuel Terminal involves the bulk volume storage of petroleum fuels, diesel, ethanol and industrial solvents.	Petroleum fuels – fire. Ethanol – fire. Solvents – fire. Diesel – fire.
Hydrogen Peroxide Plant	Hydrogen peroxide (H_2O_2) is manufactured from the catalysis of H_2 and oxygen (O_2). H_2 for the process is obtained from the steam reforming of NG.	NG – jet fire. H_2 – jet fire / explosion. O_2 – oxidising gas. H_2O_2 – oxidising and corrosive liquid.
Lime Hydration Plant (Cockburn Cement)	Quicklime (CaO), formed from the burning / calcination of limestone is hydrated with water, in an exothermic reaction.	None identified for consideration in this QRA.
Liquefied Petroleum Gas (LPG) Plant	The LPG plant will involve the liquefaction and / or storage of low weight hydrocarbons such as propane and butane.	LPG – jet fire / explosion.
Lithium Metal Facility	Lithium (Li) containing ore is extracted into a sulphate solution using sulphuric acid (H_2SO_4). This is treated with soda ash to form lithium carbonate (Li_2CO_3) and subsequently converted to a chloride using hydrochloric acid (HCl). Li metal and Cl_2 are formed at the cathode and anode respectively.	Cl_2 – toxic gas. HCl – corrosive liquid.
Nickel Refinery	The processing of nickel (Ni) matte is assumed to be carried out from a smelter elsewhere. The Sherritt-Gordon process is assumed to be used. Ni matte is finely ground and then fed to a two stage pressure leach, with NH_3, to produce a soluble amine salt. H_2SO_4 and steam are injected to remove NH_3 and precipitate copper sulphide (CuS). This is then treated with air to purify the liquor. Ni is then displaced from solution with H_2 gas in a batch process. The resulting Ni powder is then washed dried and packaged.	NH_3 – toxic gas. H_2 – jet fire / explosion. Hydrogen sulphide (H_2S) – toxic / flammable gas. Sulphur dioxide (SO_2) – toxic gas. Sulphur trioxide (SO_3) – toxic gas. H_2SO_4 – corrosive liquid.
Oil Refinery	This involves the separation of crude feedstock into various fractions. Typical final refined products stored include petroleum fuels, diesel fuel, ethanol, and other solvents. Other substances used in production include H_2 and hydrogen fluoride (HF) as raw materials.	Petroleum fuels – fire. Ethanol – fire. Solvents – fire. Diesel – fire. H_2 – jet fire / explosion. HF – toxic gas.
Oxygen and Nitrogen Plant (BOC Gases)	Supply of O_2 and nitrogen (N_2) to the adjacent TiO_2 pigment plant.	O_2 – oxidising gas. N_2 – asphyxiant gas.

Industry	Description	Hazardous Materials and Consequences
Pulp and paper mill	Pulp and paper are manufactured from raw materials such as wood, recycled paper and agricultural residues. Main steps are raw material preparation such as wood debarking and chip making, pulp manufacturing, pulp bleaching, paper manufacturing and fibre recycling. Bleaching is assumed to be carried out using H_2O_2.	H_2O_2 – oxidising and corrosive liquid. NaOH – corrosive liquid.
Silica Sand Facility (Kemerton Silica Sands)	Sand is sized and heavy minerals such as TiO_2 and Fe_2O_3 are removed.	None identified for consideration in this QRA.
Silicon Smelter (Simcoa Operations)	Silicon (Si) is produced via a smelting process in a furnace. CO is emitted during smelting, which reacts with oxygen in the atmosphere to produce carbon dioxide gas. Silicon monoxide (SiO) which fails to react within the furnace oxidises to form silicon dioxide (SiO_2) known as amorphous silica fume). Silicon fume is vented away for collection in a baghouse.	CO – fire and toxic gas. Diesel – fire. LPG - jet fire / explosion.
Sodium Cyanide Plant	Manufactured by reacting air, NH_3 and NG at elevated temperatures over a catalyst to produce hydrogen cyanide (HCN) which is then absorbed in NaOH to produce sodium cyanide (NaCN) solution.	NH_3 – toxic gas. NG – jet fires. HCN – toxic gas (limited to a few kilograms (kg) maximum quantity).
Synthetic Rutile Plant	Raw materials are fed into a kiln and heated to change the properties of the ilmenite particles. Cooled and reduced ilmenite from the kiln is fed into an aerator, a hydro cyclone and drier which changes the properties again, before the final synthetic rutile product is produced.	Diesel – fire. LPG - jet fire / explosion.
Tantalum Refining Plant	Tantalum (Ta) concentrate is treated with a mixture of HF and H_2SO_4 resulting in the formation of complex fluorides. Organic solvents such as cyclohexane (C_6H_{12}) are used for liquid extraction. Ta metal is then produced through a reduction process.	C_6H_{12} – fire. H_2SO_4 – corrosive liquid. HCl – corrosive liquid. HF – toxic gas.
Timber Products Plant	Timber products are manufactured from raw wood. Adhesives and resins are used in the process. A formaldehyde (CH_2O) plant is assumed to be located in the vicinity for the manufacture of adhesives. Methanol (CH_3OH) is used in the manufacture of formaldehyde.	CH_3OH – fire CH_2O - fire
Titanium Dioxide Plant (Pigment plant)	TiO_2 is produced using the chloride process by a refining process whereby synthetic rutile is converted to titanium tetra-chloride ($TiCl_4$) and then oxidised to TiO_2.	$TiCl_4$ – toxic gas. Cl_2 – toxic gas. O_2 production, storage and distribution – oxidising gas.

Industry	Description	Hazardous Materials and Consequences
Titanium Metal Plant	$TiCl_4$ is reacted with magnesium (Mg) metal to form titanium (Ti) metal and magnesium chloride ($MgCl_2$). The $MgCl_2$ is converted to Cl_2 and Mg metal in electrolytic cells and recycled. It is assumed that $TiCl_4$ is manufactured in the same manner as for TiO_2 pigment.	$TiCl_4$ – toxic gas. Cl_2 – toxic gas.
Urea Plant	Urea manufacture is undertaken by reacting carbon dioxide (CO_2) and NH_3. The reaction is two stage, the first being exothermic making ammonium carbamate and the second being endothermic making urea and water.	NH_3 manufacture and storage – toxic gas. CO_2 manufacture and storage – asphyxiant gas.
Vanadium Refining Plant	Titaniferrous concentrate undergoes salt roasting using sodium carbonate (Na_2CO_3) to produce a water soluble pentavalent state of vanadium. This is then leached in water and subsequently precipitated with aluminium sulphate ($Al_2(SO_4)_3$). Calcination results in a vanadium pentoxide product.	Diesel – fire. LPG - jet fire / explosion.
Waste Water Treatment Plant (Water Corporation)	Waste water is treated using the Intermittently Decanted Extended Aeration (IDEA) process where sewerage is passed through an aerated zone to allow for bacteria multiplication. Chemical dosing takes place to further disinfect the water.	Cl_2 – toxic gas. NaOH – corrosive liquid.
Xanthate Plant	This involves the production of various xanthates by bubbling carbon disulphide (CS_2) through a slurry of an appropriate alcohol to give the desired alkyl group. The slurry also includes ground NaOH or potassium hydroxide in a volatile organic solvent.	Ethanol – fire. Isobutanol – fire. Isopropanol – fire. CS_2 – flammable liquid producing SO_2 – toxic gas when combusted. NaOH – corrosive liquid. Xanthates – corrosive liquid.

5.1.2 Selection of Industrial Site Locations

Large industries such as the alumina refinery and the aluminium smelter were located on large lots for space considerations. Plants that use common substances were located close to each other. For this reason, the synthetic rutile plant was located close to the pigment (TiO_2) plant.

Other than this, plants were located in a relatively random fashion so as to provide for the best representation of industries across the site.

Figure 4-2 details the selected locations for the various industries to be located at the KIP.

5.2 Industry Assumptions

In undertaking this QRA, a number of assumptions were made in order to determine the failure case scenarios. The general study assumptions made are discussed below, and specific assumptions regarding individual industries are further detailed under the corresponding industry descriptions. Inventories and process conditions for the various lines and sections of the plants as used for the risk modelling is detailed in **Appendix E**.

The following general assumptions are made for this study:

- Valves are flanged and not welded in (conservative approach);
- Parts counts for the isolatable inventories associated with the plants that have been modelled, are based on information from previously undertaken QRA studies for similar industries, and where such existing studies were not available, engineering judgment has been used. The representative parts counts are detailed in **Appendix B**;
- Although it is normal to allow around 10% ullage for thermal expansion of the contents of storage tanks, for the purposes of this QRA, storage tanks are assumed to be 100% full at all times (conservative approach);
- Unless specifically otherwise indicated, all storage vessels, distribution systems and reactor vessels are assumed to be in use and 100% full of the hazardous material being modelled, at all times. (Fraction of time in use for modelling purposes = 1);
- Unless specifically otherwise indicated, the time for detection of a release and isolation of inventories (Emergency Shutdown (ESD)) in the event of a Loss Of Containment (LOC) = 600 seconds (s);
- Pressurised storage of NH_3 is at 25 °C and 10 bar gauge (barg);
- Refrigerated Storage of NH_3 is at -33°C and atmospheric pressure;
- Pressurised storage of Propane, Butane and LPG is at 20°C and 8.37 barg;
- Pressurised storage of H_2 gas is at 25°C and 79 barg; and
- Pressurised storage of Cl_2 is at -35°C and 3 barg.

5.3 Industry Descriptions

5.3.1 Silicon Smelter (Simcoa Operations)

Simcoa Operations (Simcoa) has an existing facility in the KIP that produces Si via a smelting process. The plant is an integrated facility consisting of a wood processing facility, two vertical gas rinsing charcoal retorts, two submerged arc furnaces and packaging and dispatch facilities. The carbon source for the reaction is a combination of coal and charcoal.

The smelting operation is carried out in submerged arc furnaces by the carbothermic reduction of silica, either as quartz or quartzite. CO is emitted during the process, which reacts with O_2 gas in the atmosphere to form CO_2 gas. This process is highly endothermic. The furnace charge consists of a mixture of quartz, carbonaceous reducing agents (charcoal, coal, petroleum coke) and wood chips.

Approximately 32,000 tonnes per annum (tpa) of lump Si is produced from the process. SiO which fails to react within the furnace oxidises in the atmosphere to form SiO_2 (a dust-like material called amorphous silica fume). The silica fume is vented away for collection in a large filtration facility (baghouse) as a by-product of the silicon production. Approximately 10,000 tpa of SiO_2 is produced from the process.

Assumptions for this QRA

The following inventories exist on site:

- 20,000 litres (L) diesel tank;
- 7,500 L LPG tank; and
- 20,000 L liquefied O2 tank.

In addition to this, the following inventories are utilised or produced on site:

- 10,000 tpa amorphous Si; and
- 40,000 tpa of coal and charcoal.

Flammable atmospheres, and fire and explosion associated with a hydrocarbon release are deemed the primary hazards.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.2 Pigment Plant (Cristal Global)

TiO_2 pigment is primarily used for the manufacture of paints, plastics and inks. Synthetic rutile (containing at least 90% TiO_2), is reacted with petroleum coke and oxidized with Cl_2 in reactors, or chlorinators, producing $TiCl_4$.

The $TiCl_4$ is purified by condensation and distillation and re-oxidized with superheated O_2 to give pure TiO_2. This process is known as the Chloride Process. The pigment is then put through a finishing process prior to packaging for distribution to consumers.

Although it is not consumed, Cl_2 gas is a vital raw material for the pigment industry, and is usually produced by chlor-alkali plants and supplied to a pigment plant via pipeline.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Pigment Plant are as follows:

- For the purposes of this QRA it is assumed that the representative TiO_2 production facility is capable of producing 165,000 tpa of TiO_2
- The facility would require 120 000 tpa O_2 and as such would store 100 tonnes (t) of liquid O_2;
- 100 t of liquid Cl_2 (in 2 x 32 cubic metre (m^3)) pressurised storage vessels housed within a specifically designed enclosure) is stored as a backup supply to that provided by the nearby Chlor-Alkali Plant;
- 2 day's supply, (2,100 t in three 700 t vessels), of $TiCl_4$ is stored as buffer storage in vertical fixed roof tanks at 75 °C and atmospheric pressure; and
- Toxic exposure associated with a Cl_2 and $TiCl_4$ release is deemed the primary hazards.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.3 Chlor-Alkali Plant (Nufarm – Coogee)

The purpose of the Chlor-Alkali plant at the KIP is primarily to produce both NaOH for local and export sale to industry, and Cl_2 gas for use in production of $TiCl_4$, an intermediate in the TiO_2 pigment production process.

The plant uses the Lurgi membrane cell technology where an electric current is passed through the solution to decompose NaCl and produce Cl_2 gas at the anodes. NaOH and H_2 are produced at the cathodes. The two halves of the process are separated by an ion-exchange membrane that prevents re-mixing of the products.

The Cl_2 gas produced is cooled, dried, compressed and liquefied by chilling to below -34°C. Any O_2 present is removed during liquefaction, and is passed to atmosphere via the Cl_2 absorption and scrubbing system. Product Cl_2 is then purified and sent via buffer storage to distribution via pipeline to the adjacent pigment plant, as required.

Liquid Cl_2 is typically stored within a specifically designed and constructed facility in pressurised refrigerated storage tanks. Generally, one storage tank is always empty to enable the entire contents of either of the other tanks be transferred and contained safely in the case of an emergency.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Chlor-Alkali Plant are as follows:

- The Chlor-Alkali Plant will supply approximately 45,000 tpa of Cl_2;
- The facility stores 100 t (64 m^3) of liquid Cl_2 in 2 x 32 m^3 pressurised storage vessels housed within a specifically designed enclosure; and
- Toxic exposure associated with a Cl_2 release is deemed the primary hazard.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.4 Oxygen and Nitrogen Plant (BOC Gases)

BOC Gases stores liquid O_2 and liquid N_2 on-site to ensure a reliable supply is provided to Cristal Global for its operations. Liquid argon (Ar) is also stored on site.

Assumptions for this QRA

The following inventories exist on site:

- 255 t liquid O_2;
- 207 t liquid N_2; and
- 45 t liquid Ar.

These are non-flammable and non-toxic liquids.

5.3.5 Water Treatment Plant (Water Corporation)

The waste water treatment plant at the KIP treats wastewater using the IDEA process. Sewerage is passed through an aerated zone where bacteria multiply in the presence of O_2, using large amounts of phosphorous. The sludge settles and clear liquid can be decanted off. Chemical dosing using $Al_2(SO_4)_3$ and NaOH is carried out. Cl_2 is also used to disinfect the water. The plant is capable of treating three million litres of wastewater per day. Some of the treated water from the plant is recycled and used to water nearby tree farms at the KIP.

Assumptions for this QRA

The following inventories exist on site:

- 2 x 920 kg Cl_2;
- 1 x 15 kilolitres (kL) NaOH; and
- 1 x 24 kL $Al_2(SO_4)_3$.

Toxic exposure associated with a Cl_2 release is deemed the primary hazard.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.6 Silica Sand Facility (Kemerton Silica Sands)

Kemerton Silica Sands produces silica sand for the glass manufacturing industry. This operation produces 400,000 to 500,000 tonnes per year of silica sand. Sand sizing and heavy mineral removal are the main operations that take place at the facility. Sizing is controlled via screening, classifiers and submerged trommels. Heavy minerals such as TiO_2 and Iron oxide (Fe_2O_3) are removed via cyclones and a three stage spiral circuit. Attritioners and electromagnets are also involved in the removal of Fe_2O_3.

5.3.7 Lime Hydration Plant (Cockburn Cement)

The lime hydration plant at KIP produces milk of lime as well as bulk hydrated lime. CaO is hydrated with water and screened to remove lime impurity to form hydrated lime ($Ca(OH)_2$).

5.3.8 Urea Plant

Urea is a nitrogen-containing chemical product that is produced on a scale of some 100,000,000 tons per year worldwide. Due to its high degree of water solubility, more than 90% of this is used as a raw material for the manufacture of a liquid fertilizer known as Urea Ammonium Nitrate (UAN) solution. Urea has the highest N_2 content, and thus lowest transportation costs, per unit of all solid nitrogenous fertilisers in common use.

Urea has the ability to form "loose compounds", called clathrates, with many organic compounds and has been used in the manufacture of aviation fuels and lubricants.

For use in industry, urea is produced from NH_3 and CO_2. It can be produced as prills, granules, flakes, pellets, crystals, and solutions. The production of urea from NH_3 and CO_2 takes place via a chemical reaction, with incomplete conversion of the reactants. Large quantities of CO_2 are produced during the steam reforming of NG to produce NH_3. This allows direct synthesis of urea from these raw materials. A urea plant can be configured to produce an excess of NH_3 which can be used to supply NH_3 to other downstream processes.

Assumptions for this QRA

Assumptions made in the course of the QRA for the urea plant are as follows:

- The plant produces 103,500 tpa NH_3 and subsequently 182,000 tpa urea (based on existing international installations);
- The plant has 4 x 15,000 t urea storage silos and a single 10,000 m^3 (approximately 6,000 t) pressurised anhydrous NH_3 storage bullet;
- 3,000 t of CO_2 is stored under pressure on site as it is used directly in the urea synthesis reaction; and
- Toxic exposure associated with an NH_3 is deemed the primary hazard.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.9 Nickel Refinery

Ni matte, an intermediate product in the production of Ni metal, is produced at a smelting plant and transported to a refinery. It is assumed that the Ni matte is refined using the Sherritt-Gordon Process which involves reacting Ni flotation concentrates under pressure, with O_2 and NH_3, forming soluble Ni-NH_3 complex ions. H_2S and steam are injected to remove NH_3 and precipitate copper sulphide (CuS). The mixture is then treated with H_2SO_4 and air to purify the liquor. Ni metal is displaced from solution with H_2 gas in a batch process. Precipitated Ni is usually washed, dried, packaged and sold as a powder or, after compaction and heating, as sintered briquettes. Any remaining Ni and cobalt (Co) left in solution is precipitated using H_2S. The remaining solution, rich in ammonium sulphate ($(NH_4)_2SO_4$), is crystallised and used as a fertiliser.

The following section details the key operating elements of a typical Ni refinery.

Sulphur Stockpile

Sulphur (S) is used in the H_2S production process whereby H_2 gas is added to molten S in a reactor to produce H_2S. S would normally be stored on site in a stockpile located near the H_2S Plant. Front end loaders are then used to transport the S to the required location.

Acid Plant and Storage Facility

The purpose of the acid plant is to supply a nickel refinery with H_2SO_4 acid and steam. To ensure a buffer volume, this is usually done via an acid storage facility.

The acid plant is essentially a gas handling and processing plant, which produces H_2SO_4 acid and steam. Generally some of the acid produced is used for gas treatment within the plant.

H_2SO_4 acid plants produce H_2SO_4 acid from molten S, air and water via the two intermediate products SO_2 and SO_3. The initial stage of the S burning produces large quantities of SO_2 which is then converted into SO_3. SO_3 then undergoes further processing to produce H_2SO_4 acid. The three chemical reactions involved in the production of H_2SO_4 acid from S can be summarised into: combustion, conversion and absorption.

- Combustion: conversion of S to SO_2. SO_2 is produced by burning S. The resulting SO_2 is then purified using a small portion of the H_2SO_4 acid produced.
- Conversion: Conversion of SO_2 to SO_3. Industrially, SO_3 is made by the Contact Process. The purified SO_2 is oxidised over a catalyst by atmospheric O_2 at between 400 - 600°C.
- Absorption: Absorption of SO_3 is carried out in an Absorbing Tower, which consists of a vertical vessel with ceramic packing, which is continuously irrigated with H_2SO_4 acid. The SO_3 rich gas enters the bottom of the tower and flows up through the packing where it countercurrently contacts the down flowing acid and the SO_3 is absorbed, increasing the acid concentration. Water is added to the absorption circuit to reduce the concentration and the resulting excess acid is removed as product acid.

NH_3 Storage Facility

NH_3 is used in the dissolution part of the Ni Refinery process. Large supplies of NH_3 would normally be stored and distributed on a Ni Refinery site, however since it is assumed that a dedicated NH_3 production facility would be located in the KIP, NH_3 storage in the Ni Refinery would be considerably less than the average storage quantities considered for such a site.

NH_3 is used for:

- The preparation of Ni and Co solutions prior to H_2 reduction;
- Precipitation of residual iron from a mixed sulphide leach solution; and
- Control of pH during solvent extraction.

Liquid anhydrous NH_3 would typically be stored under pressure in horizontal tanks at 25°C and 10 barg.

H_2S Plant

H_2S is required in the Ni Refining process to remove metals such as copper and cobalt which are components of the Ni matte feedstock.

For production of H_2S, S is normally melted and filtered and pumped to the H_2S plant in a molten state. H_2, regulated at a high pressure, is continuously fed to a reactor containing a controlled level of molten S. The S is pumped into the top of a quench tower where it cascades through to the reactor and reacts with rising H_2 gas.

The gas rises through the quench tower and is cooled as it heats the falling S. H_2S gas produced, leaves the top of the tower and is cooled further. Any entrained S remaining in the gas is removed and the H_2S is then distributed to the Ni Refinery. S from the bottom of the H_2S reactor flows through a cooler to recirculation pumps. The cooler is incorporated to remove the heat generated during the formation of H_2S. The recirculation pumps then transfer the S to the top of the quench tower.

Generally a H_2S plant operates continuously at a rate of production determined by the downstream consumers of the H_2S.

H_2 Plant

H_2 is used as a feedstock for the H_2S plant as explained above. At temperatures around 1,000°C, in the presence of a metal based catalyst, steam reacts with NG to produce H_2 and CO gas.

It is not uncommon for site based H_2 synthesis plants to be owned and operated by a separate entity.

Using a Pressure Swing Adsorption (PSA) plant, high, medium and low pressure H_2 gas can be produced. High pressure H_2 gas is typically used in the H_2 reduction process, medium pressure H_2 is sent to the H_2S plant, and low pressure H_2 may be used downstream in the production of Co.

The typical design of a H_2 synthesis plant includes the following process steps:

1. Preheating of the NG feed;
2. The removal of S components from the NG feed (desulphurisation);
3. Steam reforming of NG and the production of syngas (a H_2 and CO mixture);
4. Cooling the syngas and subsequent conversion of CO to CO_2 via the Shift reaction;
5. Removal of CO_2;
6. Purification of H_2 (to approximately 99.9% H_2);
7. Use of both the NG feed and H_2 produced as fuel gas to supply heat to the steam reforming process; and
8. Recovery of the excess heat of the steam reforming process by generating steam to feed the process.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Ni Refinery, Acid Plant, H_2S production and distribution and the H_2 Plant are as follows:

Assumptions for the Ni Refinery:

- The plant will produce 20,000 tpa nickel and 2,500 tpa cobalt;
- A two week supply of S is stored in the S stockpile, equivalent to approximately 25,000 t;
- A two week supply, of H_2SO_4 is stored on site equivalent to approximately 70,000 t;
- The acid storage facility would store approximately 5,000 t of H_2SO_4; and

- Anhydrous NH_3 is stored in two pressurised horizontal storage bullets, each capable of storing 120 m^3.

Assumptions for the Acid Plant:

- The Acid Plant is assumed to have been designed to produce 5,000 t of liquid H_2SO_4 per day at an effective concentration of 100% by volume; and
- Toxic exposure associated with a SO_2 or SO_3 release is deemed the primary hazard.

Assumptions for H_2S production and distribution:

- The H_2S Plant is assumed to have been designed to produce 60 t per day. H_2S produced by the plant is 100% pure;
- No H_2S is stored on site, and only process volumes make up inventories; and
- Toxic exposure associated with a H_2S release is deemed the primary hazard.

Assumptions for H_2 Plant:

- The H_2 plant (Synthesis Plant, PSA vessels and storage and distribution system) has a total inventory of 145 m^3 of H_2, divided as detailed in **Appendix E**; and
- Flammable atmospheres, and fire and explosion associated with a H_2 release are deemed the primary hazards.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.10 DRI Plant

DRI is a product of the direct reduction of iron ore by a reducing gas produced from NG or coal. The reducing gas is a mixture of H_2 and CO which acts as reducing agent. The process of reducing the iron ore in solid form (i.e. lumps, pellets or fine dust) is called direct reduction.

Direct reduction has been developed to overcome some of the difficulties of conventional steel making, such as highly polluting coke ovens and sintering plants, and the high capital costs relating to the economy of scale of such plants. DRI is successfully manufactured in various parts of the world employing reducing gases produced from either NG or coal.

Iron ore is reduced in solid state at approximately 1,000°C. Although this is generally a more expensive process than using a conventional process, such as a blast furnace, there are several factors which can make it economical:

- DRI does not require sintering and is richer and thus higher grade than pig iron, and an excellent feedstock for the electric furnaces used by mini mills, meaning that lower grades of scrap can be used for the rest of the charge.
- The DRI process is effective even when NG contaminated with inert gases is used as feedstock for the reducing gas. This negates the requirement to remove these gases.
- Supplies of powdered iron ore and NG are both readily available in Western Australia, avoiding high transport costs.

Assumptions for this QRA

Assumptions made in the course of the QRA for the DRI Plant are as follows:

- The proposed DRI plant is assumed to have been designed to produce 2.5 million tpa of DRI;
- Plant has a NG pipeline connection to a mains supply of NG, and a small store of LPG to provide fuel gas in the event of a temporary shortage of NG supply;
- On-site store of LPG consists of two 35 t (60 m^3) horizontal pressurised storage bullets and associated pipework; and
- Flammable atmospheres, and fire and explosion associated with a hydrocarbon release are deemed the primary hazards.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.11 Sodium Cyanide Plant

NaCN is used as a raw material in the chemical and pharmaceutical industries, for the formation of poly methyl methacrylates monomers, for electroplating and refining metals such as gold and silver. In Australia it is used primarily as a reagent in the Carbon in Leach and Carbon in Pulp methods of extracting gold from its ore. Location of a NaCN plant in the KIP would reduce the need for transport of this material from other producers.

NaCN is synthesised from a HCN precursor which is formed as a result of a reaction between NH_3, air and NG. The synthesis process involves only very small amounts of HCN, which are very quickly converted into NaCN. It is not uncommon for this process to be operated under vacuum conditions to ensure that the process does not impact on the environment

NH_3, O_2 from the air and NG, after thorough mixing and filtering are fed to reactors, and within these reactors the mixture contacts several layers of catalyst, operating at approximately 1,100 °C. The catalyst accelerates the combination of the NG and NH_3 to produce HCN gas, water and some waste gases.

The weak acid HCN is then reacted with liquid NaOH in an absorber to produce a liquid NaCN solution. The toxic, corrosive product is then processed into a solid by crystallization, separation, shaping and drying.

After manufacture, NaCN is typically stored in large storage tanks, isolated from strong acids in a dry and well ventilated area, before being transported to consumers.

Assumptions for this QRA

Assumptions made in the course of the QRA for the NaCN Plant are as follows:

- The plant will produce 150,000 tpa of NaCN (30% w/w liquid);
- 8,000 t of liquid NaCN is present in process or temporary storage;
- 5,000 t of solid NaCN is stored on site;
- Approximately 40 t of anhydrous liquid NH_3 for the process will be stored on site as a back-up for unplanned supply issues;
- Approximately 5,000 t of liquid NaOH will also be stored on site and a NG supply would be available via a connection to main pipeline;

- HCN is not stored, it is an intermediate product and is present in process under negative pressure conditions, in quantities of the order of 1 kg only; and
- Toxic exposure associated with a NH_3 release is deemed the primary hazard.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.12 Fuel Terminal

Typically fuel (LPG, Unleaded Petrol (ULP), Diesel, Biodiesel, etc.) for industrial operations is received from a refinery or from tank ships and is transferred to a site for storage in large tanks. The process of transfer is dependent on the type of fuel. The Fuel Terminal is an area where there is medium volume storage of flammable and combustible liquids in both horizontal and vertical tanks.

The typical substances to be stored are diesel fuel, ULP, LPG, Diesel, Biodiesel and Industrial solvents.

Normally LPG, ULP, Diesel, Biodiesel are predominantly used for distribution via road to surrounding service stations or much smaller localised fuel storage tanks on individual sites. Industrial solvents are typically transported in small amounts, via road, to sites requiring them on the estate.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Fuel Terminal are as follows:

- The Fuel Terminal is assumed to have an annual throughput of approximately 300,000 m^3/pa with storage tank inventory levels as illustrated in **Table 5.4** below; and
- Flammable atmospheres, and fire and explosion associated with a hydrocarbon release are deemed the primary hazards.

Table 5.4 Assumed Fuel Terminal Tank Storage Inventories

No. Of Tanks	Material	Storage Capacity (m^3)
2	ULP	25,000
4	ULP	12,400
2	Ethanol	5,000
1	Diesel	12,400

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.13 Ti Metal Plant

Ti is a light, transition group metal with a high tensile strength and excellent corrosion resistance properties. It can be alloyed with iron, aluminium, vanadium, and molybdenum to produce strong lightweight alloys for; aerospace, military, industrial processing including chemicals and petro-chemicals, desalination plants, automotive parts, medical and dental instruments, and sporting goods.

Ti metal is produced commercially using the Kroll process. TiO_2 is first converted to $TiCl_4$ via the first stage of the chloride process. The resulting $TiCl_4$ is condensed and purified by distillation, and then reduced with 800°C molten Mg in the presence of Ar to form Ti metal and $MgCl_2$. This is then is separated into Mg metal and Cl_2 and then recycled to begin the process again.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Ti Metal Plant are as follows:

- For the purposes of this QRA the proposed Ti Metal plant is assumed to be designed to manufacture 10,000 tpa;
- The plant will store a 1 week supply (750 t in 3 x 250 t vessels), of $TiCl_4$ as buffer storage in vertical fixed roof tanks at 75 °C and atmospheric pressure. Although it is typical for some Ti metal plants to store much greater volumes of $TiCl_4$ than this, this inventory is considered sufficient and realistic due to the proximity to a pigment plant, in the KIP, which can supply this raw material directly; and
- Toxic exposure associated with a $TiCl_4$ release is deemed the primary hazard.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.14 Ammonium Nitrate Storage

The AN storage facility at the KIP will store AN, ready for distribution where required. AN would typically be stored in solid form. AN for explosives use, either in prills or granules, is characterised by low bulk density (700 to 800 kg/m^3) and high porosity. The high porosity helps to increase sensitivity to detonation, and facilitates oil absorption for Ammonium Nitrate Fuel Oil production.

The fertiliser-grade AN has contrasting characteristics to explosives grade AN, with high density (around 1000 kg/m^3) and low porosity. High density AN does not absorb contaminants as readily and has a much greater resistance to detonation.

The proposed AN storage facility for the KIP comprises a mixed grade AN store.

Assumptions for this QRA

Assumptions made in the course of the QRA for the AN storage facility are as follows:

- 20,000 tpa of AN are stored at the facility; and
- All AN is in solid form.

An explosion is deemed the likely hazard from AN storage, however for this to take place, deliberate detonation is necessary. Security measures in place ensure that the likelihood of this event occurring is considerably low and therefore, for the purposes of this QRA, no hazards were identified with the AN storage facility.

5.3.15 Oil Refinery

Oil refineries typically process crude oil feedstock and produce various petroleum products. The products are generally shipped from the oil refinery for use in everyday life as fuel for heating, industry and transport or sent for further processing at a petrochemical facility. Processing involves separation of the feedstock into various fractions and subsequent conversion and purification of these fractions into a variety of specialty products. Typical final refined products stored and shipped from such a site include:

- ULP, Aviation Gasoline (AVGAS), Kerosene;
- Diesel fuel;
- Ethanol – an alcohol used as a chemical feedstock;
- Asphalt road base; and
- Other solvents, lubricants and fuel oils.

In addition to the large storage volumes of the aforementioned finished refined products, oil refineries typically store and use Crude Oil, H_2 and HF as raw materials.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Oil Refinery are as follows:

- The assumptions regarding size and inventory levels for the Oil Refinery modelled for the KIP are based directly on ERS experiences with a similar sized facility. Storage tank inventory levels were modelled as illustrated in **Table 5-5** below; and

- Flammable atmospheres, and fire and explosion associated with a hydrocarbon release are deemed the primary hazards, along with toxic exposure in the event of a HF release.

Table 5.5 Assumed Oil Refinery Inventories

Tank Number	Material	Storage Capacity (m^3)
2	ULP	200,000
30	ULP	12,500
2	Diesel	100,000
16	Diesel	12,500
2	Kerosene	20,000
4	AVGAS	12,500
2	Crude Oil	200,000
2	Crude Oil	200,000
4	Asphalt Base	60,000
2	HF	10
1	H_2	100

Note: Modelling of HF release behaviour is widely recognised as a complex process, and as such, the following assumption was made:

- For a release of liquid HF, it is assumed the full released inventory is converted into HF gas. This is based on the *Goldfish Trials*, conducted in 1986 by the Lawrence Livermore National Laboratories and the Amoco Oil Company, detailed in the 'HSE Contract Research Report No. 79/1995 (Ref. 7)'. This states that in a series of 6 tests, there was no formation of a liquid pool of HF at the release point.
- "Approximately 20% of the liquid flashed adiabatically to vapour and the remaining 80% of the acid was transported downwind as HF / water vapour aerosol."

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.16 Xanthate Plant

Xanthates are chemical entities most commonly used as flotation reagents for base metal production. They are conventionally made by bubbling CS_2 through a slurry of an appropriate alcohol to give the desired alkyl group. The slurry also includes ground NaOH or potassium hydroxide in a volatile organic solvent.

A typical Xanthate Plant produces sodium isobutyl xanthate (using isobutyl alcohol), sodium isopropyl xanthate (using isopropyl alcohol) and sodium ethyl xanthate (using ethyl alcohol). Most Xanthate plants are capable of manufacturing each type according to customer requirements and operate continuously at a rate of production determined by the customers.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Xanthate Plant are as follows:

- 132 t (165 m^3) of alcohol is stored on-site in fixed roof vertical tanks.
- Isobutyl alcohol is used for this QRA as the majority of xanthates produced in Australia currently are sodium isobutyl xanthates, in reality a variety of alcohols are likely be stored;
- 2 x 15 m^3 isotainers of CS_2, are stored on-site;
- Bund dimensions were assumed to be 15 m x 5 m x 0.5 m for the alcohol loading area, isopropyl alcohol storage area, and CS_2 storage area, with a bund dimension of 25 m x 15 m x 0.5 m for the main process / alcohol storage area;
- Scenarios to be modelled were assumed to be located at the centre of the appropriate bund, e.g. a CS_2 isotainer storage fire was located and modelled at the centre of the storage bund (all scenario locations are detailed in **Appendix E**);
- Burning pool diameters were calculated as shown in **Appendix F**; and
- Flammable atmospheres, and fire and explosion associated with a hydrocarbon release are deemed the primary hazards, along with toxic exposure in the event of a CS_2 fire (SO_2 toxic combustion product).

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.17 Ammonia Plant

Anhydrous NH_3 is consumed in large quantities by diverse industries all over the world. It is used widely as a refrigerant gas, a scrubbing gas in the oil industry, a feedstock for liquid fertilisers, in the synthesis of fabrics, as a constituent of various other widely produced chemical agents, as an additive for industrial and household cleaners, pharmaceutical products, and for pH control in the wastewater industry. It is also used extensively in metallurgical operations within the mineral processing industry, such as the dissolution part of the Ni refining process.

Commercial NH_3 synthesis takes place in large steel reactors, designed to withstand very high pressures and temperatures up to approximately 1,000 barg and 700°C. NH_3 is formed by catalytic reaction of H_2 gas and N_2 gas. N_2 gas for the synthesis process comes from the atmosphere, while most of the H_2 is sourced from a NG steam reformation plant. NH_3 gas is formed, and liquefied by cooling it with water.

Since anhydrous NH_3 is consumed in large quantities by many industries proposed to locate at the KIP, a large volume NH_3 production and storage facility is proposed for the High Density Industrial Loading Case for the estate. This facility would provide a back-up supply of NH_3 for industries such as the Urea Plant, the Ni Refinery, and the Fertiliser Plant. As such the purpose of a large volume anhydrous NH_3 storage area is to store bulk NH_3, and distribute it to the various locations in the estate where it is required.

For NH_3 plants, anhydrous NH_3 is typically stored in liquid form in refrigerated tanks.

Assumptions for this QRA

Assumptions made in the course of the QRA for the NH_3 Plant are as follows:

- The facility is capable of producing approximately 1,100 tonnes per day ;
- NH_3 is stored in 2 x 20,000 t cryogenic refrigerated NH_3 storage vessels;
- Additionally, a 10 m^3 diesel storage tank is located on site for back-up power generation;
- Toxic exposure associated with a NH_3 release is deemed the primary hazard.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.18 Fertiliser Plant

Over 20,000,000 t of AN based fertilizers are produced annually in the world. AN is also an ingredient in the manufacture of explosives used in the mining industry. It is utilised in WA in both of these capacities.

The AN fertilisers are produced via a violent acid / base reaction between NH_3 and HNO_3. For industrial production this is performed using gaseous NH_3 and concentrated HNO_3. The resulting AN “melt” is concentrated using evaporation and then spray dried into “prills” or granules, which are subsequently coated and stored or shipped.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Fertiliser Plant are as follows:

- The Fertiliser Plant is capable of producing 350,000 tpa of AN;
- It will store 200 t of NH_3 in a refrigerated vertical fixed roof tank;
- AN finished product is stored in 2 x 10,000 t silos; and

CH_2O inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.19 LPG Facility

LPG is a mixture of hydrocarbon gases, primarily butane and propane. It is being used increasingly as a fuel in heating appliances and vehicles, and also replacing chlorofluorocarbons as an aerosol propellant and a refrigerant.

LPG is gaseous at normal temperatures and pressures, and thus large volumes require storage under pressure. Since LPG is flammable, a powerful odorant, ethanethiol, is added so that leaks can be detected easily.

Assumptions for this QRA

Assumptions made in the course of the QRA for the LPG Facility are as follows:

- Propane storage includes 3 x 120 m^3 tanks (approximately 3 x 60 t of LPG);
- 3 x 60 m^3 Butane tanks (approximately 3 x 30 t of LPG);
- Small volumes of NH_3 refrigerant and small volumes of ethanethiol; and
- Flammable atmospheres, and fire and explosion associated with a hydrocarbon release are deemed the primary hazards.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.20 Hydrogen Peroxide Plant

H_2O_2 is manufactured using the anthraquinone (Q) auto-oxidation process which involves the catalysis of the reaction of H_2 with atmospheric oxygen using Q as a H_2 carrier. The synthesis loop involves two basic steps; hydrogenation and oxidation, to produce H_2O_2. Hydrogenation of Q produces anthrahydroquinone (AQ). Oxidation of the resulting AQ solution using compressed air leads to the production of H_2O_2. H_2 for the process is obtained from the steam reforming of natural gas. A H_2 plant will exist on site for the production of H_2 from NG.

Assumptions for this QRA

Assumptions made in the course of the QRA for the H_2O_2 Plant are as follows:

- Inventories for the H_2 plant on-site will be similar to the H_2 plant in the Nickel Refinery. The H_2 plant (Synthesis Plant, PSA vessels and storage and distribution system) has a total inventory of 145 m^3 of H_2, divided as detailed in **Appendix E**; and
- Flammable atmospheres, and fire and explosion associated with a H_2 release are deemed the primary hazards.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.21 Lithium Metal Facility

Li containing ore is heated to 1100˚C and crushed and then mixed with H_2SO_4 producing a lithium sulphate (Li_2SO_4) solution. It is then treated with soda ash to form Li_2CO_3. The carbonate is reacted with HCl to convert it to a chloride solution which can then be processed into Li metal by electrolysis. Li metal is produced at the cathode and Cl_2 evolves at the anode.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Ltihium Metal Facility are as follows:

- Cl_2 is produced during the electrolysis stage and is not stored. It is assumed that all Cl_2 produced, is converted to sodium hypochlorite (NaOCl), which has a viable market. In the event of a release through process equipment, approximately 1 t (270 m^3) of Cl_2 is assumed to have the potential of being released; and
- ‘Parts counts’ for the various lines / sections of the process and distribution system are assumed to be similar to those associated with the chlorine storage and distribution section of the Chlor-Alkali facility, in order to maintain the complexity of the system.
- Toxic exposure associated with a Cl_2 release is deemed the primary hazard.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.22 Timber Products Plant

Timber is separated from its bark in a debarking drum, where logs spin and rub against each other until the bark is removed. The bark can be used for fuel or mulch. The debarked logs are sent to a sawmill where they are shaped into boards, planks and beams. The lumber as it is now known, is sorted, stacked and dried in kilns.

Composites, such as plywood and particleboard are also manufactured at the plant. Plywood is made by gluing and pressing together several thin pieces of wood known as veneers. Plywood has an advantage over lumber, in that it shrinks and swells less. Particleboard is formed by mixing wood products with an adhesive and then pressing them together.

It is assumed that a CH_2O plant is located on-site for the manufacture of adhesives and CH_2O based resins. Adhesives and resins are important components for the manufacture of composites. The CH_2O production process involves the reaction of CH_3OH vapour with air over a silver (Ag) catalyst, to form CH_2O.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Timber Products Plant are as follows:

- The CH_2O plant stores approximately 100 t (130 m^3) of CH_3OH in a fixed roof vertical tank; and
- Approximately 1 t of CH_2O is stored on-site.
- Flammable atmospheres, and fire and explosion associated with a CH_3OH release are deemed the primary hazards.

5.3.23 Tantalum Refining Plant

Tantalum (Ta) bearing ore is crushed and concentrated by gravity separation. The concentrate is treated with a mixture of HF and H_2SO_4 acids at elevated temperatures. This causes the Ta and niobium (Nb) within the concentrate to dissolve as a complex fluoride, which can be separated from the impurities.

Organic solvents such as C_6H_{12} are then used for the liquid extraction of the fluoride from aqueous solution. Ta fluoride complexes are extracted separately from the organic solvent with water and precipitated with potassium fluoride (KF) to produce a KF complex. Ta metal powder is then produced by either sodium (Na) reduction of the potassium tantalum fluoride or by the carbon (C) or Al reduction of the oxide of tantalum chloride ($TaCl_5$). The choice of process is based on the specific application and it is therefore assumed that either of the two process routes may be used at the site.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Tantalum Refining Plant are as follows:

- 100 t (130 m^3) of C_6H_{12} is stored in a fixed roof vertical tank; and
- Flammable atmospheres, and fire and explosion associated with a C_6H_{12} release are deemed the primary hazards.

5.3.24 Pulp and Paper Mill

Pulp and paper are manufactured from raw materials containing cellulose fibres, generally wood, recycled paper and agricultural residues. The main steps in pulp and paper manufacturing are raw material preparation, such as wood debarking and chip making, pulp manufacturing, pulp bleaching, paper manufacturing and fibre recycling. After raw wood is debarked and chipped, pulp is manufactured using either a mechanical or a chemical process. Chemical pulps are made by mixing wood chips with caustic soda to produce brownstock. Various bleaching agents such as H_2O_2 are used during the pulp bleaching stage. An alkali, such as NaOH is also necessary in the bleaching process.

5.3.25 Synthetic Rutile Plant

Raw materials are fed into a kiln and heated to change the properties of ilmenite particles. After the ilmenite has been cooked in the kiln, it is cooled. The reduced ilmenite from the kiln is fed into an aerator, a hydro cyclone and drier which changes the properties again, before the final synthetic rutile product is produced.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Synthetic Rutile Plant are as follows:

- 20,000 L of diesel and 7,500 L LPG are stored on-site as fuel supply as well as back-up supply for the plant. This fuel storage inventory is consistent with the existing Simcoa Operations facility.; and
- Flammable atmospheres, and fire and explosion associated with a hydrocarbon release are deemed the primary hazards.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.26 Vanadium Refining Plant

Titaniferrous magnetite deposits undergo crushing, grinding and magnetic separation. The concentrate produced then undergoes salt roasting to produce a water soluble pentavalent state of vanadium. The most favoured Na salt to be used for this process is Na_2CO_3.

The salt is then leached in water as the sodium vanadates produced are very water soluble. The resulting solution is precipitated with $Al_2(SO_4)_3$ and an aluminium metavandate compound is formed. The metavandate compound is calcined to produce a vanadium pentoxide product.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Synthetic Rutile Plant are as follows:

- 20,000 L of diesel and 7,500 L LPG are stored on-site as fuel supply as well as back-up supply for the plant. The fuel storage inventory assumed here is similar to the fuel inventory at Simcoa Operation's existing facility; and
- Flammable atmospheres, and fire and explosion associated with a hydrocarbon release are deemed the primary hazards.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.3.27 Alumina Refinery

The Bayer process is the principal industrial means of refining bauxite to produce Al_2O_3. Bauxite is digested by washing with a hot solution of NaOH, at 175 °C. This converts the Al_2O_3 to $Al(OH)_3$. The other components of bauxite do not dissolve. The solution is clarified by filtering off the solid impurities, resulting in a mixture of solid impurities called red mud. The hydroxide solution is cooled, and the dissolved $Al(OH)_3$ precipitates as a white, fluffy solid. This is then heated (calcined), resulting in $Al(OH)_3$ decomposing to Al_2O_3, and giving off water vapour in the process.

5.3.28 Aluminium Smelter

The Al smelter consists of a large number of pots, (steel containers lined with carbon), in which electrolysis takes place. Al metal is deposited at the bottom of the pots and periodically drained off. Power must be constantly available, since the pots have to be repaired at significant cost if the liquid metal solidifies.

Assumptions for this QRA

Assumptions made in the course of the QRA for the Al Smelter are as follows:

- 20,000 L of diesel and 7,500 L LPG are stored on-site as fuel supply as well as back-up supply for the plant. The fuel storage inventory assumed here is similar to the fuel inventory at Simcoa Operation's existing facility; and
- Flammable atmospheres, and fire and explosion associated with a hydrocarbon release are deemed the primary hazards.

Inventories and process conditions for the various lines / sections of the process, storage and distribution systems as used for the risk modelling are provided in **Appendix E**.

5.4 Hazards Associated with the Materials Handled

The main materials assumed to be processed, stored or handled at the KIP for the purpose of this QRA, and their inherent hazardous properties are detailed below in **Table 5-6.**

Table 5.6 Material Physical and Hazardous Properties

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
Ammonia anhydrous.	Clear colourless liquefied gas. Distinctive Sharp, irritating and penetrating odour. Pungent, suffocating. Soluble in water.	Atmospheric boiling pt = -33.4^{o}C Specific Gravity (SG) of liquid = 0.674 at 20^{o}C Vapour pressure = 48 kilopascals (kPa) at (@) 25^{o}C Lower Flammability Limit (LFL) = 15 % Upper Flammability Limit (UFL) = 28 % Autoignition temp = 651 ^{o}C Relative vapour density: 0.6 (air = 1) Immediately Dangerous to Life and Health (IDLH) = 300 parts per million (ppm) Emergency Response Planning Guide (ERPG)-1 = 25 ppm ERPG-2 = 200 ppm ERPG-3 = 1,000 ppm	In enclosed spaces (e.g. vessels, closed workshops) NH_3 vapour may be flammable / explosive, but requires significant heat to initiate combustion. Ammonia produces oxides of N_2 and water vapour on normal combustion in air.	Toxic by inhalation - pulmonary oedema up to 48 h after severe exposure - could be fatal. May be fatal if inhaled in large quantities. Anhydrous ammonia, liquid and vapour, is highly irritant and corrosive to exposed tissues and to mucous membranes of the eyes and respiratory tract. Vapours in the presence of moisture may cause irritation of the skin. May produce severe burns to the skin and permanent damage to the eyes.
Ammonium Nitrate.	White solid. Soluble in water.	Solubility in water: 119 g/100 ml (0 °C); 190 g/100 ml (20 °C); 286 g/100 ml (40 °C); 421 g/100 ml (60 °C); 630 g/100 ml (80 °C); and 1024 g/100 ml (100 °C).	Explosive – velocity 5,270 m/s.	Main aspect is explosive nature of AN.
Aviation gasoline.	Clear Liquid, coloured with blue or green dye with petroleum odour.	Atmospheric boiling pt = 60 – 170^{o}C. SG = 0.65 – 0.75 at 15^{o}C (liquid). Vapour pressure = 0.38 – 0.49 bar @ 38°C. LFL = 1.2%, UFL = 7.0%. Flash Point = -46^{o}C (minimum, Tagliabue closed-cup test). Autoignition temp = 440^{o}C.	Use water fog, foam, dry chemical or CO_2 to extinguish flames. For fires involving this material, do not enter any enclosed or confined fire space without proper protective equipment, including self-contained breathing apparatus.	Contains benzene, toluene and organic lead. Irritating to skin and eyes. Harmful if swallowed. Contact with liquid or vapour may cause mild irritation to the eyes. Prolonged or repeated contact may cause skin irritation. Exposure to mist or vapour at concentrations well above the

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
				occupational exposure limits can irritate the nose, throat, respiratory tract and lungs and cause central nervous system depression.
Butane.	Colourless gas, odourless (in pure state).	Atmospheric boiling pt = 0.5°C Relative Vapour density = 2.07 SG = 0.75 at 15°C (liquid) LFL = 1.8%; UFL = 8.4% Flash point = -73.9°C Autoignition temp = 420°C	Extinguish fire with foam, dry chemicals, carbon dioxide Water may be ineffective Vapour flashback may occur	Irritating to skin and eyes Asphyxiant if breathed
Carbon Disulphide.	Clear colourless / light yellow. Strong disagreeable odour. Sinks in water. Slightly soluble in water.	Atmospheric boiling pt = 46°C. SG = 1.26 at 20°C. Vapour pressure = 40 kPa @20°C. LFL = 1%, UFL = 50%. Flash Point = -30 °C. Autoignition temp = 90 °C. Relative vapour density = 2.67	Extinguish fire with dry chemicals, carbon dioxide or other inert gas. Foam ineffective. Cool and blanket with water spray. Vapour flashback may occur. Produces SO_2 upon combustion in air.	Irritating to skin and eyes. Harmful if swallowed. Toxic combustion product SO_2.
Carbon Dioxide	Gas. Colourless with mild sweet odour.	Vapour density = 1.873 kg /m^3. Vapour pressure = 5090 kPa @15°C. Specific Gravity = 1.53.	Non flammable.	Asphyxiant if breathed in an oxygen deficient atmosphere.
Carbon Monoxide	Gas. Colourless and odourless.	Vapour density = 0.968 kg /m^3. Vapour pressure = 760 mmHg @-191°C. Water solubility = 2.3% @ 20°C.	Flammable gas. Extinguish fire with foam, dry chemicals, carbon dioxide. Vapour / air mixtures are explosive. Containers may rupture or explode if exposed to specific heat.	Harmful if inhaled, blood damage, difficulty breathing.
Chlorine.	Light greenish-yellow gas	Melting point = -101 °C.	Non flammable.	Toxic by inhalation, ingestion and through skin contact. Inhalation can

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
	with an irritating odour.	Boiling point = -34 °C. Vapour density = 2.98. Vapour pressure = 5.8 bar at 20 °C. Specific gravity = 1.47 at 0 °C. Critical temperature = 144 °C.	Stable. Incompatible with reducing agents, alcohols.	cause serious lung damage and may be fatal. 1000 ppm (0.1%) is likely to be fatal after a few deep breaths, and half that concentration fatal after a few minutes. May irritate or burn skin. OEL (8hr TWA) 1 ppm.
Diesel.	Oily liquid. Pale yellow / orange. Lube or fuel oil odour. Floats on water.	Atmospheric boiling pt = 180 – 380°C. SG = 0.84 at 15°C (liquid). Vapour pressure = <0.1 kPa @20°C. LFL = 0.7%, UFL = 5.0%. Flash Point = 65.6°C (minimum, closed-cup test). Autoignition temp = 176 – 329°C. Burning rate = – 4 mm/minute (min).	Extinguish fire with foam, dry chemicals, carbon dioxide. Diesel vapours may be ignited rapidly when exposed to sources of ignition including heat, sparks and flame. In confined spaces, a vapour and air mixture can create an explosion hazard. Combustible liquid.	Irritating to skin and eyes Harmful if swallowed Contact with liquid or vapour may cause mild irritation to the eyes. Prolonged or repeated contact may cause skin irritation. Exposure to mist or vapour at concentrations well above the occupational exposure limits can irritate the nose, throat, respiratory tract and lungs and cause central nervous system depression.
Ethanol.	Volatile watery liquid. Colourless. Characteristic odour. Soluble in water.	Atmospheric boiling pt = 78°C. SG = 0.79 at 20°C. Vapour pressure = 1.5 kPa at 21°C. LFL = 3.3%, UFL = 19%. Flash Point = 13 °C. Autoignition temp = 365 °C.	Extinguish fire with foam, dry chemical or carbon dioxide. Water may be ineffective.	Not harmful.
Hydrogen.	Gas. Colourless and odourless.	Melting point = -259.2 °C. Boiling point = -252.8 °C. Relative vapour density = 0.07. Lower Explosive Limit (LEL) = 4%,Upper Explosive Limit (UEL) = 75%. Auto ignition temperature = 560 °C.	Flammable, may form explosive mixture with air. All known extinguishants can be used. If possible, stop flow of product. Move away from container and cool with	No known toxicological effects from this product.

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
			water from a protected position. Do not extinguish a leaking gas flame unless absolutely necessary. Spontaneous / explosive re-ignition may occur. Extinguish any other fire. In confined space use self-contained breathing apparatus.	
Hydrogen Chloride.	Gas. Colourless with an irritating odour.	Melting point = -114.2 °C. Boiling point = -85.1 °C. Vapour density = 1.64 grams / litre. Vapour pressure = 613 pounds per square inch at 21.1 °C. Critical pressure = 82.6 atmospheres. Critical temperature = 51.6 °C. Water solubility = 82.3 grams /100grams water at 0 °C.	Non flammable. Extreme heat or contact with metals can release flammable hydrogen gas. In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode. Structural firefighter's protective clothing is ineffective for fires involving hydrochloric acid. Stay away from ends of tanks. Cool tanks with water spray until well after fire is out.	Corrosive. Inhalation of vapours can cause coughing, choking, inflammation of the nose, throat, and upper respiratory tract, and in severe cases, pulmonary oedema, circulatory failure, and death. Vapours are irritating and may cause damage to the eyes.
Hydrogen cyanide.	Colourless or pale blue liquid, or colourless gas, (depending upon temperature) with a bitter almond odour.	Melting Point = 25.6 °C. Atmospheric boiling pt = -14°C. SG = 0.6899 at -18°C (liquid). Vapour pressure = 0.827 bar at 20 °C.	Highly Flammable. Severe fire hazard. Containers may rupture or explode if exposed to heat. Vapour / air	Very Toxic. Hydrogen Cyanide may be fatal if inhaled. Vapours may deaden sense of smell, decreasing the possibility of detection prior to fatal

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
		Relative vapour density: 0.941. Flash point = -18 °C. LFL = 5.6%, UFL = 40%. Autoignition temp = 538°C.	mixtures are explosive. Gas or vapour is lighter than air. Vapours or gases may ignite at distant ignition sources and flash back. EXTINGUISHING MEDIA: Let burn unless leak can be stopped immediately. Large fires: Use regular foam or flood with fine water spray. Move container from fire area if it can be done without risk. Withdraw immediately in case of rising sound from venting safety device or any discoloration of tanks due to fire. Cool containers with water spray until well after the fire is out. Keep unnecessary people away, isolate hazard area and deny entry. For tank, rail car or tank truck, evacuation radius: Evacuation radius: 800 meters (1/2 mile). Do not attempt to extinguish fire unless flow of material can be stopped first. Flood with fine water spray. Do not scatter spilled material with high-pressure water streams. Cool containers with	concentrations. Symptoms of poisoning appear within seconds to minutes after breathing vapours. Massive doses may produce, without warning, sudden loss of consciousness and prompt death from respiratory arrest. With smaller but still lethal doses, the illness may be prolonged for one or more hours. Vapours may irritate the eyes and HCN may be fatal if liquid or vapour is absorbed through the skin.

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
			water. Apply water from a protected location or from a safe distance. Avoid inhalation of material or combustion by-products. Stay upwind and keep out of low areas.	
Hydrogen Fluoride.	Colourless fuming liquid with an acrid odour. Infinitely soluble.	Melting point = -36 °C. Boiling point = 108°C. Vapour density = 1.97. Vapour pressure = 25 mm Mercury (Hg) at 20 °C. SG = 1.15 – 1.18.	Not considered to be a fire hazard. Fire may produce poisonous or irritating gases. Violent exothermic reaction occurs with water. Sufficient heat may be produced to ignite combustible materials. Reacts with metals forming flammable H_2 gas. Keep upwind of fire. Use water or CO_2 on fires in which HF is involved. Halon or foam may also be used. In case of fire, the sealed containers can be kept cool by spraying with water. In the event of a fire, wear full protective clothing and self-contained breathing apparatus with full facepiece operated in the pressure demand or other positive pressure mode. Avoid getting water in tanks or drums; water can cause generation of heat	Exposure to hydrofluoric acid can produce harmful health effects that may not be immediately apparent. Severely corrosive to the respiratory tract. May cause sore throat, coughing, laboured breathing and lung congestion/inflammation. May cause sore throat, abdominal pain, diarrhoea, vomiting, severe burns of the digestive tract, and kidney dysfunction. Corrosive to the skin. Skin contact causes serious skin burns which may not be immediately apparent or painful. Symptoms may be delayed 8 hours or longer. The fluoride ion readily penetrates the skin causing destruction of deep tissue layers and even bone. Corrosive to the eyes. Symptoms of redness, pain, blurred vision, and permanent eye damage may occur. Intake of more than 6 mg of fluorine per day may result in fluorosis, bone and joint damage. Hypocalcemia and hypomagnesemia can occur from

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
			and spattering. In contact with air, the acid gives off corrosive fumes which are heavier than air.	absorption of fluoride ion into blood stream.
Hydrogen Sulphide.	Gas. Colourless. Strong odour of rotten eggs.	Melting point = -85°C. Boiling point = -60°C. Vapour Pressure = 2716 kPa @ 37.8°C. Relative vapour density = 1.19. Specific gravity = 0.993 (liquid at BP), 1.539 g/L at 0°C, 760 mm Hg (gas). Flash point = -82°C. LEL = 4.3 %,UEL = 46 %. Auto ignition temperature = 260°C.	Flammable, may form explosive mixture with air. Sulphur oxides formed when burned. Vapours are heavier than air and may travel to an ignition source and flashback. Shut off source, if possible. Water or spray may be used to cool exposed containers and equipment. Use NIOSH/MSHA approved self-contained breathing apparatus. Use Dry chemical, foam or CO_2.	Highly toxic - may be fatal if inhaled. Inhalation of a single breath at a concentration of 1,000 ppm (0.1%) may cause coma. Corrosive when moist. Skin contact may cause burns. There is a rapid loss of sense of smell on exposure to gas concentrations above 150 ppm, and this means that the extent of exposure may be underestimated. Perception threshold ranges from 0.5 ppt to 0.1 ppm. Irritant. Asphyxiant. ERPG1 = 0.1 ppm. ERPG2 = 30.0 ppm. ERPG3 = 100.0 ppm.
Isobutyl Alcohol.	Volatile watery liquid. Colourless. Characteristic odour. Soluble in water.	Atmospheric boiling pt = 78°C. SG = 0.79 at 20°C. Vapour pressure = 1.5 kPa at 21°C. LFL = 3.3%, UFL = 19%. Flash Point = 13 °C. Autoignition temp = 365 °C.	Extinguish fire with foam, dry chemical or CO_2. Water may be ineffective.	Not harmful.
Kerosene.	Clear Liquid, coloured with blue or green dye with petroleum odour. Insoluble.	Atmospheric boiling pt = 145 – 300°C. SG = 0.785 – 0.8 at 15°C (liquid). Vapour pressure = < .0093 bar @ 25 °C. LFL = 0.7%, UFL = 6.0%. Flash Point = 38 - 44°C . Autoignition temp = 210°C.	Use CO_2, dry chemical or foam. Under fire conditions this product may emit toxic and / or irritating fumes including carbon monoxide and carbon	Inhalation of product vapours may cause irritation of the nose, throat and respiratory system. May cause symptoms of drowsiness or narcosis from inhalation of high vapour concentrations. Harmful: may cause lung damage if

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
			dioxide. Fire fighters should wear full protective clothing and self-contained breathing apparatus. Use water to cool fire-exposed containers. If a leak or spill has not ignited, use water spray to disperse the vapours and to provide protection for persons attempting to stop the leak. Flammable liquid. May form flammable vapour mixtures with air. All potential sources of ignition (open flames, pilot lights, furnaces, spark producing switches and electrical equipment etc) must be eliminated both in and near the work area. Do NOT smoke. Flameproof equipment necessary in area where this chemical is being used. Nearby equipment must be earthed. Vapour may travel a considerable distance to source of ignition and flash back.	swallowed. Ingestion of this product may irritate the gastric tract causing nausea and vomiting. Ingestion of this product and subsequent vomiting can result in aspiration of light hydrocarbon liquid into the lungs, causing chemical pneumonia and lung damaged. May cause redness, itching and irritation. May be absorbed through the skin. May cause eye irritation, tearing, stinging, blurred vision, and redness.
Liquefied Petroleum Gas. (Propane – butane	Gas. Colourless. Odourless (in pure state).	Atmospheric boiling pt = -40 to -0.5 ^{o}C. Vapour density: 1.5 to 2.07. SG = 0.49 to 0.57 at 15 ^{o}C (liquid). LFL = 1.9%; UFL = 9.5%.	Extinguish fire with foam, dry chemicals, CO_2. Water may be ineffective. Vapour flashback may	Irritating to skin and eyes. Asphyxiant if breathed.

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
mixture).		Flash point -104 to -73.9 °C. Autoignition temp = 420 °C.	occur.	
Methanol.	Clear liquid. Colourless. Mild characteristic alcohol odour. Soluble in water.	Atmospheric boiling pt = 64.7°C. Relative density = 0.791 at 20°C. Vapour pressure = 12.8 kPa at 20°C. LEL = 6%, UEL = 36%. Autoignition temp = 385 °C.	Extinguish small fires with dry chemical or carbon dioxide. Water spray can be used for large fires.	Moderately irritating to skin and eyes. Inhalation can cause irritation to the mucous membranes, headaches, nausea, sleepiness and confusion
Natural gas. (primarily methane with 5-10 % ethane).	Gas. Colourless. Odourless (unless odorised – mercaptan).	Atmospheric boiling pt = -162°C. SG = 0.42 at -162°C (liquid). Vapour pressure = 4,000 kPa at -95°C. LFL = 3.8%, UFL = 17%. Flash Point = -180 °C. Autoignition temp = 482 °C. Relative vapour density = 0.55.	Gas fires should not be extinguished unless flow of gas can be immediately stopped. Shut off gas source and allow gas to burn out. Vapour flashback.	Irritating to skin and eyes. Asphyxiant if inhaled.
Propane.	Colourless gas, odourless (in pure state).	Atmospheric boiling pt = -0.42°C. Vapor density: 1.52. SG = 0.51 at 15°C (liquid). LFL = 2.4%; UFL = 9.6%. Flash point -104°C. Autoignition temp = 494 - 549°C.	Extinguish fire with foam, dry chemicals, CO_2. Water may be ineffective. Vapour flashback may occur.	Irritating to skin and eyes. Asphyxiant if breathed.
Sodium cyanide.	Granular or flaky solid with a faint almond-like odour. (Odourless when perfectly dry. Emits odour of hydrogen cyanide when damp).	Melting Point = 563.7 °C. Atmospheric boiling pt = 1496°C. SG = 1.595. Vapour pressure = 0.0013 bar at 817 °C. Relative vapour density = 1.7. Flash point = Not Available.	May be combustible at High Temperatures. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray, fog or foam. Do not use water jet. Dangerous on contact with acids, acid fumes, water or stream. It will produce toxic and flammable vapours of	Very hazardous in case of skin contact (irritant), of ingestion, of inhalation. May be fatal if absorbed through broken skin. Absorbed through skin, Dermal contact, Eye contact, Inhalation, and Ingestion. May cause damage to the skin, eyes and central nervous system (CNS). May cause itching and irritation. May be fatal if inhaled. The substance inhibits cellular

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
			HCN and sodium oxide. Contact with acids and acid salts causes immediate formation of toxic and flammable HCN gas. When heated to decomposition it emits toxic fumes HCN and oxides of nitrogen.	respiration causing metabolic asphyxiation. May cause headache, weakness, dizziness, laboured breathing, nausea, vomiting. May be followed by cardiovascular effects, unconsciousness, convulsions, coma, and death. Ingestion: May be fatal if swallowed. May cause gastrointestinal tract irritation with nausea, vomiting. May affect behaviour and nervous systems (seizures, convulsions, change in motor activity, headache, dizziness, confusion, weakness stupor, anxiety, agitation, tremors), cardiovascular system, respiration (hyperventilation, pulmonary oedema, breathing difficulty, respiratory failure), cardiovascular system (palpitations, rapid heart-beat, hypertension, hypotension). Massive doses may produce sudden loss of consciousness and prompt death from respiratory arrest.
Sulphur.	Solid. Yellow powder or fused solid, or amber to yellow crystals. Faint odour.	Melting point = ca. 116°C (depending upon form). Boiling point = 445°C. Specific Gravity = 2.07 at 20°C. Relative vapour density (air = 1) =8.8. Flash point = 207°C. Auto ignition temperature = 232°C. Explosive limits, dust in air, grams /m^3 = LEL - 35, UEL – 1400.	Fire hazard when exposed to heat or flame. Sulphur dust suspended in air ignites easily, and can cause an explosion in confined spaces. Use water spray to blanket fire, cool fire exposed containers, and to flush non-ignited spills	Sulphur is essentially non-toxic. Sulphur dust is an eye irritant. Avoid contact with eyes, especially contact wearers. Prolonged inhalation may cause irritation of the respiratory tract. Ingested sulphur is converted to sulphides in the gastrointestinal tract, and ingestion of 10 to 20 grams has caused irritation of the

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
			or vapours away from fire. Solid streams of water should not be used because of possibility of dispersing dust clouds of sulphur in air. In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full face-piece operated in the pressure demand or other positive pressure mode.	gastro intestinal tract and renal injury. Sulphur oxides are formed when sulphur burns - refer to SO_2 for toxic effects.
Sulphur Dioxide.	Gas. Colourless. Choking / suffocating odour.	Melting Point = -75.51°C. Boiling Point = -10.06°C. Relative vapour density = 2.26.	Not flammable. Remove sulfur dioxide containers from fire zone if possible. Apply water to cool containers unless there is a SO_2 leak. In presence of SO_2, use self-contained breathing apparatus and full protective clothing. Gas tight suits are required in extreme (>1000 ppm) concentrations of SO_2. Evacuate residents who are downwind of fire. Prevent unauthorized entry to fire area. Dike area to contain runoff and prevent contamination of water sources. Neutralize runoff with lime, soda ash or other suitable	Corrosive and irritating to the eyes. Contact with the liquid or vapour causes painful burns and ulcerations. Burns to the eyes result in lesions and possible loss of vision. Corrosive and irritating to the upper and lower respiratory tract and all mucosal tissue. ERPG1 = 0.3 ppm. ERPG2 = 3.0 ppm. ERPG3 = 15.0 ppm.

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
			neutralizing agents. Cool containers that are exposed to flame with streams of water until fire is out.	
Sulphur Trioxide.	Liquid/vapour. (Fuming oily liquid.).	Melting Point = 16.8°C. Boiling Point = 45°C. Specific Gravity = 1.92. Vapour pressure = 280 mm Hg at 20°C. Relative vapour density = 2.8.	Not flammable. Do not use water.	Causes severe skin irritation and burns. Causes severe eye irritation and burns. May cause irreversible eye injury. Harmful if swallowed. May cause permanent damage to the digestive tract. May cause severe irritation of the respiratory tract and mucous membranes with sore throat, shortness of breath, chemical pneumonitis, and delayed lung oedema. Inhalation may be fatal. ERPG1 = 0.6 ppm. ERPG2 = 3.0 ppm. ERPG3 = 9.0 ppm.
Titanium tetrachloride.	Colourless to yellowish liquid with a penetrating acidic odour.	Melting point = -24.1 °C. Boiling point = 136.4 °C. Vapour density = 6.6. Vapour pressure = 10 mm Hg at 20 °C. SG: 1.73.	Stable. Reacts violently with water. Incompatible with moisture, ammonia, amines, alcohols, potassium and other chemically active metals.	Poison. Harmful if swallowed, inhaled or absorbed through the skin. Corrosive - causes burns. Very destructive of mucous membranes. May cause permanent eye damage if splashed into the eyes. Inhalation: Corrosive. Extremely destructive

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
				to tissues of the mucous membranes and upper respiratory tract. Symptoms may include burning sensation, coughing, wheezing, laryngitis, shortness of breath, headache, nausea and vomiting. Inhalation may be fatal as a result of spasm inflammation and oedema of the larynx and bronchi, chemical pneumonitis and pulmonary oedema. Inhalation can cause permanent lung damage. Ingestion: Corrosive. May cause burning pain in throat, abdominal pain, nausea, and vomiting. Skin Contact: Corrosive. Liquid contact may cause blistering burns, irritation, and pain. Vapours may be severely irritating to the skin. Eye Contact: Corrosive! Vapours are irritating and may cause damage to the eyes. Contact may cause severe burns and permanent eye damage.
Unleaded Petrol.	Volatile watery liquid. Red or purple (depending on dye dosed). Strong odour. Floats on water.	Atmospheric boiling pt = 30-230°C. SG = 0.75 at 15°C (liquid). LFL = 1.4%; UFL = 7.6%. Flash point = <18°C. Autoignition temp = 540°C. Burning rate = 5.8 mm/min.	Extinguish fire with foam, dry chemicals, CO_2. Water may be ineffective. Vapour flashback may occur.	Irritating to skin and eyes. Harmful if swallowed.
Urea	White crystalline solid. Almost odourless; may	Atmospheric melting pt = 135 - 137°C. SG = 1.323 (solid).	Slightly flammable to flammable in presence of	Hazardous in case of skin contact (irritant), of ingestion, of inhalation.

Hazardous Substances	Common Characteristics	Properties	Fire Hazard Summary	Toxic Exposure Hazard
	gradually develop slight odour of NH_3, especially in presence of moisture.	Vapour pressure = N/A. LFL = Not Available UFL = Not Available. Flash Point = Not Available. Autoignition temp = Not Available. Relative vapour density = 2.07.	heat. SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray, fog or foam. Do not use water jet.	MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. May cause damage to the following organs: blood, cardiovascular system. Acute Potential Health Effects: Skin: Causes skin irritation. Eyes: Causes eye irritation. Inhalation: Causes irritation of the respiratory tract, nose, and throat, coughing and sneezing. May also affect blood, metabolism and urinary system. Ingestion: Causes digestive (gastrointestinal) tract irritation with nausea, vomiting, and diarrhoea. May affect behaviour (altered sleep time, change in motor activity), cardiovascular system (heart rate), and the brain. May also affect the blood and may cause tumorigenic effects.

5.5 Release Duration

No information was available at the time of this study as to the release detection and ESD systems that would be provided for each plant / facility. Although for certain special cases, for example Cl_2 storage, inherent safety devices and design features have been considered in establishing reasonable and realistic practical limits for release duration when LOC occurs. Therefore, other than where specifically identified and specified, for the purposes of this study the duration of releases has been approximated at 10 min (600 s). This release duration is considered conservative.

Typically, significant releases would be readily detectable:

- As a process upset;
- By detectors in the toxic gas storage areas or reactors (e.g. H_2SO_4, H_2S, NH_3 Plants), with resultant automatic or manual plant shut-down; or
- In the worst case by onlookers or employees on-site, e.g. smoke, flames, cloud with resultant manual plant shutdown.

Minor releases of non-toxic, lighter than air gases that are not quickly detectable (and do not ignite), will dissipate safely to the atmosphere until detected. Therefore 10 min should provide adequate time for detection and inventory isolation, assuming an adequate ESD system is installed.

A release of NH_3 would be readily detectable as it is stored as a liquid, and hence a leak would be visible to personnel before detection by the installed gas detectors. As a gas it is lighter than air, therefore small leaks would dissipate safely into the atmosphere, or until detected by the gas detectors. Note, whilst NH_3 is a colourless gas, upon release of a liquid the latent heat of vaporisation causes the gas to condense water vapour in the air and hence appears as a white fog and for large releases will initially behave as a dense gas. Similarly $TiCl_4$ also stored as a liquid, forms HCl vapour exothermically when released into moist air, which would also result in a visible white cloud.

Cl_2, SO_2, SO_3 and H_2S are heavier than air and hence a release would be readily detectable at ground level either by detectors, manually by operators in the area, or as a process upset. Therefore 10 min should provide adequate time for detection and inventory isolation.

5.6 Release Parameters

5.6.1 Release Locations

Release points (eastings and northings) within the KIP's proposed plant layout were selected for each plant / facility under consideration. Points were selected to mimic the locations of a typical industrial site relevant to each type of installation. The actual release points were chosen based on the areas of greatest concentrations of equipment, e.g. at the centre point of bunded areas and along the path of the pipelines.

5.6.2 Release Height

For the purposes of this study, an approximate release height has been taken for each individual scenario. These approximations are based on available information and measurements taken during previous ERS personnel site visits to similar operations. For all above ground storage vessels, the release height was estimated at 3 metres (m) above ground. This takes into account supporting structure, and civil foundations for large tanks.

5.6.3 Jet Fires

For the purposes of this study all jet fires are assumed to be horizontal which provides greater heat radiation distances for all scenarios (conservative approach).

The inventories used in the model were calculated from volumes, temperatures and pressures of pipelines and vessels as detailed in the **Appendix E** and assumption of instantaneous release of the entire contents has been used in the catastrophic failure scenarios. Actual mass flow rates from different hole-sizes were calculated using *TNO Effects* (Version 7.6.5), as presented in **Appendix E**.

6. HAZARD IDENTIFICATION AND SCREENING ANALYSIS

6.1 General

The industrial processes designated as most likely to contribute to off-site risk levels for the KIP are described in more detail in this section. The descriptions have been separated into three major areas of operation pertinent to the QRA. They are:

- Toxic gas generation, liberation, storage and distribution;
- Flammable or explosive gas storage and distribution; and
- Flammable or explosive liquid or solid storage and distribution.

The hazard identification process involved:

- A review of relevant documentation;
- Previous ERS experience of similar plant hardware; and
- A review of relevant drawings of typical plants / facilities.

Hazards that pose a negligible risk have been screened from further analysis and the following section details the hazards identified and outlines the rationale for screening hazards from further analysis.

General hazards have also been screened from further analysis as they do not represent a significant off-site risk (they do not present a high risk other than to personnel or equipment directly adjacent to the equipment or site that they are present within). Examples of these materials are provided below.

General Hazards with Negligible Off-Site Risk

Almost all industrial sites contain small volumes of common materials, often identified as dangerous goods (DG) under law. Examples of these are ‘industrial solvents’, compressed gases such as acetylene, argon, O_2, N_2 and some cryogenic liquids such as liquid O_2 and N_2. Most sites also contain diesel fuel tanks for fire water pumps, and small vehicles and small LPG cylinders for use as heating fuels. The hazards presented by this storage has been screened from further analysis as typically the volumes of these goods are so low so as to be inconsequential when compared with the hazards that significantly affect the levels of off-site risk.

Additionally these types of plants may also contain various HV installations. The hazards presented by these installations have also been screened from further analysis due to the low potential for off-site impacts.

Finally, several installations described in this report, often contain large volume stores, of other materials, identified as DG under WA law, such as:

- HNO_3, HCl (liquid), H_2SO_4, and other corrosive liquids;
- NaOH, calcium hydroxide, potassium hydroxide, calcium carbonate, and other alkaline liquids; and
- Nuisance and explosive dusts.

The hazards presented by these materials have been screened out for further analysis. It is assumed that industrial sites located at the KIP that store large volumes of corrosive liquids, have appropriate procedures and Personal Protective Equipment (PPE) in place to deal with corrosive liquid spills. Furthermore, off-site risks related to a corrosive liquid spill are considered negligible and therefore not included for analysis in this QRA.

Occupational Hazards

Occupational hazards include those related to trips and falls. These hazards present risks to the on-site workforce and there are no off-site consequences.

6.2 Silicon Smelter (Simcoa Operations)

SiO_2 (silica fume), a by-product of the smelting process is not classified as a DG. The fume is safely vented into a baghouse. Liquefied O_2 is an oxidising agent and will support burning.

The above ground diesel and LPG tanks stored on site contain combustible and flammable liquids respectively. As LPG is flammable, once a release has occurred a number of potential consequences may result, ranging a jet to a flash fire or to an explosion.

Gas releases from holes in high-pressure flammable inventories result in jet flames if ignited. Jet fires tend to have relatively small areas of impact.

Flash fires can result from the release of LPG through the formation of a vapour cloud with delayed ignition and a fire burning through the cloud. A fire can then flash back to the source of the leak and result in a jet fire.

Explosions can occur when a flammable gas cloud in a confined area is ignited. A Vapour Cloud Explosion (VCE) may result in overpressure effects that become more significant as the degree of confinement increases.

A Boiling Liquid Expanding Vapour Explosion (BLEVE) could result from catastrophic failure of equipment. The conditions under which each of these scenarios could occur are described in further detail in **Section 7.2**.

The main hazardous scenarios associated with the storage of diesel are a pool or bund fire, resulting from failure of equipment, LOC and subsequent ignition. **Section 7.2** describes this scenario in further detail. The likelihood of a BLEVE to occur from the catastrophic failure of the diesel tank is low, as the tank would have atmospheric vents and should a pool fire result in a ‘kettle’ scenario the consequences of failure of the tank would result in more fuel being added to the pool fire.

The most significant consequence associated with these fires is thermal radiation, the effects of which are dependent on intensity and duration. The potential for any of the above scenarios to have an offsite impact is dependent primarily on the size of the fire and the distance to the boundary.

Screening Analysis Conclusion:

Jet fires, flash fires, VCEs and BLEVEs from the LPG storage, have been carried forward for further analysis. Pool fires from the diesel storage have also been carried forward for further analysis.

The hazard associated with the storage of liquefied O_2, is screened out from further analysis as a liquefied O_2 release on its own will not have significant off-site impact as it merely acts as an oxidising agent. A liquefied O_2 release could be potentially hazardous in the event of a fire. However, the likelihood of failure of the liquefied O_2 tank along with the failure of the other tank inventories and subsequent fires is considered low and hence not carried forward for analysis.

6.3 Pigment Plant (Cristal Global)

TiO_2 is a white solid that may cause irritation to the skin, eyes and respiratory tract. Long term exposure may cause mild fibrosis (scarring of the lungs).

Pigment plants typically produce and store large volumes of the intermediate product $TiCl_4$ in liquid form. $TiCl_4$, a corrosive liquid under atmospheric conditions, reacts violently with moisture to form HCl gas. The gas has a substantially large coefficient of thermal expansion that can produce large clouds of acidic vapour. Contact with water and metal at the same time can produce H_2 and, if there is ignition, an explosion.

Cl_2 is used for the production of $TiCl_4$, and is obtained directly from a neighbouring Chlor-Alkali facility, with only a small volume of buffer storage on site. The storage volumes of Cl_2 for the purposes of this QRA are assumed to be identical in size to those maintained at the Chlor-Alkali plant. Cl_2 is stored as a liquid under pressure in steel containers within a specifically designed enclosure equipped with various detection and safety devices. If a container leaks, liquid chlorine could be present for a very short time as it evaporates very rapidly.

The TiO_2 plant also uses large amounts of O_2, supplied from nearby BOC gases. Only a small volume buffer of liquefied O_2 is therefore stored on site. The hazard associated with releases of O_2 is its oxidizing nature, which can accelerate the burning rate for combustible materials.

Screening Analysis Conclusion:

As the consequences of an incident involving O_2 are dependent on the presence of a fire, the hazard associated with the storage of liquefied O_2, is screened out from further analysis.

The toxic hazards presented by the storage and handling of Cl_2 and $TiCl_4$ have been carried forward for further analysis.

6.4 Chlor-Alkali Plant (Coogee-Nufarm)

The Chlor-Alkali plant stores NaCl as a raw material and NaOH and liquefied Cl_2 as finished products. Small volumes of H_2 produced at the cathode during electrolysis, are also present. Additionally these types of plants may also have various High Voltage (HV) installations on-site.

There is a potential for release and dispersion of Cl_2 from any Cl_2 storage or distribution system located on-site.

Screening Analysis Conclusion:

Although the chemicals listed above are hazardous, and some are classified as DGs, with the exception of Cl_2, they do not represent a significant off site risk and will not be considered further. NaOH, a corrosive liquid, will have minimal off-site impact in the event of a spill. H_2, though a flammable gas, is only present in small quantities, and therefore screened out from further analysis.

As Cl_2 is toxic by inhalation, ingestion and skin contact and is gaseous under atmospheric conditions, it will be carried forward for further analysis.

6.5 Oxygen and Nitrogen Plant (BOC Gases)

Liquid O_2, N_2 and Ar are stored on-site. The hazard associated with the release of liquid O_2 is its oxidizing nature, which can accelerate the burning rate for combustible materials. Exposure to N_2 or Ar could result in asphyxiation.

Screening Analysis Conclusion:

As the consequences of an incident involving liquefied O_2 are dependent on the presence of a fire, the hazard associated with the storage of liquefied O_2, is screened out from further analysis.

The release of N_2 or Ar gas is not considered to have a significant off-site impact. Upon release, dilution of the gas with air as it travels downwind will reduce the severity of potential consequences such as asphyxiation and therefore the storage of liquefied N_2 and Ar is screened out from further analysis.

This facility will not be carried forward for further analysis.

6.6 Water Treatment Plant (Water Corporation)

The chemicals stored on site are $Al_2(SO_4)_3$, NaOH and Cl_2. NaOH, is a corrosive liquid, whilst $Al_2(SO_4)_3$ has no significant hazards associated with it. .

There is a potential for release and dispersion of Cl_2 from any Cl_2 storage or distribution system located on-site. Cl_2 is toxic by inhalation, ingestion and skin contact.

Screening Analysis Conclusion:

NaOH, a corrosive liquid, will have minimal off-site impact in the event of a release, and is therefore screened out from further analysis, as is $Al_2(SO_4)_3$.

Due to the highly toxic nature of Cl_2, a release could result in significant consequences to the health of personnel within the affected areas. Cl_2 will be carried forward for further analysis.

6.7 Silica Sand Facility (Kemerton Silica Sands)

Silica sand is produced at the facility. Small quantities of heavy minerals such as TiO_2 and Fe_2O_3 are also produced.

Screening Analysis Conclusion:

No hazards have been identified, associated with silica sand, TiO_2 and Fe_2O_3, which are significant for consideration in this QRA. Furthermore, these materials are in solid form, hence minimising their potential off-site impact further. This facility will not been carried forward for further analysis.

6.8 Lime Hydration Plant (Cockburn Cement)

CaO is hydrated with water to form $Ca(OH)_2$ in an exothermic reaction.

Screening Analysis Conclusion:

CaO and $Ca(OH)_2$ storage are not considered to contribute significantly to offsite risk. This facility will not been carried forward for further analysis.

6.9 Urea Plant

Both NH_3 and urea are stored in the Urea Plant. NH_3 is stored in pressurised horizontal bullets.

Due to the highly toxic nature of NH_3, a release could result in significant consequences to the health of personnel within the affected areas.

There is a potential for release and dispersion of anhydrous NH_3 from any NH_3 storage area and its accompanying distribution pipe lines. As the NH_3 is stored and distributed at approximately 10 barg, a release would result in a jet emission, and for conservatism, a horizontal jet release would result in the greatest area being affected.

Repeated or prolonged contact with urea in fertilizer form on the skin may cause dermatitis. Urea irritates the skin, eyes and respiratory tract. High blood concentrations damage body organs. Low concentrations of urea are not particularly dangerous. Urea can cause algal blooms, which subsequently produce toxins, and runoff from fertilisers may result in such blooms.

Urea decomposes when heated above its melting point, producing toxic gases. It reacts violently with strong oxidants, nitrites, inorganic chlorides, chlorites and perchlorates, causing a fire and explosion hazard.

Screening Analysis Conclusion:

Toxic releases from the NH_3 storage vessels have been carried forward for further analysis. NH_3 is also flammable in the range of 16 – 25 % by volume, however due to its highly toxic nature and the resultant health hazards from a release, NH_3 fire / explosion has been screened out from further analysis, whilst the toxic effect from an NH_3 release has been analysed instead.

Since the hazards posed by urea are so slight in comparison to those associated with NH_3 storage and use, urea has been screened from further analysis.

6.10 Nickel Refinery

6.10.1 S Stockpile

S is a Class 4.2 DG and in general is classified as a stable compound. S, if ignited under atmospheric conditions, may form SO_2, a toxic gas. S dust, if confined and ignited may result in an explosion. Large uncontrolled S fires can occur which would require evacuation of any adjacent premises due to potential inhalation of poisonous fumes.

In the event of a S fire, it is common practice to smother the fire using un-reacted solid S. This practice has been found to be effective in controlling S fires. Such methods are usually incorporated in procedures along with other mitigating measures such as a dust suppressing compound being applied to the stockpile to ensure that S fires on site can be contained or eliminated, and to provide ample time for personnel to evacuate the affected area.

Screening Analysis Conclusion:

Due to the relatively remote location of the KIP and the fire mitigation measures assumed (as detailed above), a S stockpile fire has not been considered as a major offsite risk contributor, and as such has not been carried forward for further analysis.

6.10.2 Acid Plant

Acid mist and spray are produced in the Absorbing Towers, which are fitted with special mist eliminators as part of standard design to prevent acid affecting the down-stream equipment.

There is a potential for release and dispersion of gaseous SO_2 and SO_3 from the Acid Plant during the production of H_2SO_4. There is also potential for release of liquid H_2SO_4, as well as the remote possibility of dispersion of gaseous SO_2 and SO_3 from the Acid Storage facility during a spill of H_2SO_4.

The most likely scenarios would be for a toxic release of SO_2 to occur from pipe work or equipment associated with the S burning process, up to the 1st Converter pass (SO_2 is then converted to SO_3). A release of SO_3 would most likely occur from pipe work or equipment from the 1st Converter pass through to the end of the scrubbing tower where SO_3 is always present.

Screening Analysis Conclusion:

Toxic releases of SO_2 and SO_3 from the Acid Plant vessels / equipment have been carried forward for further analysis. A release of H_2SO_4, a corrosive liquid, is not considered a major offsite risk contributor, and as such has not been carried forward for further analysis.

6.10.3 NH_3 Storage

The NH_3 stored on a Ni Refinery is typically stored in pressurised horizontal bullets. A distribution pipeline system is used to deliver the product to the required process vessels at various locations on site.

See **Section 6.9** for details on NH_3 storage hazard.

Screening Analysis Conclusion:

Toxic releases from the NH_3 storage vessels have been carried forward for further analysis.

6.10.4 H_2S Plant and Distribution

H_2S is produced in the H_2S Plant from H_2 gas in the reactors. It is then passed through heat exchangers before being distributed to multiple locations on the Ni Refinery where it is required for various processes.

Due to the highly toxic nature of H_2S, a release could result in significant consequences to the health of personnel within the affected areas.

The most likely scenarios would be for a toxic release to occur either from the H_2S reactors and associated equipment, or from the various distribution lines. As the H_2S is produced and distributed under pressure, a release would result in a jet emission, and for conservatism, a horizontal jet release would result in the greatest area affected.

Standard design means that all H_2S areas are typically vented and controlled to minimise H_2S released into the atmosphere. All unwanted gases containing H_2S are normally directed to a flare system for combustion. N_2 is typically used throughout the plant as a purge gas to ensure systems can be freed of H_2S. NG, or another fuel gas, is typically added to the flare system to increase the likelihood of complete combustion of H_2S.

There is a potential for release and subsequent dispersion of H_2S gas from a H_2S plant and from distribution lines to other plant areas that require H_2S.

Screening Analysis Conclusion:

Toxic releases from the H_2S Plant vessels / equipment and distribution system have been carried forward for further analysis. H_2S is also flammable in the range of 4 – 44 % by volume, however due to its highly toxic nature and the resultant extreme health hazards from a release, H_2S fire / explosion has been screened out from further analysis.

The release of N_2 gas, an asphyxiant, is not considered to have a significant off-site impact. Upon release, dilution of the gas with air as it travels downwind will reduce the severity of potential consequences and this is therefore screened out from further analysis.

NG is added in small amounts to the flare system and therefore will not be carried forward for further analysis.

6.10.5 H_2 Plant and Distribution

H_2 is produced from NG in the H_2 Plant. Once produced it is distributed at a low pressure to the Sintering Furnaces, at a medium pressure to the H_2S plant, and to the Reduction Autoclaves at a high pressure via a high pressure H_2 storage vessel. The most likely events would be a flammable release of H_2 or NG to occur from a pipe, vessel or piece of equipment in the H_2 Plant, or a H_2 release from the distribution system.

As H_2 and NG are flammable, once a release has occurred a number of potential consequences may result ranging from a safe dissipation of non-toxic gas to atmosphere, through a jet or flash fire, to an explosion.

Gas releases from holes in high-pressure flammable inventories result in jet flames if ignited. Jet fires tend to have relatively small areas of impact.

Flash fires can result from the release of H_2 and NG through the formation of a vapour cloud with delayed ignition and a fire burning through the cloud. A fire can then flash back to the source of the leak and result in a jet fire.

Explosions can occur when a flammable gas cloud in a confined area is ignited. A VCE may result in overpressure effects that become more significant as the degree of confinement increases.

There is a potential for release, dispersion and possible ignition of H_2 gas from the H_2 plant and distribution lines.

Screening Analysis Conclusion:

Jet fires, flash fires and explosions from the H_2 plant vessels / equipment and distribution system have been carried forward for further analysis. NG has been screened out from further analysis, as it will be piped in and will occur in smaller quantities in comparison to H_2 gas. Any hazardous consequences related to a NG release will be outweighed by the consequences of a H_2 release.

6.11 DRI Plant

DRI plants typically store and use significant volumes of NG and other fuel gases such as H_2 and LPG. The hazards associated with these compounds are described above in **Section 6.10**. These plants also produce and use CO, and contain large HV installations.

There is a potential for release and dispersion of NG, LPG, H_2 and CO from any storage area and distribution lines. There is also the potential of ignition of NG, LPG, H_2 or CO and fire or explosion.

Screening Analysis Conclusion:

HV poses no off-site risk and will not be carried forward for further analysis.

Although CO is a toxic material it is present in such limited quantities that it has not been considered further in this capacity.

NG is not stored on the site and as such is present on the site in such small quantities that its storage does not contribute significantly to offsite risk and hence, it will not be carried forward for further analysis.

Although H_2 is a flammable material, it is present in small quantities and therefore not carried forward for further analysis.

LPG is the only flammable substance present in large enough quantities to present an offsite risk and as such will be carried forward for further analysis. Jet fires, flash fires, VCEs and BLEVEs from the LPG storage have been carried forward for further analysis.

6.12 Sodium Cyanide Plant

NaCN facilities typically store NH_3 as a raw material and typically source NG from a nearby pipeline. They also store NaCN as a finished product, and process equipment contains small volumes (less than 1 kg) of HCN gas.

HCN is a product of the reaction between NG and NH_3 in the presence of air. NaCN is a product of the secondary reaction between the HCN formed and NaOH solution.

NaCN is normally manufactured under negative pressure conditions, drastically lowering the risk of any release to the external environment. Water used in the process is recycled and or treated before release.

There is a potential for release of corrosive NaCN and dispersion of resulting toxic HCN gas from any storage area and distribution lines or during loading, transport and unloading operations. There is also the chance of ignition of HCN and fire.

There is a potential for release and dispersion of anhydrous NH_3 from any NH_3 storage area and its accompanying distribution pipe lines. Should there be any need to transport NH_3 by any means other than via pipeline, there is the added potential for release and dispersion during any loading, transport and unloading activities.

<u>Screening Analysis Conclusion</u>:

Although NaCN is a hazardous material and a dangerous good, its storage does not contribute significantly to offsite risk and risks associated with it will not be carried forward for further analysis.

Since HCN is present in almost insignificant quantities, as a process intermediate only (and therefore not stored), it too represents an insignificant off site risk level and will not be carried forward for further analysis.

NG is not stored on the site and as such is present on the site in such small quantities that its storage does not contribute significantly to offsite risk and hence, it will not be carried forward for further analysis.

Toxic releases from the NH_3 storage vessels have been carried forward for further analysis.

6.13 Fuel Terminal

The Fuel Terminal is an area where a quantity of flammable and combustible liquids, such as ULP, is stored on site in above ground vertical and horizontal tanks.

The main hazards identified for the facility are the storages of ULP and ethanol. There is a potential for release and dispersion of fuels or combustible or flammable industrial solvents from any storage area and distribution lines. Spillage of petroleum products or ethanol may be due to failure of lines, valves, pumps or fittings; or overfilling of tanks. Ignition of any flammable and combustible liquid spillage may result in a fire.

The main hazard scenarios associated with the storage of flammable and combustible liquids are a roof fire and a pool or bund fire. A roof fire may be due to failure of the seals on the floating roof and subsequent ignition or failure of the roof of a fixed roof tank, potentially due to an explosion within the tank, and subsequent ignition. A pool or bund fire may be due to failure of equipment, LOC and subsequent ignition.

The most likely hazard scenario is that of a pool fire due to LOC and ignition. The likelihood for these tanks to result in a BLEVE is considered to be not significant, as the tanks would have atmospheric vents and should a pool fire result in a ‘kettle’ scenario the consequences of failure of the tank are considered to result in more fuel being added to the pool fire.

The most significant consequence associated with these fires is thermal radiation, the effects of which are dependent on intensity and duration.

The potential for either of the above scenarios to have an offsite impact is dependent primarily on the size of the fire and the distance to the boundary. All storage tanks have been included in the scenarios in order to facilitate the effects of knock-on.

Diesel and the generic ‘industrial solvents’ allocated to this area for the purposes of the QRA, are combustible substances. Diesel typically has a flash point of approximately 66 °C, with a representative ‘industrial solvent’ having a flashpoint of 75 °C.

Screening Analysis Conclusion:

The following flammable and combustible liquids storage hazards have identified as representing a potentially significant offsite level of risk and have been carried forward for further analysis:

- Roof fire – all floating roof ULP and ethanol tanks in the main storage bund area,
- Pool or bund fire – all above ground ULP or ethanol storage tanks; and
- A 50% knock-on effect is assumed for a catastrophic bund fire in major bund storage areas.

Due to their high flash points, and the fact that the fuel farm would be separated from the nearest inhabited building by a reasonably large distance, diesel and ‘industrial solvent’ fire has not been considered as a major risk contributor, and hence flammable scenarios associated with them have been screened out from further analysis.

6.14 Titanium Metal Plant

The major hazard present on a Ti production facility is the large volume buffer storage of $TiCl_4$ required to produce the metal via reaction. The hazards presented by this storage are described in **Section 6.3**.

Screening Analysis Conclusion:

The toxic hazards presented by the storage and handling of $TiCl_4$ have been carried forward for further analysis.

6.15 Ammonium Nitrate Storage

The proposed AN storage facility for the KIP includes a mixed grade AN store where both explosive grade and fertiliser grade AN are kept at the facility. Whilst AN is explosive under suitable conditions, historically AN fertilisers have not been involved in any great number of large scale offsite incidents.

Screening Analysis Conclusion:

The storage of AN will not be carried forward for further analysis as the potential for an incident involving AN is very low.

6.16 Oil Refinery

Despite the fact that the refining process involves many different blending, separation and chemical treatment processes, for the purposes of this QRA, the Oil Refinery will be represented by storage scenarios only. Similar to the Fuel Terminal, only on a much larger scale, the Oil Refinery is an area where a quantity of flammable and combustible liquids is stored on site in above ground vertical and horizontal tanks.

The main hazards identified for the facility are the liquid storages of ULP, Diesel, Kerosene, AVGAS and HF, and the gaseous storage of H_2. There is a potential for release and dispersion of fuels or combustible or flammable liquids from any storage area and its associated distribution lines. As for the Fuel Terminal, spillages may be due to failure of lines, valves, pumps or fittings; or overfilling of tanks. Ignition of any flammable and combustible liquid spillage may result in a fire.

The main hazard scenarios associated with the storage of flammable and combustible liquids are a roof fire and a pool or bund fire. See **Section 6.13** for a detailed description of these scenarios.

The most significant consequence associated with these fires is thermal radiation, the effects of which are dependent on intensity and duration.

Screening Analysis Conclusion:

The following flammable and combustible liquids storage hazards have identified as representing a potentially significant offsite level of risk and have been carried forward for further analysis:

- Roof fire – all floating roof ULP, Diesel, Kerosene and AVGAS tanks in the main storage bund area, and
- Pool or bund fire – all above ground ULP, Diesel, Kerosene and AVGAS storage tanks.
- A 50% knock-on effect is assumed for a catastrophic bund fire in major bund storage areas.

Due to its extremely toxic nature, despite the small storage volumes, and the fact that previous studies of this nature specifically for Oil refineries have found that this material is not likely to have consequences beyond the site boundary, the hazardous scenarios associated with HF Storage have been carried forward for further analysis.

Jet fires, flash fires and explosions from the H_2 vessel and distribution system have been carried forward for further analysis.

Finally, due to their high flash point, and the presence of relatively large volumes of significantly more volatile substances, crude oil and asphalt fire has not been considered as a major risk contributor, and hence flammable scenarios associated with these have been screened out from further analysis.

6.17 Xanthate Plant

Xanthate plants typically include medium to large volume storage of the raw materials, CS_2 and various alcohols, including ethanol and isopropanol. For the purposes of this QRA, all alcohol has been assumed to be Isobutanol, a constituent of the most common Xanthate used in Australia, sodium isobutyl xanthate. Both materials are flammable and, in addition, CS_2 liberates SO_2 when combusted under atmospheric conditions.

A N_2 blanket is maintained in the reactor throughout the processing, supplied from a small liquid N_2 facility on site and a small reserve of diesel is also maintained on site.

Xanthate Plants also typically store large volumes of NaOH or a similar alkali, and of finished xanthate product.

Screening Analysis Conclusion:

Liquid N_2 and diesel have been screened out from further analysis as the inventories associated with them are small. CS_2 fires and resulting toxic gas combustion product scenarios have been carried forward for further analysis. Additionally flammable scenarios for the alcohol storage and transfer will also be carried forward for further analysis.

6.18 Ammonia Plant

There is a potential for release and dispersion of anhydrous NH_3 from any NH_3 storage area and its accompanying distribution pipe lines and a release of NH_3 could result in significant consequences to the health of personnel within the affected areas.

Since large volume storage of NH_3 is typically refrigerated at atmospheric pressure, the most likely scenarios would be for a toxic release to occur from the NH_3 storage vessels. For conservatism, a horizontal jet release at low level would result in the greatest area being affected.

Screening Analysis Conclusion:

Toxic releases from the NH_3 storage vessels have been carried forward for further analysis. Although diesel and CO_2 are present on the site in small volumes, the hazards presented by these are insignificant when compared to those of a large volume NH_3 release.

6.19 Fertiliser Plant

An AN fertiliser facility would typically contain significant storage volumes of:

- Liquid anhydrous NH_3;
- Liquid HNO_3; and
- Both solid and liquid AN.

Similar to the NH_3 Plant, large volume storage of NH_3 is assumed to be refrigerated at atmospheric pressure. Refer to **Section 6.9** for more details regarding hazards associated with this type of NH_3 storage.

Screening Analysis Conclusion:

HNO_3, whilst being a strong acid and harmful to personnel, would not present any significant offsite risks, and therefore has been excluded from any further analysis.

Whilst AN is explosive under suitable conditions, historically AN fertilisers have not been involved in any great number of large scale offsite incidents. The storage of AN will not be carried forward for further analysis.

Toxic releases from the NH_3 storage vessels have been carried forward for further analysis. Since the transfer of NH_3 occurs at the storage location, additional hazards relating to this activity have been incorporated into the storage vessel failure scenarios, using an increased failure frequency to account for the transfer operation.

6.20 LPG Facility

Although typically, an LPG facility would involve various process steps other than the simple compression, refrigeration and liquefaction of petroleum gases, for the purposes of this QRA the LPG facility will be considered as a collection of large volume pressurised storage vessels containing either propane or butane liquids.

Screening Analysis Conclusion:

The hazards associated with the storage of propane and butane liquids have been carried forward for further analysis. Jet fires, flash fires, VCEs and BLEVEs associated with the storage of propane and butane liquids, will be considered.

The diameter of the process lines is typically small and any leak or rupture would result in a local gas release and, upon ignition, a flash fire followed by a jet fire. This scenario would not result in significant offsite consequences and has not been carried forward for further analysis.

Note, only liquid releases have been considered as the fittings that may result in a release from the gas side of a storage tank will not result in offsite consequences. These events may be initiators for a BLEVE i.e., there is an escalation of the nature of the event. This escalation or 'knock-on' effect has been included in the determination of a BLEVE frequency.

A 120 kL BLEVE of butane, as an example, would give rise to a 115 metre diameter fireball with a duration of 14 s, and hence, a 50% knock-on causing a terminal fire involving all storage tanks which has been carried forward for further analysis.

6.21 Hydrogen Peroxide Plant

H_2O_2 is stored on site in large volumes. Aside from being a strong oxidising agent and a powerful corrosive, H_2O_2 is readily decomposed by dirt, undistilled water and heavy metal ions, liberating O_2. The slow decomposition of peroxide in storage containers can build up sufficient pressure to create overpressure conditions that may lead to an explosion. It is assumed that storage tanks containing H_2O_2 are clean and have the necessary safety features to prevent this scenario from occurring.

The H_2 plant located on-site is assumed to have inventories similar to the H_2 plant that will potentially locate in the Ni Refinery. As H_2 and NG are flammable, once a release has occurred a number of potential consequences may result ranging from a safe dissipation of non-toxic gas to atmosphere, through a jet or flash fire, to an explosion.

Gas releases from holes in high-pressure flammable inventories result in jet flames if ignited. Jet fires tend to have relatively small areas of impact.

Flash fires can result from the release of H_2 and NG through the formation of a vapour cloud with delayed ignition and a fire burning through the cloud. A fire can then flash back to the source of the leak and result in a jet fire.

Explosions can occur when a flammable gas cloud in a confined area is ignited. A VCE may result in overpressure effects that become more significant as the degree of confinement increases.

Screening Analysis Conclusion:

Any hazardous consequences related to a H_2O_2 release is not considered a major offsite risk contributor and as such has not been carried forward for further analysis.

Jet fires, flash fires and explosions from the H_2 plant vessels / equipment and distribution system have been carried forward for further analysis. NG has been screened out from further analysis, as it will be piped in and will occur in smaller quantities in comparison to H_2 gas. Any hazardous consequences related to a NG release will be outweighed by the consequences of a H_2 release.

6.22 Lithium Metal Facility

Acids such as HCl and H_2SO_4, that are used to treat Li ore, will be stored on site. Cl_2, is a product of the electrolysis process. It is assumed that all Cl_2 produced is not stored, but converted to NaOCl, which has a viable market.

Screening Analysis Conclusion:

A release of HCl, H_2SO_4 or NaOCl is screened out from further analysis, as it would not present any significant offsite risk.

Although not stored, a Cl_2 release from process could result in significant consequences to the health of personnel within the affected areas due to its highly toxic nature. Cl_2 will be carried forward for further analysis

6.23 Timber Products Plant

CH_3OH and CH_2O, both flammable materials, are stored at the CH_2O plant located on the premises. The main hazard scenarios associated with the storage of flammable liquids are a roof fire and a pool or bund fire.

A roof fire may be due to failure of the seals on the floating roof and subsequent ignition or failure of the roof of a fixed roof tank, potentially due to an explosion within the tank, and subsequent ignition. A pool or bund fire may be due to failure of equipment, LOC and subsequent ignition.

The likelihood for this storage to result in a BLEVE is considered to be not significant, as the tanks would have atmospheric vents and should a pool fire result in a 'kettle' scenario the consequences of failure of the tank are considered to result in more fuel being added to the pool fire.

Screening Analysis Conclusion:

As CH_2O is stored in smaller quantities as compared to CH_3OH storage, a release of CH_2O is screened out from further analysis as it would not present any significant offsite risk due to its low inventories.

CH_3OH, a flammable material, will be carried forward for further analysis as its storage could have a potentially significant offsite level of risk.

6.24 Tantalum Refining Plant

HF and H_2SO_4 acids, are both corrosive liquids. C_6H_{12}, is a flammable material. The main hazard scenarios associated with the storage of flammable liquids are a roof fire and a pool or bund fire, as described in **Section 6.23** above.

Screening Analysis Conclusion

H_2SO_4, a corrosive liquid, is screened out from further analysis as they would not present any significant offsite risk. HF will be present in small quantities and is therefore also screened out from further analysis.

C_6H_{12}, a flammable material, will be carried forward for further analysis as its storage could have a potentially significant offsite level of risk.

6.25 Pulp and Paper Mill

Bleaching chemicals such as H_2O_2 as well as other chemicals such as NaOH are stored on-site. H_2O_2, is a corrosive as well as oxidising material whilst NaOH has corrosive properties. The hazards associated with H_2O_2 are described in **Section 6.21** above.

Screening Analysis Conclusion

H_2O_2 and NaOH acids are screened out from further analysis as they are not considered to present any significant offsite risk.

This facility is not carried forward for further analysis.

6.26 Synthetic Rutile Plant

A fuel supply with inventories similar to that found in the existing Silicon Smelter facility is assumed to be stored at the site. Both LPG and diesel will be stored. LPG is flammable whilst diesel is a combustible liquid. The hazards associated with the storage of LPG and diesel are described in further detail in **Section 6.2**.

Screening Analysis Conclusion:

Jet fires, flash fires, VCEs and BLEVEs from the LPG storage, have been carried forward for further analysis. Pool fires from the diesel storage have also been carried forward for further analysis.

6.27 Vanadium Refining Plant

A fuel supply with inventories similar to that found in the existing Silicon Smelter facility is assumed to be stored at the site. Both LPG and diesel will therefore be stored. LPG is flammable whilst diesel is a combustible liquid. The hazards associated with the storage of LPG and diesel, are described in further detail in **Section 6.2**.

Screening Analysis Conclusion:

Jet fires, flash fires, VCEs and BLEVEs from the LPG storage, have been carried forward for further analysis. Pool fires from the diesel storage have also been carried forward for further analysis.

6.28 Alumina Refinery

NaOH, a corrosive liquid is stored on site. Al_2O_3 and $Al(OH)_3$, will also be present on-site. Hazardous consequences posed by Al_2O_3 and $Al(OH)_3$ are minimal in terms of risk.

Screening Analysis Conclusion:

NaOH, Al_2O_3 and $Al(OH)_3$ are screened out from further analysis as they are not considered to present any significant offsite risk. This facility will not be carried forward for further analysis.

6.29 Aluminium Smelter

A fuel supply with inventories similar to that found in the existing Silicon Smelter facility is assumed to be stored at the site. Both LPG and diesel are therefore assumed to be stored on site. LPG is flammable whilst diesel is a combustible liquid. The hazards associated with the storage of LPG and diesel, are described in further detail in **Section 6.2**.

Screening Analysis Conclusion:

Jet fires, flash fires, VCEs and BLEVEs from the LPG storage, have been carried forward for further analysis. Pool fires from the diesel storage have also been carried forward for further analysis.

6.30 Hazard Screening Summary

This section contains a summary of Hazard Scenarios carried forward for further analysis.

Table 6.1 details all hazardous scenarios identified together with those that have been carried forward for further analysis.

Table 6.1 Hazard Scenarios Identified for Further Analysis

Plant ID	Hazard Scenario	Carried Forward for Further Analysis (Y/N)	
1	**Silicon Smelter**		
	Liquefied O_2 storage		N
	LPG Storage	Y	
	Diesel Storage	Y	
2	**Pigment Plant**		
	Liquefied O_2 storage		N
	$TiCl_4$ storage	Y	
	Liquefied Cl_2 storage	Y	
3	**Chlor-Alkali Plant**		
	NaOH storage		N
	H_2 storage		N
	Liquefied Cl_2 storage	Y	
4	**Oxygen and Nitrogen Plant**		
	Liquefied O_2 storage		N
	Liquefied N_2 storage		N
	Liquefied Ar storage		N
5	**Water Treatment Plant**		
	NaOH storage		N
	$Al_2(SO_4)_3$ storage		N
	Liquefied Cl_2 storage	Y	
6	**Silica Sand Facility**		
	Silica sand storage		N
7	**Lime Hydration Plant**		
	CaO		N
	$Ca(OH)_2$		N
8	**Urea Plant**		
	Urea Storage		N
	NH_3 Storage	Y	
9	**Ni Refinery**		
	S stockpile		N
	H_2SO_4 Plant – (SO_2, SO_3)	Y	
	NH_3 storage	Y	
	H_2S Plant and distribution	Y	
	H_2 Plant and distribution	Y	

Plant ID	Hazard Scenario	Carried Forward for Further Analysis (Y/N)	
10	**DRI Plant**		
	HV Electrical Installations		N
	CO storage and distribution		N
	NG supply pipeline		N
	H_2 storage		N
	LPG storage	Y	
11	**Sodium Cyanide Plant**		
	NaCN Storage		N
	HCN production		N
	NG supply pipeline		N
	NH_3 storage	Y	
12	**Fuel Terminal**		
	ULP and Ethanol storage	Y	
	Diesel and 'industrial solvent' storage		N
13	**Titanium Metal Plant**		
	$TiCl_4$ storage	Y	
14	**Ammonium Nitrate Storage**		
	AN storage		N
15	**Oil Refinery**		
	Flammable and combustible liquids storage	Y	
	Crude Oil and Asphalt storage		N
	HF storage	Y	
	H_2 storage and reticulation	Y	
16	**Xanthate Plant**		
	Alcohol storage	Y	
	CS_2 storage	Y	
	Xanthate storage		N
	NaOH storage		N
17	**Ammonia Plant**		
	NH_3 storage	Y	
	Diesel storage		
18	**Fertiliser Plant**		
	NH_3 storage	Y	
	HNO_3 storage		N
	AN storage		N
19	**LPG Facility**		

Plant ID	Hazard Scenario	Carried Forward for Further Analysis (Y/N)	
	Liquid Propane storage	Y	
	Liquid Butane storage	Y	
20	**Hydrogen Peroxide Plant**		
	H_2O_2 storage		N
	NG supply pipeline		N
	H_2 storage	Y	
21	**Lithium Metal Facility**		
	HCl storage		N
	H_2SO_4 storage		N
	NaOCl storage		N
	Cl_2 in process	Y	
22	**Timber Products Plant**		
	CH_2O storage		N
	CH_3OH storage	Y	
23	**Tantalum Refining Plant**		
	HF acid storage		N
	H_2SO_4 acid storage		N
24	**Pulp and Paper Mill**		
	H_2O_2 storage		N
	NaOH storage		N
25	**Synthetic Rutile Plant**		
	LPG storage	Y	
	Diesel storage	Y	
26	**Vanadium Refining Plant**		
	LPG storage	Y	
	Diesel storage	Y	
27	**Alumina Refinery**		
	NaOH storage		N
	Al_2O_3 storage		N
	$Al(OH)_3$ storage		N
28	**Aluminium Smelter**		
	LPG storage	Y	
	Diesel storage	Y	

7. CONSEQUENCE ANALYSIS

7.1 Risk Modelling Approach

Consequence analysis was undertaken by using the internal programs contained within the TNO QRA software program *Riskcurves* and is based on parameters such as:

- Process conditions (temperature, pressure);
- Quantity of gas available for release;
- Hole size;
- Height above ground; and
- Outflow orientation.

Input data for the program for each of the hazard scenarios considered is provided in **Appendix E.**

Meteorological data used in the program is summarised in **Appendix A**.

7.2 Potential Events

7.2.1 Flammable Liquids

As flammable and combustible liquids by their nature are flammable, once a release has occurred a number of potential consequences may result:

- Roof fire (storage tanks only);
- Pool fire; or
- Unignited spill (requiring clean-up only).

7.2.2 Flammable Gases

As H_2 and LPG are flammable, once a release has occurred a number of potential consequences may result:

- Jet fire;
- Flash fire;
- Explosion; or
- Safe dissipation of non-toxic gas to atmosphere.

Gas releases from holes in high-pressure flammable inventories result in jet flames if ignited. Jet fires tend to have relatively small areas of impact.

Flash fires can result from the release of H_2 and LPG through the formation of a vapour cloud with delayed ignition and a fire burning through the cloud. A fire can then flash back to the source of the leak and result in a jet fire. Flash fires have the potential for offsite impact as the vapour clouds can travel considerable distances downwind of the source.

Explosions can occur when a flammable gas cloud in a confined area is ignited. VCEs may result in overpressure effects that become more significant as the degree of confinement increases.

BLEVEs can occur when the vessel wall surrounding the vapour space is subject to extreme heat radiation, normally as a result of a jet fire. The incident heat radiation weakens the vessel wall and increases the internal pressure until the vessel fails instantly, resulting in a fire ball. A BLEVE has significant potential for offsite impact.

These potential consequences resulting from the accidental release of material are dependent upon a number of factors, including:

- The rate of release of material from the release source. The rate of release is influenced mainly by process conditions, properties of the material being released, and dimensions of the 'hole' from which the material is being released;
- The duration of the release. The duration of the release is influenced by the time to detect a release and the time taken to shut down;
- The dispersion of the gas cloud. The cloud dispersion is influenced by the release rate, the relative buoyancy of the gas and the prevailing weather conditions at the time of the release; and
- The ignition or otherwise of the gas cloud. The probability of ignition of the gas is influenced by the relative proximity of the release source to potential sources of ignition.

Immediate ignition scenarios were modelled as jet fires (torch fires) and delayed ignition scenarios were modelled as flash fires / explosions. BLEVEs were modelled for the catastrophic failure of vessels containing flammable material under pressure, such as LPG.

As H_2 and LPG are lighter than air, non-toxic gases and exhibit simple asphyxiant properties, the consequence of an un-ignited gas cloud is negligible, as the gas will safely dissipate.

7.2.3 Toxic Materials

Toxic releases of Cl_2, and NH_3, were modelled as dense toxic gas dispersions.

Releases of HF, $TiCl_4$ ($HCl_{(g)}$), H_2S, SO_2, SO_3 and $HF_{(g)}$ were modelled as neutral toxic gas dispersions. Although $TiCl_4$ ($HCl_{(g)}$), H_2S, SO_2 and SO_3 are denser than air, these gases have been modelled as neutral gas dispersions as the temperature of the releases, (in the case of HCl, this temperature is generated by the exothermic reaction between $TiCl_4$ and water vapour in the surrounding air), means that the releases will mimic the behaviour of neutral gas dispersions.

7.2.4 Consequence Modelling Assumptions

During the undertaking of the QRA, a number of modelling assumptions were made. These are detailed below:

- **Catastrophic release durations ($TiCl_4$)** – in the special case of HCl releases evolved from catastrophic failures of vessels containing $TiCl_4$, the release of HCl has been modelled as a continuous release of HCl for a period of 1800 s (30 min). It is assumed that during this period HCl will evolve continuously from a pool of finite surface area (assumed to be the dimensions of the bunded area), from the reaction of $TiCl_4$ with atmospheric water vapour. The period of 30 min has been selected as it is assumed that a cleanup operation will recover any remaining liquid $TiCl_4$ within this timeframe;

- **Catastrophic vessel failures** – catastrophic failures of vessels have been modelled using the assumption that the total vessel inventory is lost instantaneously (conservative approach);
- **Release orientation** – for pressurised inventories, all releases were assumed to be horizontal (conservative approach); and
- **Release rates** – release rates for HCl gas released as a result of a spill of $TiCl_4$, were taken from 'TiO_2 Pigment Plant at Kwinana' (Ref. 28). All other material release rates were calculated using *Effects*, and the results are detailed in the Scenario Summaries in **Appendix E.**

8. QUANTITATIVE RISK ASSESSMENT

8.1 Model Inputs

Risk modelling was undertaken using specific QRA software programs *TNO Effects* and *Riskcurves. Riskcurves* uses as a basis, the models detailed in the "Methods for the calculation of physical effects", Committee for the Prevention of Disasters, 1997, commonly referred to as the 'Yellow Book' (Ref. 8). The TNO tools are internationally recognised by industry and government authorities, including the DMP.

Meteorological data as outlined in **Appendix A**, provided by Air Assessments was used. A 'roughness length' of 0.5 m was utilised in the model, which corresponds to 'parkland, bushes and numerous obstacles' (Ref.9).

Event frequencies as determined from a detailed analysis provided in **Appendix B, C** and **D** were input into each scenario. Scenarios detailed in **Appendix E** provided all the KIP failure cases analysed in the QRA.

8.2 Model Outputs

The model output was in the form of risk contours. The model calculated iso-risk contours of 1×10^{-6}, 5×10^{-5}, 1×10^{-5}, 1×10^{-4}, and 1×10^{-3} pa as required by the EPA Individual Fatality Risk Criteria. Risk contours for the Base Case and High Density Industrial Loading Case are provided in **Figure 1.1** and **1.2.**

9. RESULTS

Figure 1.1 and **Figure 1.2** demonstrate that the highest risk level posed by the KIP, based on the conceptual set of industries is 1 x 10^{-3} (red coloured contour). This is true for both the Base Case Industrial Loading scenarios, and the High Density Industrial Loading Case. The 1 x 10^{-3} Individual Risk Per Annum (IRPA) contours are generally located in areas corresponding to major hazardous inventories and are well within site boundary limits.

The IRPA contour representing a risk level of 5 x 10^{-5} per year (fifty in a million per year), is the EPA criteria for the site boundary for each individual industry (purple in colour). The 5 x 10^{-5} IRPA contour for the existing Pigment Plant at the southern end of the KIP extends beyond the site boundary and into the area occupied by the existing Silicon Smelter, to the west, as well as to the other areas surrounding the site. The Base Case does not contain industries located close to the Pigment Plant's site boundaries that could be impacted by this contour, apart from the existing facilities within the Pigment Plant's site boundaries. In the High Density Case however, the Synthetic Rutile Plant, is located near the northern end of the Pigment Plant site and is impacted by this contour. As the location of this industry is only conceptual at this stage, it can be moved further away. The main hazard associated with the Pigment Plant is the potential release of Cl_2, which is a toxic dense gas. The 5 x 10^{-5} IRPA contour associated with the Oil Refinery located at the northern end of the KIP extends beyond its site boundary, as does the contour associated with the Fertiliser Plant, located towards the eastern end of the KIP. This is mainly due to the toxic effects of a potential release of HF, in the case of the Oil Refinery and NH_3, in the case of the Fertiliser Plant. The release of toxic material has a far wider effect in terms of consequences, than the release of flammable material associated with the Oil Refinery. Re-location of such industries to larger sites could potentially result in the 5 x 10^{-5} IRPA falling within the site boundary.

The IRPA contour representing a risk level of 1 x 10^{-5} per year (ten in a million per year), which is the EPA criteria for risk levels in buffer zones, is depicted as green in colour. This risk level must be met within the buffer areas, for the location of any non-industrial activity within the buffer zones. The contour extends to the Water Treatment Plant, in the southern end of the KIP, however, the activities associated with the Water Treatment Plant are industrial, and the contour is applicable to only non-industrial activity located within the buffer zone. The KIP's buffer zone is largely outside the confines of this contour and therefore the location of non-industrial activities within most of the buffer zone would meet EPA criteria. The Inter-Industry Buffer between the Support Industry Area located in the south eastern corner of the KIP and the Industry Core, provides sufficient buffer for effects associated with industrial activities within the Industry Core.

The IRPA contour representing a risk level of 1 x 10^{-6} per year (one in a million per year), is the EPA criteria for risk levels in residential areas, (light blue in colour). The area encompassing this contour is within the boundaries of the buffer zone for both the Base and High Density Cases. Leschenault, the nearest residential area located approximately south west to the KIP is outside the reaches of this contour. The contour extends to the Kemerton Support Industry Area, located to the south eastern side of the Industry core. Since the Support Industry Area is not proposed to contain residential areas, this is deemed to be within EPA criteria.

10. CONCLUSIONS AND ALARP RECOMMENDATIONS

10.1 Conclusions

The IRPA contours for the Pigment Plant, located in the southern end of the KIP, do not generally meet site boundary EPA criteria. The EPA criteria for buffer zones and residential areas for this plant, is however, met.

Industries that could breach EPA site boundary criteria based on the conceptual layout used in this study include the Nickel Refinery, Oil Refinery and Fertiliser Plant. If these were located on bigger sites within the KIP,the criterion might be met

The results of this QRA demonstrate that the buffer zone is sufficient in containing the impacts of a range of high and medium industries located within the core of the KIP. However, when specific industries are proposed for the KIP, individual QRAs should be undertaken for each facility to ensure that risk levels associated with these plants do not result in non-compliance with EPA criteria.

It should also be noted that in the process of undertaking this QRA study, industry specific safety controls and risk mitigation measures which should be included as part of good design and operating practice for the various facilities have not been considered, as this information was not available at this early stage of the Kemerton project. As such, the results of this QRA represent a conservative approach.

10.2 ALARP Recommendations

There is clear recognition that QRA is not a precise science and that the confidence level of results is limited with regard to the accuracy of the resultant calculated level of risk. The strength of QRA lies in the process and the assessment of the relative level of the risk contributors so that there is an appropriate allocation of resources to risk reduction measures that may have the greatest influence in reducing the level of risk.

From the QRA results discussed above, the following recommendation is made:

Notwithstanding the compliance recommendations within this report, each industry shall be required to undertake individual QRA studies to locate in the KIP, ensuring that the risk levels associated with each facility do not result in non-compliance with EPA risk criteria.

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APPENDIX A

METEOROLOGICAL DATA

LIST OF TABLES

A1. Introduction

This section details the meteorological data used as input into the *Riskcurves* modelling software package. For further information on the data used, see **Section 4.7.2.**

Table A.1 Stability Category vs Wind Direction

Pasquill Stability Category	Relative probability of wind blowing from each sector											
	1	2	3	4	5	6	7	8	9	10	11	12
A	0.06	0.17	0.31	0.18	0.19	0.08	0.09	0.12	0.1	0.1	0.09	1.57
B	0.47	0.96	2.58	2.82	1.84	1.28	1.06	3	1.54	0.6	0.5	17.26
C	0.66	0.71	1.8	2.65	1.8	0.96	1.53	3.57	1.76	1.33	0.83	18.14
D	0.58	0.91	1.41	4.81	3.39	1.67	1.82	2.95	2.95	1.71	0.43	24.66
E	0.83	1.01	1.55	4.44	2.33	2.56	1.2	0.78	1	0.71	0.19	18.57
F	0.97	2.64	3.3	3.6	3.12	2.01	0.61	0.45	0.57	0.48	0.54	19.44

Table A.2 Stability Category vs Wind Speed

Pasquil Stability Category	Representative wind speeds (m/s)	Day / Night Probabilities	
		Day	Night
A	2.7	1.6	0
B	4.2	17.2	0
C	5.2	18.1	0
D	4.7	13.6	11.1
E	3.8	2.1	16.4
F	2.4	1.6	18.1

Table A.3 Values for Parameters Related to Meteorological Conditions

Parameter	Value	Units
Relative Humidity	75	%
Roughness Length	0.5	m
Ambient Temperature	17	°C
CO_2 Percentage in Atmosphere	0.03	%

APPENDIX B

FREQUENCY ANALYSIS

LIST OF TABLES

B1. Introduction

This section discusses the various modes of failure for equipment together with the failure frequencies utilised in the risk assessment. The method for determining probability of ignition is detailed.

B2. Hole Size Selection

Part of the QRA methodology involves selection of representative scenarios that will be entered as input data into the *Riskcurves* model. The development of such scenarios requires that a discrete number of hole sizes are selected to represent the infinite range of hole sizes that may occur in actual equipment failure scenarios. Representative hole sizes selected and corresponding leak descriptions are:

- 10 mm – hole size representing small hole or small crack failures;
- 25 mm - medium hole size representing developed cracks and corrosion/erosion type failures; and
- 50 mm – large hole size representing major releases associated with catastrophic failure of equipment.

Table B.1 shows the basis for the selection of the above hole diameters by relating the range of hole areas to the above representative hole sizes.

Table B.1 Representative Hole Sizes vs Range of Hole Areas

Hole Area Range (mm^2)	Equivalent Diameter Range (mm)	Representative Hole Diameter (mm)
< 100	<11.3	10
100 – 1,000	11.3 – 35.7	25
>1,000	>35.7	50

Note: for the purposes of this QRA, for Flammable and Combustible Liquid storage tanks (Fuel Terminal and Oil Refinery):

- 25 mm – medium hole size represents a Serious Leak from developed cracks and corrosion / erosion type failures; and
- Catastrophic Failure – large hole represents catastrophic failures of vessels, pumps and large diameter pipe.

B3. Failure Case Frequencies and Parts Count

The frequency of a release from an isolatable section of plant or equipment being considered may be determined from counting the number of discrete parts of that section and multiplying that number by generic leak frequency data associated with that part to obtain an overall frequency of release.

All equipment associated with the proposed KIP industries may be categorised with regard to the parts count as being one of the following:

- Pipe;
- Flange;
- Valve;
- Small bore connection;
- Pump; or
- Vessel;

In order to determine the overall failure frequency of a section of plant, the number of the above plant items in the section need to be determined.

Normally, for each industry, a parts count is undertaken for each isolatable inventory of hazardous material to be modelled, by counting the number of each of the plant items using the relevant plant P&IDs from each plant. Since the KIP industrial layout is proposed only at this stage and no actual specific process design information was available, representative parts counts were proposed based on previous ERS experience and engineering judgment. The parts counts are presented in **Appendix B**.

The generic failure frequencies for the above parts, taking into account the representative hole sizes considered, is detailed below under respective headings.

B3.1 Pipe leak Frequency

Table B.2 provides release hole sizes and associated frequencies (Ref. 10). The percent area refers to the area of the diameter of the hole that is leaking compared to the diameter of the pipe.

Table B.3 provides the adjustment of the leak frequencies to account for the above selection of discrete hole sizes. For example, for a representative leak diameter of 50 mm for pipework above 250 mm the leak frequency becomes $3 \times 10^{-6} + 1 \times 10^{-7} = 3.1 \times 10^{-6}$.

Table B.2 Pipe Leak Size and Frequency for Various Pipe Diameters (Ref. 10)

Leak	Area	Pipe Diameter (mm)					
		25 / 50		100		300	
	(%)	Leak Diam (mm)	Leak Freq. (/yr)	Leak Diam (mm)	Leak Freq (/yr)	Leak Diam (mm)	Leak Freq (/yr)
Minor	**1**	2.5/5.0	1 x 10^{-4}	10	3 x 10^{-5}	30	1 x 10^{-5}
Major	**10**	7.9/15.8	1 x 10^{-5}	31.6	6 x 10^{-6}	94.9	3 x 10^{-6}
Rupture	**100**	25/50	1 x 10^{-6}	100	3 x 10^{-7}	300	1 x 10^{-7}

Table B.3 Representative Pipe Leak Size and Frequency for Various Pipe Diameters

Leak Diam (mm)	Pipe Diameter (mm)		
	≤ 50	50 < D < 250	≥ 250
	Leak Freq.(/yr)		
10	1 x 10^{-4}	3 x 10^{-5}	
25	1 x 10^{-5}	6 x 10^{-6}	1 x 10^{-5}
50	1 x 10^{-6}	3 x 10^{-7}	3.1 x 10^{-6}

B3.2 Flange Leak Frequency

A release from a flange may be due to a partial (minor) or complete (major) failure of the gasket or seal. The frequency of release from a flange is relatively high and with a large proportion of flange failures being due to human error, particularly in maintenance operations whereby the flange may be incorrectly inserted, left out or the bolts not tightened. This has been taken into account by Cox, Lees & Ang (Ref. 10) and is reflected in the data provided in **Table B.4**.

The size of a release from a flange is dependent on a number of variables including the type of flange:

- Spiral wound joint (SWJ) type of gasket is typically 3 mm thick and is located entirely within the circle of flange bolts;
- Ring type joint (RTJ) which are employed on high pressure lines and are typically a metal gasket compressed between V-shaped grooves in the mating flanges; and
- Synthetic type gaskets (similar to Compressed Asbestos Fibre (CAF) types of gaskets, typically 2 mm thick and used on low pressure and utility systems with or without raised face flanges.

or the type of failure:

- Section of flange between the bolts fails (not considered possible for SWJ & RTJ types of gasket);
- Corrosion leak / weep; and
- Human error, such as failing to insert a gasket, incorrect gasket or incorrect placement of the gasket.

The frequencies detailed in **Table B.4** are based on the work conducted by Cox, Lees and Ang combined with the following rationale. Note, Cox, Lees and Ang (Ref. 10) consider that minor leaks apply to flange failures and hence a 50 mm leak hole size is considered not to be a credible scenario. Potentially large leaks are considered to be adequately represented by a 25 mm hole size.

Pipe Diameter ≤ 50mm

A section failure of a gasket of this size will result in a hole size which is less than 10 mm in diameter and the failure frequency has been assumed to be 10-4 /y (Ref. 10).

Human error type failure, where larger releases (25 mm) are possible, account for approximately 4% of the total releases (Ref.12). Failure frequency for larger releases has been assumed to be 4 x 10-6 /y.

50 < Pipe Diameter < 250 mm

10 mm hole sizes are considered to fall between a minor release and a section failure as given by Cox, Lees and Ang (Ref. 10). The failure frequency assigned to this hole size is 3 x 10-3 /y.

A section failure is considered to correspond to a 25 mm leak and has a frequency of 1 x 10-4 /y.

250 ≥ Pipe Diameter

10 mm hole size frequency is considered to be double that of the smaller pipe size to account for the length of gasket being approximately twice that of the smaller pipe size. Frequency is to 6 x 10-3.

A section failure is considered to correspond to a 25 mm leak and has a frequency of 1 x 10^{-4} / y.

Table B.4 Flange Leak Size and Frequency for Various Pipe Diameters

Leak Diam (mm)	Pipe Diameter (mm)		
	≤ 50	50 < D < 250	≥ 250
	Leak Freq.(/yr)		
10	1 x 10^{-4}	3 x 10^{-4}	6 x 10^{-4}
25	4 x 10^{-6}	1 x 10^{-4}	1 x 10^{-4}
50			

B3.3 Screw Fitting Leak Frequency

The Liquefied Petroleum Gas Industry Technical Association, UK (LPGITA) considered that pipeline failures represented a negligible risk. This comment is considered to also apply to screw fittings as the analysis clearly identifies flange fittings and potential failure and the piping isometrics indicate that the pipework would need to be all welded or some screw connections would need to be made.

Regardless, the type of failure from a screw fitting is considered to be different to that of a flanged fitting. There is no potential for a gasket blow - out and the type of leak would be that of a weep along the pipe thread should the connection not be correctly tightened.

The failure frequency is considered to be similar to that of a pipeline release rate and have not been allocated a specific failure frequency rate. This assumption is considered justified taking into account:

- Pipe failures have been included in this analysis; and
- The type of leak is that of a weep.

B3.4 Valve Leak Frequency

The same approach has been used for valve release frequencies as was used for pipe release frequencies. **Table B.5** and **Table B.6** provides the leak frequency from Cox, Lees and Ang (Ref. 10) and the leak frequency associated with the discrete hole size selection.

Table B.5 Valve Leak Size and Frequency for Various Pipe Diameters (Ref. 10)

Leak	Area	Pipe Diameter (mm)			Leak Freq
		25 / 50	100	300	
	(%)	Leak Diam (mm)	Leak Diam (mm)	Leak Diam (mm)	(/yr)
Minor	**1**	2.5 / 5.0	10	30	1×10^{-3}
Major	**10**	7.9 / 15.8	31.6	94.9	1×10^{-4}
Rupture	**100**	25 / 50	100	300	1×10^{-5}

Table B.6 Valve Leak Size and Frequency for Various Pipe Diameters

Leak Diam (mm)	Pipe Diameter (mm)		
	≤ 50	50 < D < 250	≥ 250
	Leak Freq.(/yr)		
10	1×10^{-3}	1×10^{-3}	
25	1×10^{-4}	1×10^{-4}	1×10^{-3}
50	1×10^{-5}	1×10^{-5}	1.1×10^{-4}

B3.5 Small Bore Connection Leak Frequency

Table B.7 provides the leak frequency associated with small bores (Ref. 10). The values are considered to be conservative in that the full bore size has been taken as 25 mm.

Table B.7 Representative Small Bore Connection Leak Size and Frequency

Leak Diam (mm)	Leak Freq.(/yr)
10	5 x 10^{-3}
25	5 x 10^{-4}

B3.6 Pump Leak Frequency

The release frequency of pumps is three times the release frequency of valves (Ref. 10). These are provided in **Table B.8**.

Table B.8 Pump Leak Size and Frequency for Various Pipe Diameters

Leak Diam (mm)	Pipe Diameter (mm)		
	≤ 50	50 < D < 250	≥ 250
	Leak Freq.(/yr)		
10	3 x 10^{-3}	3 x 10^{-3}	
25	3 x 10^{-4}	3 x 10^{-4}	3 x 10^{-3}
50	3 x 10^{-5}	3 x 10^{-5}	3.3 x 10^{-4}

B3.7 Pressure / Process Vessel Leak Frequency

Table B.9 details the frequency of a release from a pressure vessel (Ref. 13). Failures associated with connections, valves and flanges on the vessel are included in the parts count for those respective items of equipment.

The frequency of a catastrophic failure of a vessel resulting in the instantaneous loss of the total vessel inventory is based on a single walled containment tank. This is a conservative approach, and is derived from the Purple Book (Ref. 9). **Table B.9** provides the frequency data selected and used in this QRA.

Table B.9 Representative Pressure Vessel Leak Size and Frequency

Leak Diam (mm)	Leak Freq.(/yr)
10	1 x 10^{-5}
25	5 x 10^{-6}
50	5 x 10^{-6}
Catastrophic	5 x 10^{-6}

B3.8 Acid Plant Duct Failure Frequency

Typically, Acid Plants (as proposed for the Ni Refinery in the KIP) predominantly have ducting work ranging from approximately 1-2 m in diameter as opposed to small bore pipework for transfer of the SO_2/SO_3 through the process.

The large diameter and lagging of the Acid Plant duct work, the low pressures involved (typically 0.5 barg), and duct runs being located at height, suggests that a lower full bore rupture failure frequency would be more applicable than that of small bore process pipework. Full bore ruptures of this duct work would realistically only occur due to impact from falling objects, crane collision, or sudden vacuum due to a major process failure, which are generally minimised through specific operating controls and procedures.

As such, acid plant specific operational failure data was obtained from an Acid Plant manufacturer, MECS Global Ltd, and the information was used to derive a failure frequency value for a full bore rupture of an Acid Plant duct work.

- Based on 8,000 installed acid plant duct runs;
- Approximately 30 m duct run length;
- 20 year average life span per duct run; and
- 3 documented full bore ruptures.

$$\text{Full bore rupture failure frequency} = \frac{\underline{3 / (8{,}000 \times 30)}}{20} = 6.25\text{x } 10^{-7}\ \text{m/y}$$

B3.9 $TiCl_4$, NH_3, Cl_2, and LPG Storage Vessel Leak Frequency

The catastrophic failure frequency for the $TiCl_4$, NH_3, Cl_2 and LPG storage vessels has been sourced from '*Failure frequencies for major failures of high pressure storage vessel at COMAH sites: A comparison of data used by HSE and the Netherlands'* by the UK HSE (Ref. 16), and is quoted as 2×10^{-6} per year.

Similarly, a catastrophic failure frequency value of 2×10^{-6} per vessel year is quoted for storage vessels in the '*Risk Assessment For the Siting of Developments Near Liquefied Petroleum Gas Installations*' from the I.Chem.E Symposium Series No.10 (Ref. 13), and is also considered to be applicable to the $TiCl_4$, NH_3, Cl_2 and LPG storage bullets due to vessel design, and applicable common design standards (e.g. Ref. 20).

B3.10 Event Tree Analysis

Event Tree Analysis (ETA) has been used to determine the pathways and associated probabilities for the possible outcomes for a LOC event, namely jet fires, flash fires, explosions and dispersions for the LPG, propane, butane and H_2 Plant.

Each Event Tree incorporates the failure case frequency for each scenario as input data, together with release rates and ignition probabilities. **Appendix D** provides details of each Event Tree, whereby the overall failure frequencies are further resolved into the specific scenario failure frequencies. The input data used in the Event Trees is outlined later in this section.

B3.11 Fault Tree Analysis

Fault Tree Analysis (FTA) has been used to determine the pathways and associated probabilities for the possible outcomes for a LOC event for flammable and combustible liquids storage vessels, defined as pool or bund fires, and roof fires.

Each Fault Tree incorporates the failure case frequency for various components of each system inherent in a given scenario as input data, together with release rates and ignition probabilities. **Appendix C** provides details of each Fault Tree, whereby the overall failure frequencies are further resolved into the specific scenario failure frequencies. The input data used in the Fault Trees is outlined later in this section.

B3.12 Generic Failure Data for Flammable and Combustible Liquid Storage

Tank Roof Fire

A study of 12 fires involving floating roof tanks showed that all fires started as rim fires and only one of these escalated in to a full surface fire (Ref. 15). These results have been included in the Fault Tree Analysis (FTA) for determining the overall frequency of a roof top fire, refer to **Appendix C**.

Table B.10 Floating Roof Tank Fire

Failure (mm)	Fire Frequency (fires 10^{-3}/tank/y)	Reference
Roof Fire	2.4	E&P Forum (Ref. 15)

Probability of failure of foam deluge

It is assumed that any flammable and combustible liquid storage area would be fitted with a foam deluge system. Reliability of such a system is considered to be high and, hence, it is considered that the probability of failure of this equipment is approximately 0.1. This value also corresponds to historical data whereby one out of 12 rim fires escalated to a full roof top fire (Ref. 15). To account for the presence of this system an Event frequency of 2.4×10^{-4} has been used for Tank Roof Fires.

Tank Farm Bund Fire

A bund fire requires LOC through the failure of a tank or associated pipework, valves or pumps.

The main causes of leaks in above ground storage tanks are due to (Ref. 15):

- Corrosion (60%);
- Improper installation and tank failure (18%);
- Loose fittings (12%); and
- Overfills and spills (10%).

An American Petroleum Institute (API) review of the storage tank incidents concluded that the causes of major failure of storage tanks were due to (Ref. 15):

- Improper operations, including operating and maintenance errors (21%);
- Improper procedures (19% contribution);
- Equipment failure (18% contribution);

- Weather (17% contribution);
- Improper design (3% contribution); and
- Others (22% contribution).

Table B.11 details the failure rates for an Atmospheric Storage Tank. For catastrophic failure scenarios resulting in bund fires, a conservative value one order of magnitude higher than that stated in **Table B.11** has been used to account for additional possible failure points such as distribution piping, pumping, instrumentation and valve arrangements.

Table B.11 Generic Failure Frequencies for Flammable and Combustible Liquid Storage

Item	Failure Rate	Units	Reference / Notes
Atmospheric Storage Tank Failure			
Catastrophic	6×10^{-6}	Per vessel yr	Ref. 11
Partial (Serious leakage)	9.6×10^{-5}	Per vessel yr	Ref. 11

It is assumed that bunded areas are separated sufficiently such that failure of a tank in one bund does not have the potential to impact on a tank in the adjacent bunds. Potential for catastrophic tank failure is per vessel per year as stated above, however as there are different numbers of storage vessels in each bund, the overall event frequency has been determined in each case by multiplying this figure by the number of tanks in each bund. In this scenario, as the release is considered to be catastrophic, the probability of ignition was determined to be 0.08 (i.e. massive), from **Table B.12** below.

The probability of knock on, i.e. a pool fire in a tank bund impacting on another storage tank and causing fire in an adjacent tank within the same bund was assumed to be 0.5 (This assumption is based on previous experience of undertaking QRAs for similar facilities). This is a conservative figure as the potential for failure of all tanks is included in assumption of catastrophic failure rate described above and includes provision for all of the tanks to be always full (which is rarely the case).

B3.13 Overall Ignition Probabilities

Upon release of a flammable material, ignition can occur. The probability of ignition is dependent on:

- The quantity and rate of material release;
- The material flammability, based on flammability range and ignition spark energy;
- The number of ignition sources that may be contacted within the flammable vapour envelope; and
- The energy of the ignition source.

Even within a hazardous area there could be ignition sources and if a flammable vapour cloud travels to a non-hazardous area, the probability of ignition increases.

Ignition can occur immediately upon material release or be delayed. Auto-ignition due to hot or unprotected process conditions can also occur. These outcomes are discussed below.

The overall ignition probability for a material is the sum of the immediate ignition probability and the delayed ignition probability. For liquids this is not of vital importance as whether the ignition occurs immediately or is delayed is of little consequence, as a pool fire is the result in both cases, however for flammable gases, the consequences may be markedly different in each case.

Immediate Ignition

Ignition probabilities, for flammable or combustible materials are derived from ignition energies, flammability ranges and fire properties, which can be markedly different for different materials. For example LPG, with a flammability range of 1.8-9.5% and minimum ignition spark energy of 0.25 milliJoules (mJ) in air, is an average reactive gas while H_2 with a flammability range of 4-75% and minimum ignition spark energy of 0.017 mJ in air, is a highly reactive gas. Ignition probabilities for the different flammable and combustible materials are presented and discussed here.

Delayed Ignition / Explosion Probabilities

Ignition of a flammable or combustible gas release may result in a jet fire, which may be preceded by a flash fire, or a VCE should the ignition be delayed.

The probability of a delayed ignition occurring is dependent on the size of the dispersion cloud within the flammable range and the location of the ignition source (Ref. 11). The probabilities of delayed ignition given an ignition source are also presented here.

Auto-Ignition

Often temperatures in plant areas exceed the auto ignition temperature, resulting in immediate ignition. As there is limited information available about the detailed design of any industry proposed for the KIP at this stage, no auto-ignition scenarios were modelled.

The Event Trees developed are presented in **Appendix D**. These determine the frequency of flammable material releases resulting in pool fire or roof fire for flammable and combustible liquids and a jet fire, flash fire or explosion for flammable gases.

A summary of scenarios and associated overall scenario failure frequencies are provided in **Appendix E**.

B3.14 Flammable and Combustible Liquid Ignition Probabilities

Ignition sources may be due to:

- Welding, cutting, grinding;
- Engines and exhausts;
- Hot surfaces other than engines and exhausts;
- Electrical source, including lights, instrumentation, switchgear, motors, mobile phones, radios;
- Static electricity;
- Flames, e.g. fuel fired equipment, matches, cigarette lighters; or
- Arson.

Of the above sources, the most significant source is considered to be electrical. Hot surfaces from operational equipment, could also be a major contributor to ignition sources.

The probability of ignition is dependent on:

- The flammability of the liquid (or the Minimum Ignition Energy (MIE) of a liquid); and

- The number of ignition sources that may be contacted within the flammable vapour envelope associated by the flammable cloud/liquid area associated with the leak; and the energy of the ignition source. **Table B.12** provides ignition probabilities given by Cox, Lees and Ang and have been used for flammable and combustible liquids in this QRA. (Ref. 10)

Table B.12 Flammable and Combustible Liquid Ignition Probabilities

Leak Size (mm)	Probability of Ignition
Minor (< 1 kg/s)	0.01
Major (1 – 50 kg/s)	0.03
Massive (> 50 kg/s)	0.08

B3.15 CS_2 Ignition Probabilities

Ignition probability data which is specific to CS_2 is limited. Ignition probability is dependent on numerous factors including the flammability characteristics of the material together with the potential sources of ignition. For CS_2 the flammability characteristics of wider flammability limits and lower auto-ignition temperature compared to petrol would suggest that a higher ignition probability should be assumed. However, there needs to be consideration of the hazardous area classification requirements which should take into account the higher flammability potential of CS_2, and other specific safety requirements (including those associated with the inerting of reaction vessels and bunds being partially filled with water) should reduce the probability of ignition.

A conservative value of 0.2 has been used.

B3.16 LPG Ignition Probabilities

LPG, with a flammability range of 1.8-9.5% and minimum ignition spark energy of 0.25 milliJoules (mJ) in air, is an average reactive gas.

For the purposes of this QRA, a conservative assumption was made that LPG, propane and butane have the same ignition probability as LPG. **Table B.13** shows ignition probabilities derived from the Safety and Reliability Directorate (SRD) (Ref. 20) for LPG releases. The ignition probabilities are dependent on the ignition source density surrounding the tank and the distance that a gas cloud may travel before there is dilution below the Lower Flammability Limit (LFL).

Ignition sources include goods receival areas, typically located immediately adjacent to storage tanks, with the transport vehicles providing an ignition source.

A conservative assumption was made for this study, whereby the ignition probabilities are increased by an order of magnitude for all releases except for the 50 mm liquid release where the probability was doubled. This was done to account for the ignition sources detailed above. This approach is consistent with the SRD which states that, '"The derived ignition probabilities would appear to be at least an order of magnitude lower for some small and medium leaks. This is not unexpected since this study neglects the effects of temporary ignition sources."

Table B.13 Ignition Probabilities

	Liquid Release			Gas Release		
	10 mm	25 mm	50 mm	10 mm	25 mm	50 mm
SRD	0.007	0.018	0.321	0.002	0.005	0.011
LPG Storage	0.07	0.18	0.642	0.02	0.05	0.11

Final Ignition and Explosion Probabilities for LPG, propane and butane are detailed in **Table B.14** below.

LPG Flash Fire / Explosion Probability

Ignition of a LPG release will result in a jet fire but may be preceded by a Vapour Cloud Explosion or a Flash Fire.

The probability of an explosion occurring given ignition of a flammable gas, is dependent on the rate of the release. **Table B.14** details ignition probabilities given by Cox, Lees and Ang (Ref. 10) for the likelihood of an explosion given the ignition of a flammable gas

Table B.14 Probability of an Explosion Given Ignition

Leak Rate (kg/s)	Probability of Explosion Given Ignition
<1	0.04
1 – 50	0.12
>50	0.3

The probability of delayed ignition occurring resulting in a flash fire followed by a jet-fire has been assumed to be equal to that of an explosion. Final values for Event frequencies were calculated using ETA and are detailed in **Appendix D**.

LPG BLEVE Probability

Although the catastrophic failure frequency for LPG storage vessels is 2 x 10^{-6} as discussed above in Section B4.9, no event tree was employed to determine the relative frequency of consequence for catastrophic failure of LPG storage vessels in the KIP QRA, as a BLEVE was determined to be by far the most significant consequence for this event. A Safety and Reliability Directorate (SRD) report (Ref. 20) provides a range of BLEVE frequencies from 2.1 x 10^{-8} to 73 x 10^{-8} /y depending on the method of modelling and fire brigade response time. These values were based on 100 transfers per year. SRD also note that based on a review of historical accidents the frequency of a BLEVE is 300 x 10^{-8} /y.

The above values compare with derived frequencies of 1,000 x 10^{-8} BLEVEs/y for a fixed storage tank and 1,300 x 10^{-8} BLEVEs/y for a road tanker for a similar LPG storage facility (Ref. 20)

Extensive work to more accurately derive BLEVE failure frequencies was undertaken as part of a “Risk Assessment for Automotive LPG Facilities” (Ref. 21). The result of this work gave derived BLEVE frequencies of 13.4 x 10^{-8} for the tank and 0.65 x 10^{-8} for the road tanker for a typical petrol station LPG tank.

Taking into consideration the confidence limits that may be placed on a derived estimate of a BLEVE frequency, as compared to historical information, a derivation of the BLEVE frequency was not considered warranted. BLEVE failure frequencies for the storage tanks were assumed to be 135 x 10^{-8}/y for each tank. A conservative approach has been made of assuming the frequency is an order of magnitude higher than that derived by Melchers and Feutril (Ref. 21).

Cold Catastrophic Failure

Generic failure frequency for cold catastrophic failure (CCF) range from:

- 6.5 x 10-6, taken from failure data of registered pressure vessels of all kinds (Ref. 14);
- 2 – 6 x 10-6 for values typically used by the HSE for Cl_2 storage vessels (Ref. 13);
- 1 x 10-6 pressure vessels in well operated chemical plants (Ref. 21); to
- 0.12 x 10-6 for LPG storage tanks (Ref. 21).

CCF frequency, for LPG tanks, is considered to have been accounted for in the BLEVE frequency determination detailed above.

B3.17 Overall Final LPG Ignition, Flash Fire and Explosion Probabilities

LPG, Propane or Butane StorageTank Leak (10 mm hole)

Frequency of an LPG, propane or butane release

The frequency of an LPG, propane or butane release (10 mm hole) was determined from parts count.

Probability of immediate ignition

The probability of ignition following an LPG, propane or butane release was derived as follows:

Assume an overall ignition probability of 0.07 (refer to **Table B.13**).

The probability of explosion given ignition was assumed to be 0.12 (refer to **Table B.14**).

Hence, the explosion probability is 0.07 x 0.12 = 0.0084

The probability of delayed ignition resulting in a flash fire followed by a jet fire has been assumed to be equal to that of an explosion, i.e. 0.0084.

The overall probability of immediate ignition / jet fire is: 0.07 – (0.0084 x 2) = **0.0532**.

Hence, the overall probability of not having immediate ignition / jet fire is 1 – 0.0532 = **0.9468**.

Probability of gas cloud explosion

Based on the fact that it was assumed that the probability of delayed ignition resulting in a flash fire followed by a jet fire is equal to that of an explosion (from above), i.e. the probability of a gas cloud explosion following delayed ignition is assumed to be 0.5.

Probability of delayed ignition

The probability of delayed ignition following an LPG, propane or butane release was derived as follows:

The probability of not having an immediate ignition (from above) is **0.9468**.

Hence, 0.9468 x Y x 0.5 = 0.0084 (where Y is probability of delayed ignition).

Hence, the probability of delayed ignition (Y) = 0.0084 / (0.9468 x 0.5) = **0.0177**.

The probability of not having delayed ignition is 1 – 0.0177 = **0.9823**.

LPG, Propane or Butane StorageTank Leak (25 mm hole)

Frequency of an LPG, propane or butane release

The frequency of an LPG, propane or butane release (25mm hole) was determined from parts count.

Probability of immediate ignition

The probability of ignition following an LPG, propane or butane release was derived as follows:

Assume an overall ignition probability of 0.18 (refer to **Table B.13**).

The probability of explosion given ignition was assumed to be 0. 12 (refer to **Table B.14**).

Hence, the explosion probability is 0.18 x 0.12 = 0.0216

The probability of delayed ignition resulting in a flash fire followed by a jet fire has been assumed to be equal to that of an explosion, i.e. 0.0216.

The overall probability of immediate ignition / jet fire is: 0.18 – (0.0216 x 2) = **0.1368**.

Hence, the overall probability of not having immediate ignition / jet fire is 1 – 0.1368 = **0.8632**.

Probability of gas cloud explosion

Based on the fact that it was assumed that the probability of delayed ignition resulting in a flash fire followed by a jet fire is equal to that of an explosion (from above), i.e. the probability of a gas cloud explosion following delayed ignition is assumed to be 0.5.

Probability of delayed ignition

The probability of delayed ignition following an LPG, propane or butane release was derived as follows:

The probability of not having an immediate ignition (from above) is **0.8632**.

Hence, 0.8632 x Y x 0.5 = 0.0216 (where Y is probability of delayed ignition).

Hence, the probability of delayed ignition (Y) = 0.0216 / (0.8632 x 0.5) = **0.05**.

The probability of not having delayed ignition is 1 – 0.05 = **0.95**.

LPG, Propane or Butane StorageTank Leak (50 mm hole)

Frequency of an LPG, propane or butane release

The frequency of a LPG, propane or butane release (50mm hole) was determined from parts count.

Probability of immediate ignition

The probability of ignition following an LPG, propane or butane release was derived as follows:

Assume an overall ignition probability of 0.642 (refer to **Table B.13**).

The probability of explosion given ignition was assumed to be 0. 3 (refer to **Table B.14**).

Hence, the explosion probability is 0.642 x 0.3 = 0.1926 (rounded up to 0.193).

The probability of delayed ignition resulting in a flash fire followed by a jet fire has been assumed to be equal to that of an explosion, i.e. 0.193.

The overall probability of immediate ignition / jet fire is: 0.642 – (0.193 x 2) = **0.256**.

Hence, the overall probability of not having immediate ignition / jet fire is 1 – 0.256 = **0.744**.

Probability of gas cloud explosion

Based on the fact that it was assumed that the probability of delayed ignition resulting in a flash fire followed by a jet fire is equal to that of an explosion (from above), i.e. the probability of a gas cloud explosion following delayed ignition is assumed to be 0.5.

Probability of delayed ignition

The probability of delayed ignition following an LPG, propane or butane release was derived as follows:

The probability of not having an immediate ignition (from above) is **0.744**.

Hence, 0.744 x Y x 0.5 = 0.193 (where Y is probability of delayed ignition).

Hence, the probability of delayed ignition (Y) = 0.193 / (0.744 x 0.5) = **0.519**.

The probability of not having delayed ignition is 1 – 0.519 = **0.481**.

B3.18 H_2 Ignition Probabilities

Immediate Ignition

Ignition probabilities, for H_2 gas, used in this assessment are derived from the Purple Book's (Ref. 9) probability of direct ignition for stationary installations and are presented in **Table B.15**. H_2 with a flammability range of 4-75% and minimum ignition spark energy of 0.017 mJ in air, is a highly reactive gas.

Table B.15 H2 Gas Immediate Ignition Probabilities

Release Source		Substance Ignition Probability
Continuous (kg / s)	**Instantaneous (kg)**	**H_2 (High reactive)**
Minor: < 1	<100*	0.1
Int.: >1 – 10	>100 – 1,000	0.2
Major: >10 – 100	>1,000 – 10,000	0.5
Massive: > 100	>10,000	0.7

* Although instantaneous releases of less than 100 kg are classed as minor having an ignition probability of 0.1, for conservatism, a value of 0.2 was used for the purposes of modelling for this QRA.

Delayed Ignition / Explosion Probabilities

Ignition of a H_2 release may result in a jet fire, which may be preceded by a flash fire or a vapour cloud explosion should the ignition be delayed.

The probability of a delayed ignition occurring is dependent on the size of the dispersion cloud within the flammable range and the location of the ignition source (Ref. 11). In his account of vapour cloud explosions Kletz gives estimates which are evidently for the probability of explosion given leak. These are a probability of >0.1 for a large vapour cloud (>10 ton) and 0.0001 – 0.01 for a medium vapour cloud (1 ton or less) (Ref. 11). Since the mass of H_2 released modelled for this QRA ranges from 0.03 to 0.74 t a value of 0.001 has been used.

All of the continuous releases and the instantaneous inventories listed in **Appendix E** are classed by Ref. 9 as minor or intermediate, where the explosion probability is low. Explosive detonation is largely dependent on speed of flame propagation. In general, the mode of flame propagation will be deflagration (combustion). Under extraordinary conditions a detonation might occur (Ref. 8). Therefore the frequencies of explosion were included in the flash fire frequencies and modelled as such.

The generic failure frequencies used in this assessment are summarised in **Table B.16** below.

Table B.16 Summary of Generic Failure Frequencies

Equipment	**Generic Leak Frequency**		
	(/y x 10^{-6})		
	Hole Diameter		
	10 mm	**25 mm**	**50 mm**
D < 51 mm			
Pipes (m)	100	10	1
Flanges	100	4	
Valves	1,000	100	10
Pumps	3,000	300	30
Connections	5,000	500	
51 mm < D < 251 mm			
Pipes (m)	30	6	0.3
Flanges	300	100	
Valves	1,000	100	10
Pumps	3,000	300	30
D > 251 mm			
Pipes (m)		10	3.1
Flanges	600	100	
Valves		1000	110
Pumps		3,000	330
Other Equipment			
Pressure Vessels	10	5	5
Vessels	10	5	5

B4 PARTS COUNTS

The parts count of plant items for specified inventories as developed in **Section 5** are presented in spreadsheet **Table B.17** to **Table B.56**. A parts count was not conducted for the Fuel Terminal. The derivation of its failure frequency is discussed above. The derivation of the failure frequency for the methanol storage system in the formaldehyde plant located in the Timber Products Plant is based on the failure frequencies calculated for the ethanol storage system in the Fuel Terminal. The derivation of the cyclohexane storage in the Tantalum Refining Plant is also based on the failure frequency of ethanol storage systems in the fuel terminal which is derived as discussed above.

A parts count for the LPG and diesel tanks located in the Silicon Smelter, Synthetic Rutile Plant Vanadium Refining Plant and Aluminium Smelter was not conducted as these were assumed to be stand-alone tanks. Generic failure frequencies discussed above, have been used.

INDUSTRY - FAILURE FREQUENCIES DERIVED FROM PARTS COUNT

Table B.17 Pigment (TiO_2) Plant, Chlorine Storage – Failure Frequencies Derived from Parts Count

Chlorine Storage

Equipment	**No. Parts**	**Part Count Frequency (leaks/y x 10-^{6})**		
		Hole Diameter		
	No.	**10 mm**	**25 mm**	**50 mm**
D < 51 mm				
Pipes (m)	50	5,000	500	50
Flanges	20	2,000	80	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	100	3,000	600	30
Flanges	40	12,000	4,000	0
Manual Valves	20	20,000	2,000	200
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**52,010**	**8,185**	**385**

Table B.18 Pigment (TiO2) Plant, TiCl4 Storage – Failure Frequencies Derived from Parts Count

TiCl$_4$ Storage

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	50	5,000	500	50
Flanges	20	2,000	80	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	400	12,000	2,400	120
Flanges	80	24,000	8,000	0
Manual Valves	40	40,000	4,000	400
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**93,010**	**15,985**	**675**

Table B.19 Chlor-Alkali Plant – Failure Frequencies Derived from Parts Count

Chlorine Storage

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	50	5,000	500	50
Flanges	20	2,000	80	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	100	3,000	600	30
Flanges	40	12,000	4,000	0
Manual Valves	20	20,000	2,000	200
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**52,010**	**8,185**	**385**

Table B.20 Water Treatment Plant – Failure Frequencies Derived from Parts Count based on Chlor-Alkali Plant

Chlorine Storage

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	50	5,000	500	50
Flanges	20	2,000	80	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	100	3,000	600	30
Flanges	40	12,000	4,000	0
Manual Valves	20	20,000	2,000	200
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**52,010**	**8,185**	**385**

Table B.21 Urea Plant – Failure Frequencies Derived from Parts Count

NH_3 Storage and distribution

Equipment	No. Parts	Part Count Frequency (leaks/y x 10^{-6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	20	2,000	200	20
Flanges	20	2,000	80	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	50	1,500	300	15
Flanges	20	6,000	2,000	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	50	0	500	155
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**31,510**	**5,085**	**395**

NICKEL REFINERY – FAILURE FREQUENCIES DERIVED FROM PARTS COUNT

Table B.22 Nickel Refinery, NH_3 Storage – Failure Frequencies Derived from Parts Count

NH_3 Storage

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	20	2,000	200	20
Flanges	20	2,000	80	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	450	13,500	2,700	135
Flanges	122	36,600	12,200	0
Manual Valves	61	61,000	6,100	610
Pumps	1	3,000	300	30
D > 251 mm				
Pipes (m)	50	0	500	155
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**128,110**	**23,085**	**1,055**

Table B.23 Nickel Refinery, H_2S – Failure Frequencies Derived from Parts Count

H_2S Reactor

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	10	1,000	100	10
Flanges	40	4,000	160	0
Manual Valves	20	20,000	2,000	200
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	100	3,000	600	30
Flanges	60	18,000	6,000	0
Manual Valves	30	30,000	3,000	300
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	4	40	20	20
	Total	**76,040**	**11,880**	**560**

Table B.24 Nickel Refinery, SO_2 System – Failure Frequencies Derived from Parts Count

SO_2 System

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-6)		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	5	500	50	5
Flanges	20	2,000	80	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
Connections	10	50,000	5,000	0
51 mm < D < 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	50	0	500	155
Flanges	20	12,000	2,000	0
Manual Valves	5	0	5,000	550
Pumps	0	0	0	0
Other Equipment				
Vessels	0	0	0	0
	Total	**74,500**	**13,630**	**810**

Table B.25 Nickel Refinery, SO_3 System – Failure Frequencies Derived from Parts Count

SO_3 System

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	**10 mm**	**25 mm**	**50 mm**
D < 51 mm				
Pipes (m)	0	0	0	0
Flanges	64	6400	256	0
Manual Valves	32	32000	3200	320
Pumps	0	0	0	0
Connections	35	175000	17500	0
51 mm < D < 251 mm				
Pipes (m)	5	150	30	1.5
Flanges	30	9000	3000	0
Manual Valves	10	10000	1000	100
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	270	0	2700	837
Flanges	40	24000	4000	0
Manual Valves	3	0	3000	330
Pumps	0	0	0	0
Other Equipment				
Vessels	2	20	10	10
	Total	**256570**	**34696**	**1598.5**

Table B.26 Nickel Refinery, H_2 synthesis (PSA) – Failure Frequencies Derived from Parts Count

H_2 synthesis (PSA)

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	0	0	0	0
Flanges	70	7000	280	0
Manual Valves	30	30000	3000	300
Pumps	0	0	0	0
Connections	35	175000	17500	0
51 mm < D < 251 mm				
Pipes (m)	100	3000	600	30
Flanges	220	66000	22000	0
Manual Valves	35	35000	3500	350
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	3	30	15	15
	Total	**316030**	**46895**	**695**

Table B.27 Nickel Refinery, H_2 Storage and distribution – Failure Frequencies Derived from Parts Count

H_2 Storage and distribution

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	400	12000	2400	120
Flanges	100	30000	10000	0
Manual Valves	50	50000	5000	500
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**92010**	**17405**	**625**

Table B.28 Direct Reduced Iron Plant, LPG Storage – Failure Frequencies Derived from Parts Count

LPG Storage

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	20	2,000	200	20
Flanges	20	2,000	80	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	50	1,500	300	15
Flanges	20	6,000	2,000	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	50	0	500	155
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**31,510**	**5,085**	**395**

Table B.29 Sodium Cyanide Plant – Failure Frequencies Derived from Parts Count

NH_3 Storage

Equipment	No. Parts	Part Count Frequency (leaks/y x 10^{-6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	20	2,000	200	20
Flanges	20	2,000	80	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	50	1,500	300	15
Flanges	20	6,000	2,000	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	50	0	500	155
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**31,510**	**5,085**	**395**

Table B.30 Titanium Metal Plant – Failure Frequencies Derived from Parts Count

$TiCl_4$

Equipment	No. Parts	Part Count Frequency (leaks/y x 10^{-6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	30	3,000	300	30
Flanges	60	6,000	240	0
Manual Valves	27	27,000	2,700	270
Pumps	2	6,000	600	60
Connections	30	150,000	15,000	0
51 mm < D < 251 mm				
Pipes (m)	0	0	0	0
Flanges	6	1,800	600	0
Manual Valves	3	3,000	300	30
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	3	30	15	15
	Total	**196,830**	**19,755**	**405**

Table B.31 Oil Refinery, H_2 Storage and Distribution – Failure Frequencies Derived from Parts Count

H_2 Storage and distribution

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	400	12000	2400	120
Flanges	100	30000	10000	0
Manual Valves	50	50000	5000	500
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**92010**	**17405**	**625**

Table B.32 Oil Refinery, HF Storage and Distribution – Failure Frequencies Derived from Parts Count

HF storage and distribution

Equipment	No. Parts	Part Count Frequency (leaks/y x 10^{-6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	30	3000	300	30
Flanges	32	3200	128	0
Manual Valves	17	17000	1700	170
Pumps	1	3000	300	30
Connections	7	35000	3500	0
51 mm < D < 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	2	20	10	10
	Total	**61220**	**5938**	**240**

Table B.33 Xanthate Plant, CS_2 Storage and Transfer – Failure Frequencies Derived from Parts Count

CS_2 Storage and transfer

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	30	3,000	300	30
Flanges	32	3,200	128	0
Manual Valves	17	17,000	1,700	170
Pumps	1	3,000	300	30
Connections	7	35,000	3,500	0
51 mm < D < 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	2	20	10	10
	Total	**61,220**	**5,938**	**240**

Table B.34 Xanthate Plant, Alcohol Storage and Transfer – Failure Frequencies Derived from Parts Count

Alcohol Storage and transfer

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	30	3000	300	30
Flanges	60	6000	240	0
Manual Valves	27	27000	2700	270
Pumps	2	6000	600	60
Connections	30	150000	15000	0
51 mm < D < 251 mm				
Pipes (m)	0	0	0	0
Flanges	6	1,800	600	0
Manual Valves	3	3,000	300	30
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	6	3600	600	0
Manual Valves	3	0	3000	330
Pumps	0	0	0	0
Other Equipment				
Vessels	3	30	15	15
	Total	**200,430**	**23,355**	**735**

Table B.35 Ammonia Synthesis Plant, NH_3 Storage and Distribution – Failure Frequencies Derived from Parts Count

NH_3 Storage and Distribution

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	40	4,000	400	40
Flanges	40	4,000	160	0
Manual Valves	20	20,000	2,000	200
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	100	3,000	600	30
Flanges	40	12,000	4,000	0
Manual Valves	20	20,000	2,000	200
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	100	0	1,000	310
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	2	20	10	10
	Total	**63,020**	**10,170**	**790**

Table B.36 Fertiliser Plant – Failure Frequencies Derived from Parts Count

Ammonia Storage

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	20	2,000	200	20
Flanges	20	2,000	80	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	50	1,500	300	15
Flanges	20	6,000	2,000	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	50	0	500	155
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**31,510**	**5,085**	**395**

Table B.37 LPG Facility, Propane Storage Bullet – Failure Frequencies Derived from Parts Count

Propane Storage Bullet

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	20	2,000	200	20
Flanges	20	2,000	80	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	50	1,500	300	15
Flanges	20	6,000	2,000	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	50	0	500	155
Flanges	0	0	0	0
Manual Valves	50	0	50,000	5,500
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**31,510**	**55,085**	**5,895**

Table B.38 LPG Facility, LPG, Propane or Butane Storage Bullet – Failure Frequencies Derived from Parts Count

LPG, propane or butane Storage Bullet

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	20	2000	200	20
Flanges	20	2000	80	0
Manual Valves	10	10000	1000	100
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	50	1,500	300	15
Flanges	20	6,000	2,000	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	50	0	500	155
Flanges	40	24000	4000	0
Manual Valves	20	0	20000	2200
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**55,510**	**29,085**	**2,595**

Table B.39 Hydrogen Peroxide Plant, H_2 synthesis (PSA) – Failure Frequencies Derived from Parts Count based on Nickel Refinery

H_2 synthesis (PSA)

Equipment	**No. Parts**	**Part Count Frequency (leaks/y x 10-^{6})**		
		Hole Diameter		
	No.	**10 mm**	**25 mm**	**50 mm**
D < 51 mm				
Pipes (m)	0	0	0	0
Flanges	70	7000	280	0
Manual Valves	30	30000	3000	300
Pumps	0	0	0	0
Connections	35	175000	17500	0
51 mm < D < 251 mm				
Pipes (m)	100	3000	600	30
Flanges	220	66000	22000	0
Manual Valves	35	35000	3500	350
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	3	30	15	15
	Total	**316030**	**46895**	**695**

Table B.40 Hydrogen Peroxide Plant, H_2 Storage and distribution – Failure Frequencies Derived from Parts Count based on Nickel Refinery

H_2 Storage and distribution

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	400	12000	2400	120
Flanges	100	30000	10000	0
Manual Valves	50	50000	5000	500
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**92010**	**17405**	**625**

Table B.41 Lithium Metal Facility, Chlorine Storage – Failure Frequencies Derived from Parts Count based on Pigment Plant

Chlorine Storage

Equipment	No. Parts	Part Count Frequency (leaks/y x 10-^{6})		
		Hole Diameter		
	No.	10 mm	25 mm	50 mm
D < 51 mm				
Pipes (m)	50	5,000	500	50
Flanges	20	2,000	80	0
Manual Valves	10	10,000	1,000	100
Pumps	0	0	0	0
Connections	0	0	0	0
51 mm < D < 251 mm				
Pipes (m)	100	3,000	600	30
Flanges	40	12,000	4,000	0
Manual Valves	20	20,000	2,000	200
Pumps	0	0	0	0
D > 251 mm				
Pipes (m)	0	0	0	0
Flanges	0	0	0	0
Manual Valves	0	0	0	0
Pumps	0	0	0	0
Other Equipment				
Vessels	1	10	5	5
	Total	**52,010**	**8,185**	**385**

Table B.42 Representative Parts Count – Pigment (TiO_2) Plant

Pigment

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***Chlorine Storage***	1	50	20	10			100	40	20					
Total	**1**	**50**	**20**	**10**	**0**	**0**	**100**	**40**	**20**	**0**	**0**	**0**	**0**	**0**
2 ***$TiCl_4$ Storage***	1	50	20	10			400	80	40					
Total	**1**	**50**	**20**	**10**	**0**	**0**	**400**	**80**	**40**	**0**	**0**	**0**	**0**	**0**

Table B.43 Representative Parts Count – Chlor-Alkali Plant

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***Chlorine Storage***	1	50	20	10			100	40	20					
Total	**1**	**50**	**20**	**10**	**0**	**0**	**100**	**40**	**20**	**0**	**0**	**0**	**0**	**0**

Table B.44 Representative Parts Count – Water Treatment Plant based on Chlor-Alkali Plant

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***Chlorine Storage***	1	50	20	10			100	40	20					
Total	**1**	**50**	**20**	**10**	**0**	**0**	**100**	**40**	**20**	**0**	**0**	**0**	**0**	**0**

Table B.45 Representative Parts Count – Urea Plant

Urea Plant

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***NH_3 Storage and distribution***	1	20	20	10			50	20	10		50	40	20	
Total	**1**	**20**	**20**	**10**	**0**	**0**	**50**	**20**	**10**	**0**	**50**	**40**	**20**	**0**

Table B.46 Representative Parts Count – Nickel Refinery

Ni Refinery

		D < 51 mm					**50 mm < D < 251 mm**				**D > 251 mm**			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***NH_3 Storage***	1	20	20	10			450	122	61	1	50	40	20	
Total	**1**	**20**	**20**	**10**	**0**	**0**	**450**	**122**	**61**	**1**	**50**	**40**	**20**	**0**
2 ***H_2S Reactor***	4	10	40	20			100	60	30					
Total	**4**	**10**	**40**	**20**	**0**	**0**	**100**	**60**	**30**	**0**	**0**	**0**	**0**	**0**
3 ***SO_2 System***		5	20	10		10					50	20	5	
Total	**0**	**5**	**20**	**10**	**0**	**10**	**0**	**0**	**0**	**0**	**50**	**20**	**5**	**0**
4 ***SO_3 System***	2		64	32		35	5	30	10		270	40	3	
Total	**2**	**0**	**64**	**32**	**0**	**35**	**5**	**30**	**10**	**0**	**270**	**40**	**3**	**0**
5 ***H_2 synthesis (PSA)***	3		70	30		35	100	220	35					
Total	**3**	**0**	**70**	**30**	**0**	**35**	**100**	**220**	**35**	**0**	**0**	**0**	**0**	**0**
6 ***H_2 Storage and distribution***	1						400	100	50					
Total	**1**	**0**	**0**	**0**	**0**	**0**	**400**	**100**	**50**	**0**	**0**	**0**	**0**	**0**

Table B.47 Representative Parts Count – Direct Reduced Iron Plant

DRI

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***LPG Storage***	1	20	20	10			50	20	10		50	40	20	
Total	**1**	**20**	**20**	**10**	**0**	**0**	**50**	**20**	**10**	**0**	**50**	**40**	**20**	**0**

Table B.48 Representative Parts Count – Sodium Cyanide Plant

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 NH_3 ***Storage***	1	20	20	10			50	20	10		50	40	20	
Total	**1**	**20**	**20**	**10**	**0**	**0**	**50**	**20**	**10**	**0**	**50**	**40**	**20**	**0**

Table B.49 Representative Parts Count – Titanium Metal Plant

Ti Metal Plant

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***$TiCl_4$***	3	30	60	27	2	30		6	3			6	3	
Total	**3**	**30**	**60**	**27**	**2**	**30**	**0**	**6**	**3**	**0**	**0**	**6**	**3**	**0**

Table B.50 Representative Parts Count – Oil Refinery

Oil Refinery

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***H_2 Storage and distribution***	1						400	100	50					
Total	**1**	**0**	**0**	**0**	**0**	**0**	**400**	**100**	**50**	**0**	**0**	**0**	**0**	**0**
2 ***HF storage and distribution***	2	30	32	17	1	7								
Total	**2**	**30**	**32**	**17**	**1**	**7**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table B.51 Representative Parts Count – Xanthate Plant

Xanthate Plant

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***CS_2* Storage and transfer**	2	30	32	17	1	7								
Total	**2**	**30**	**32**	**17**	**1**	**7**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2 ***Alcohol Storage and transfer***	3	30	60	27	2	30		6	3			6	3	
Total	**3**	**30**	**60**	**27**	**2**	**30**	**0**	**6**	**3**	**0**	**0**	**6**	**3**	**0**

Table B.52 Representative Parts Count – Ammonia Synthesis Plant

Ammonia Plant

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***NH_3* Storage and Distribution**	2	40	40	20			100	40	20		100	80	40	
Total	**2**	**40**	**40**	**20**	**0**	**0**	**100**	**40**	**20**	**0**	**100**	**80**	**40**	**0**

Table B.53 Representative Parts Count – Fertiliser Plant

Fertiliser Plant

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***Ammonia Storage***	1	20	20	10			50	20	10		50	40	20	
Total	**1**	**20**	**20**	**10**	**0**	**0**	**50**	**20**	**10**	**0**	**50**	**40**	**20**	**0**

Table B.54 Representative Parts Count – LPG Facility

LPG

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***Propane Storage Bullet***	1	20	20	10			50	20	10		50	40	20	
Total	**1**	**20**	**20**	**10**	**0**	**0**	**50**	**20**	**10**	**0**	**50**	**40**	**20**	**0**
2 ***LPG, propane or butane Storage Bullet***	1	20	20	10			50	20	10		50	40	20	
Total	**1**	**20**	**20**	**10**	**0**	**0**	**50**	**20**	**10**	**0**	**50**	**40**	**20**	**0**

Table B.55 Representative Parts Count – Hydrogen Peroxide Plant based on Nickel Refinery

H_2 Storage and Distribution

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***H_2 synthesis (PSA)***	3		70	30		35	100	220	35					
Total	**3**	**0**	**70**	**30**	**0**	**35**	**100**	**220**	**35**	**0**	**0**	**0**	**0**	**0**
1 ***H_2 Storage and distribution***	1						400	100	50					
Total	**1**	**0**	**0**	**0**	**0**	**0**	**400**	**100**	**50**	**0**	**0**	**0**	**0**	**0**

Table B.56 Representative Parts Count – Lithium Metal Facility based on Pigment Plant

Cl_2 Storage

		D < 51 mm					50 mm < D < 251 mm				D > 251 mm			
Line	**Vessel**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Connections**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**	**Pipes (m)**	**Flanges**	**Valves**	**Pumps**
1 ***Chlorine Storage***	1	50	20	10			100	40	20					
Total	**1**	**50**	**20**	**10**	**0**	**0**	**100**	**40**	**20**	**0**	**0**	**0**	**0**	**0**

APPENDIX C

FAULT TREE ANALYSIS

LIST OF FIGURES

LIST OF TABLES

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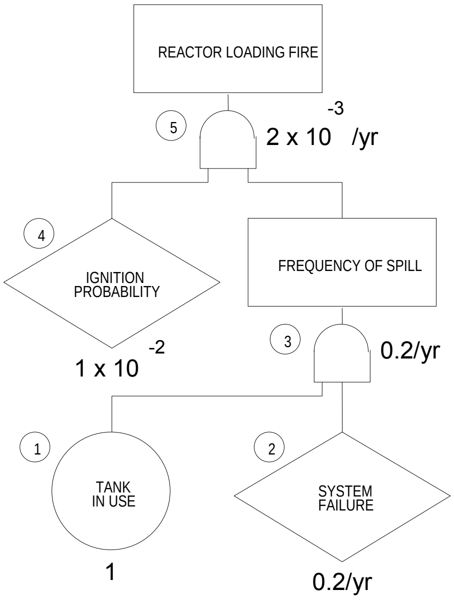
C1. Introduction

This section details the Fault Tree Analyses (FTA) used to determine failure event frequencies used in the *Riskcurves* modelling. The methanol storage system in the formaldehyde plant located in the Timber Products Plant and the cyclohexane storage system in the Tantalum Refining Plant are assumed as only containing one tank each. There is therefore no potential for knock-on and a FTA has not been carried out. The LPG and diesel tanks located in the Silicon Smelter, Synthetic Rutile Plant Vanadium Refining Plant and Aluminium Smelter are also assumed as stand-alone tanks.

Figure C.1 Fault Tree Analysis – Fire from Transferring Alcohol to Xanthate Reactor

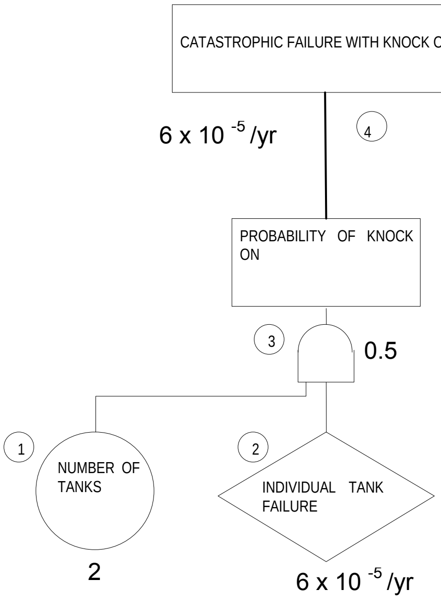


1. As per calculation table below.
2. See Parts Count Table Above.

Table C.1 Fault Tree Analysis – Fire from Transferring Alcohol to Xanthate Reactor Result

Alcohol Transfer To Xanthate Reactor Hole Size (mm)	10	25	50	Catastrophic (25 m x 15 m bunded area)
Tank Storage and Reactor Filling (Time in operation)	1	1	1	1
System failure	2.00E-01	2.34E-02	7.35E-04	1.00E-05
Frequency of spill	2.00E-01	2.34E-02	7.35E-04	1.00E-05
Ignition probability	1.00E-02	3.00E-02	3.00E-02	8.00E-02
Alcohol Storage and Reactor Filling Fire	2.00E-03	7.01E-04	2.21E-05	8.00E-07

Figure C.2 Fault Tree Analysis – Catastrophic Failure of Large ULP Tanks with Knock On Effects at Fuel Terminal

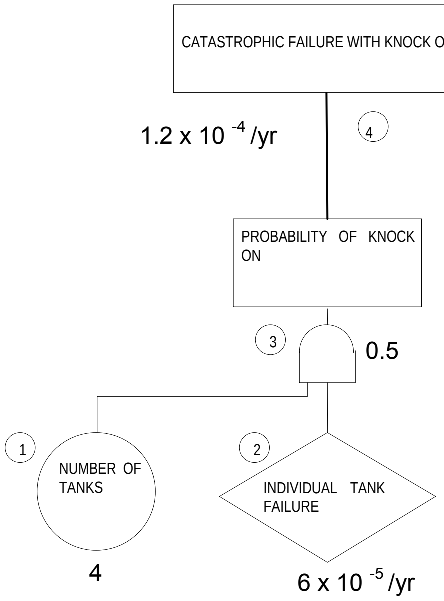


1. As per calculation table below.
2. See Parts Count Table Above.

Table C.2 Fault Tree Analysis – Catastrophic Failure of Large ULP Tanks with Knock On Effects at Fuel Terminal

Catastrophic Failure of Large ULP Tanks with Knock On	Probability /yr
Individual Tank Failure	6.00E-05
Total tanks	2
Probability of Knock on	0.5
Catastrophic failure with Knock On	6.00E-05

Figure C.3 Fault Tree Analysis – Catastrophic Failure of ULP Tanks with Knock On Effects at Fuel Terminal.

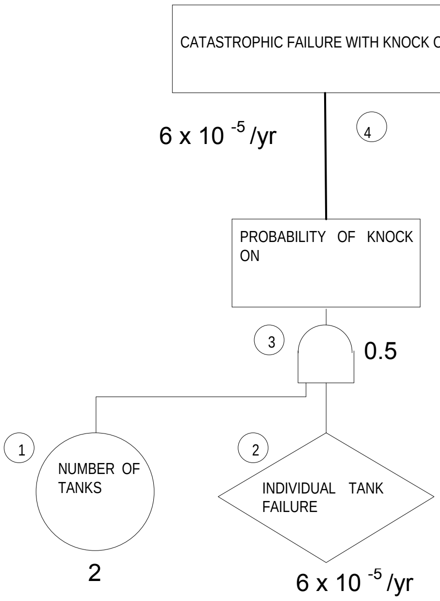


1. As per calculation table below.
2. See Parts Count Table Above.

Table C.3 Fault Tree Analysis – Catastrophic Failure of ULP Tanks with Knock On Effects at Fuel Terminal

Catastrophic Failure of ULP Tanks with Knock On	Probability /yr
Individual Tank Failure	6.00E-05
Total tanks	4
Probability of Knock on	0.5
Catastrophic failure with Knock On	1.20E-04

Figure C.4 Fault Tree Analysis – Catastrophic Failure of Ethanol Tanks with Knock On Effects at Fuel Terminal

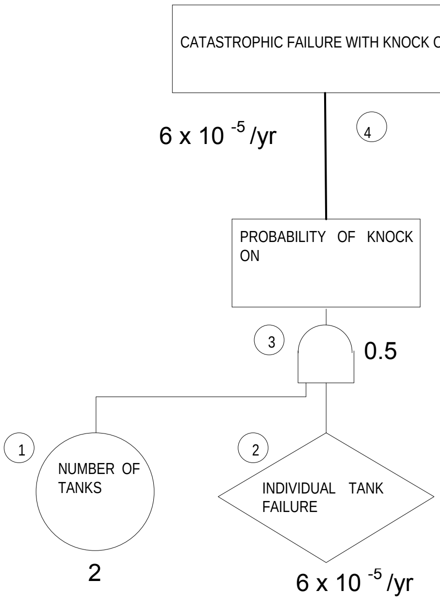


1. As per calculation table below.
2. See Parts Count Table Above.

Table C.4 Fault Tree Analysis – Catastrophic Failure of Ethanol Tanks with Knock On Effects at Fuel Terminal

Catastrophic Failure of Ethanol Tanks with Knock On	Probability /yr
Individual Tank Failure	6.00E-05
Total tanks	2
Probability of Knock on	0.5
Catastrophic failure with Knock On	6.00E-05

Figure C.5 Fault Tree Analysis – Catastrophic Failure of Large ULP Tanks with Knock On Effects at Oil Refinery

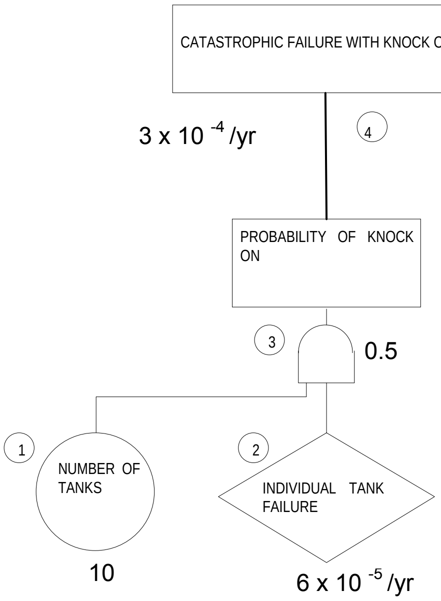


1. As per calculation table below.
2. See Parts Count Table Above.

Table C.5 Fault Tree Analysis – Catastrophic Failure of Large ULP Tanks with Knock On Effects at Oil Refinery

Catastrophic Failure of Large ULP Tanks with Knock On	Probability /yr
Individual Tank Failure	6.00E-05
Total tanks	2
Probability of Knock on	0.5
Catastrophic failure with Knock On	6.00E-05

Figure C.6 Fault Tree Analysis – Catastrophic Failure of ULP Tanks with Knock On Effects at Oil Refinery.

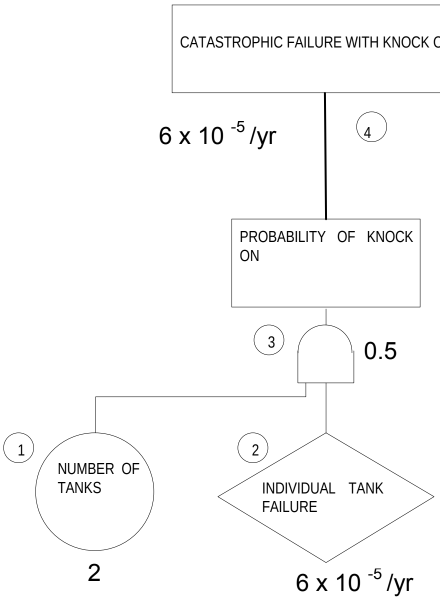


1. As per calculation table below.
2. See Parts Count Table Above.

Table C.6 Fault Tree Analysis – Catastrophic Failure of ULP Tanks with Knock On Effects at Oil Refinery

Catastrophic Failure of ULP Tanks with Knock On	Probability /yr
Individual Tank Failure	6.00E-05
Total tanks	10
Probability of Knock on	0.5
Catastrophic failure with Knock On	3.00E-04

Figure C.7 Fault Tree Analysis – Catastrophic Failure of Large Diesel Tanks with Knock On Effects at Oil Refinery

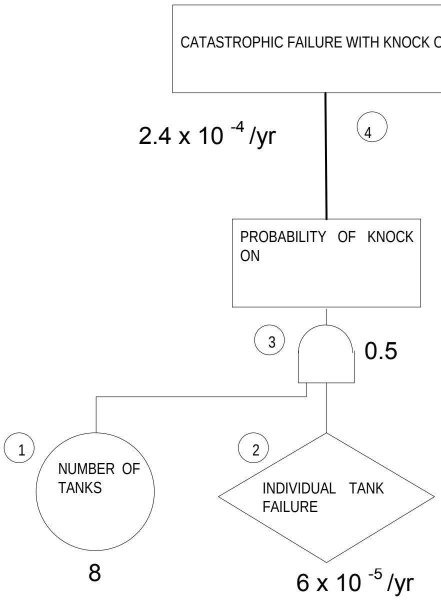


1. As per calculation table below.
2. See Parts Count Table Above.

Table C.7 Fault Tree Analysis – Catastrophic Failure of Large Diesel Tanks with Knock On Effects at Oil Refinery

Catastrophic Failure of Large Diesel Tanks with Knock On	**Probability /yr**
Individual Tank Failure	6.00E-05
Total tanks	2
Probability of Knock on	0.5
Catastrophic failure with Knock On	6.00E-05

Figure C.8 Fault Tree Analysis – Catastrophic Failure of Diesel Tanks with Knock On Effects at Oil Refinery.

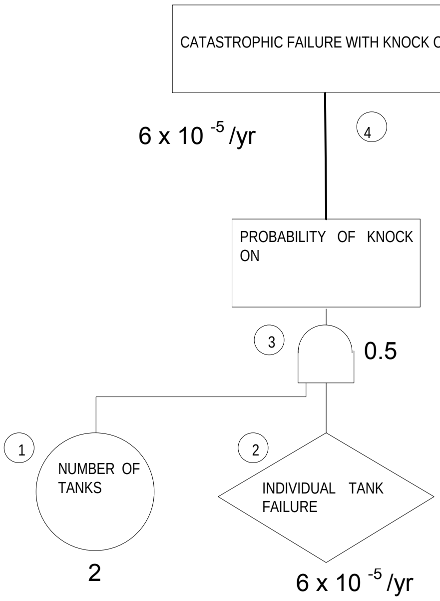


1. As per calculation table below.
2. See Parts Count Table Above.

Table C.8 Fault Tree Analysis – Catastrophic Failure of Diesel Tanks with Knock On Effects at Oil Refinery

Catastrophic Failure of Diesel Tanks with Knock On	Probability /yr
Individual Tank Failure	6.00E-05
Total tanks	8
Probability of Knock on	0.5
Catastrophic failure with Knock On	2.40E-04

Figure C.9 Fault Tree Analysis – Catastrophic Failure of Kerosene Tanks with Knock On Effects at Oil Refinery.

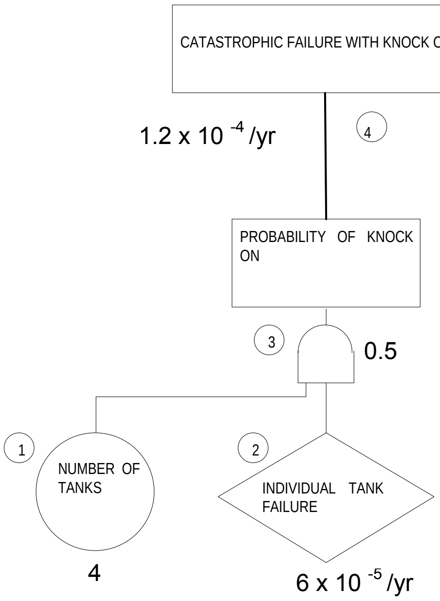


1. As per calculation table below.
2. See Parts Count Table Above.

Table C.9 Fault Tree Analysis – Catastrophic Failure of Kerosene Tanks with Knock On Effects at Oil Refinery

Catastrophic Failure of Kerosene Tanks with Knock On	Probability /yr
Individual Tank Failure	6.00E-05
Total tanks	2
Probability of Knock on	0.5
Catastrophic failure with Knock On	6.00E-05

Figure C.10 Fault Tree Analysis – Catastrophic Failure of AVGAS Tanks with Knock On Effects at Oil Refinery.



1. As per calculation table below.
2. See Parts Count Table Above.

Table C.10 Fault Tree Analysis – Catastrophic Failure of AVGAS Tanks with Knock On Effects at Oil Refinery

Catastrophic Failure of AVGAS Tanks with Knock On	Probability /yr
Individual Tank Failure	6.00E-05
Total tanks	4
Probability of Knock on	0.5
Catastrophic failure with Knock On	1.20E-04

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APPENDIX D

EVENT TREES

LIST OF FIGURES

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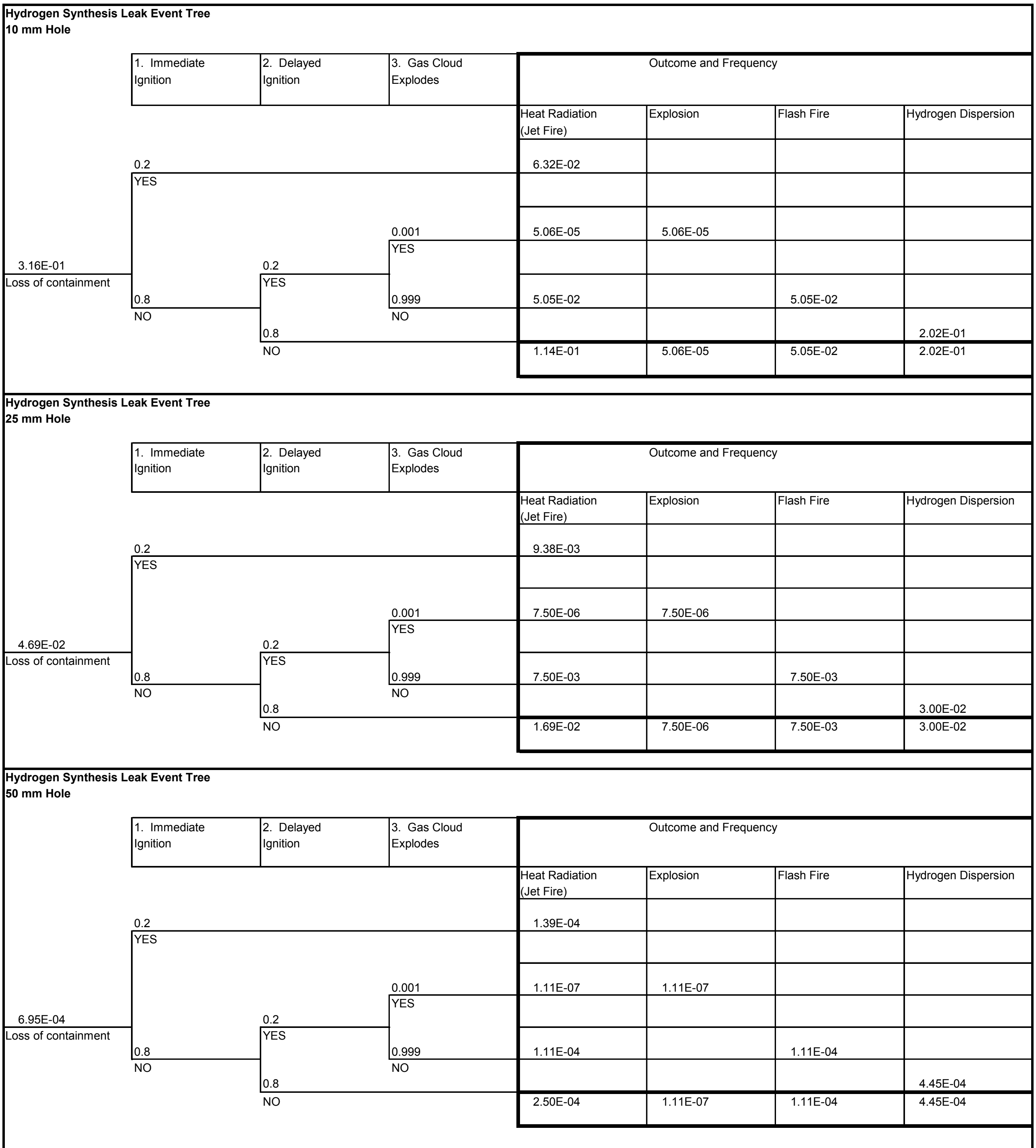
D1 Introduction

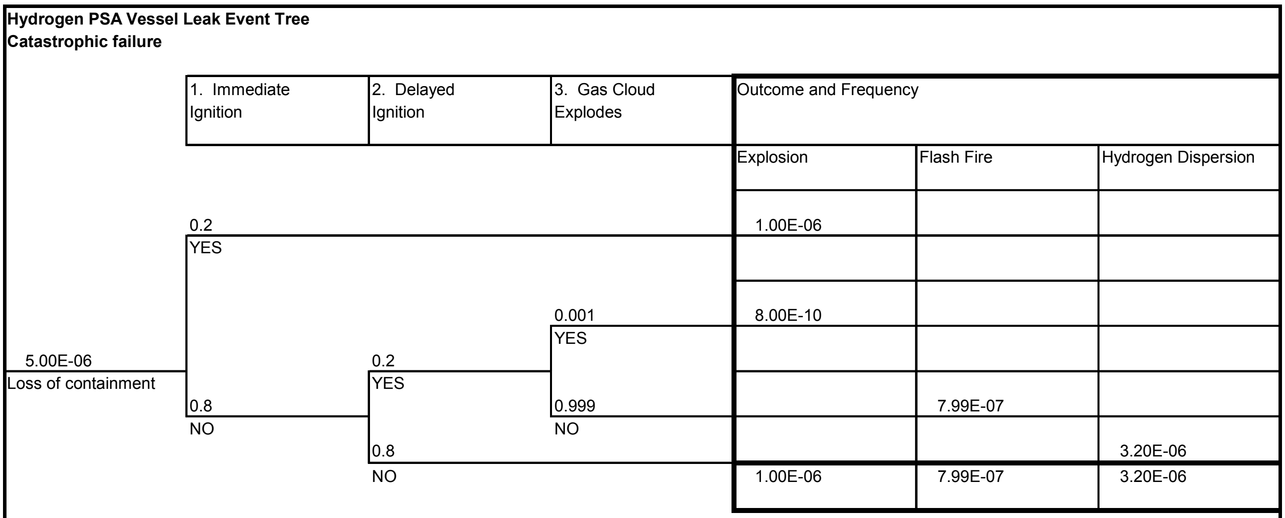
This section details the Event Tree Analyses (ETA) that have been used to determine final event frequencies for the various flammable substances modelled in this study. These have been used as inputs into the *Riskcurves* modelling software package.

Figure D.1 Event Tree for Nickel Refinery Hydrogen Synthesis Plant



1. Ignition probability dependent on flammability characteristics, release rate and ignition sources (refer to main body of report).
2. Relative probability of delayed ignition assumed to be the same as for immediate ignition.
3. Probability of explosion is dependent on the degree of confinement, mass of flammable material in cloud, with a value of 0.001 based on mass of material being less than 1t (Lees).

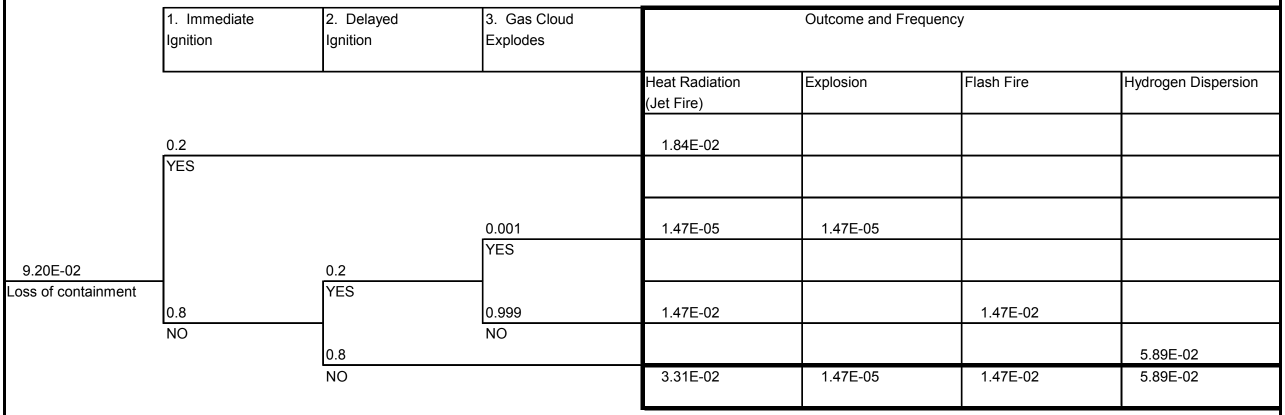
Figure D.2 Event Tree for Nickel Refinery Hydrogen PSA Vessel



1. Ignition probability dependent on flammability characteristics, release rate and ignition sources (refer to main body of report).
2. Relative probability of delayed ignition assumed to be the same as for immediate ignition.
3. Probability of explosion is dependent on the degree of confinement, mass of flammable material in cloud, with a value of 0.001 based on mass of material being less than 1t (Lees).

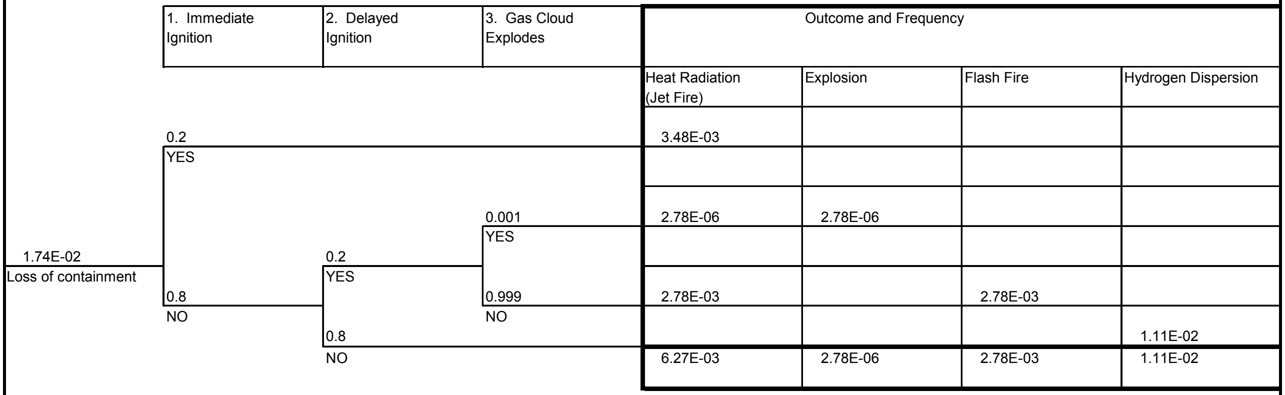
Figure D.3 Event Tree for Nickel Refinery Hydrogen Storage Vessel and Reticulation

Hydrogen Storage Leak Event Tree
10 mm Hole



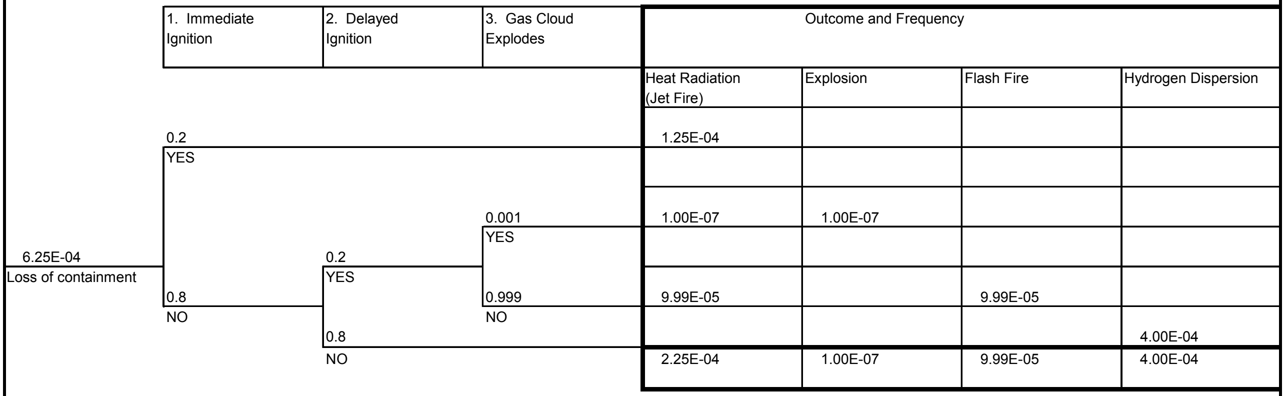
	1. Immediate Ignition	2. Delayed Ignition	3. Gas Cloud Explodes	Outcome and Frequency			
				Heat Radiation (Jet Fire)	Explosion	Flash Fire	Hydrogen Dispersion
9.20E-02 Loss of containment	0.2 YES			1.84E-02			
	0.8 NO	0.2 YES	0.001 YES	1.47E-05	1.47E-05		
			0.999 NO	1.47E-02		1.47E-02	
		0.8 NO					5.89E-02
				3.31E-02	1.47E-05	1.47E-02	5.89E-02

Hydrogen Storage Leak Event Tree
25 mm Hole



	1. Immediate Ignition	2. Delayed Ignition	3. Gas Cloud Explodes	Outcome and Frequency			
				Heat Radiation (Jet Fire)	Explosion	Flash Fire	Hydrogen Dispersion
1.74E-02 Loss of containment	0.2 YES			3.48E-03			
	0.8 NO	0.2 YES	0.001 YES	2.78E-06	2.78E-06		
			0.999 NO	2.78E-03		2.78E-03	
		0.8 NO					1.11E-02
				6.27E-03	2.78E-06	2.78E-03	1.11E-02

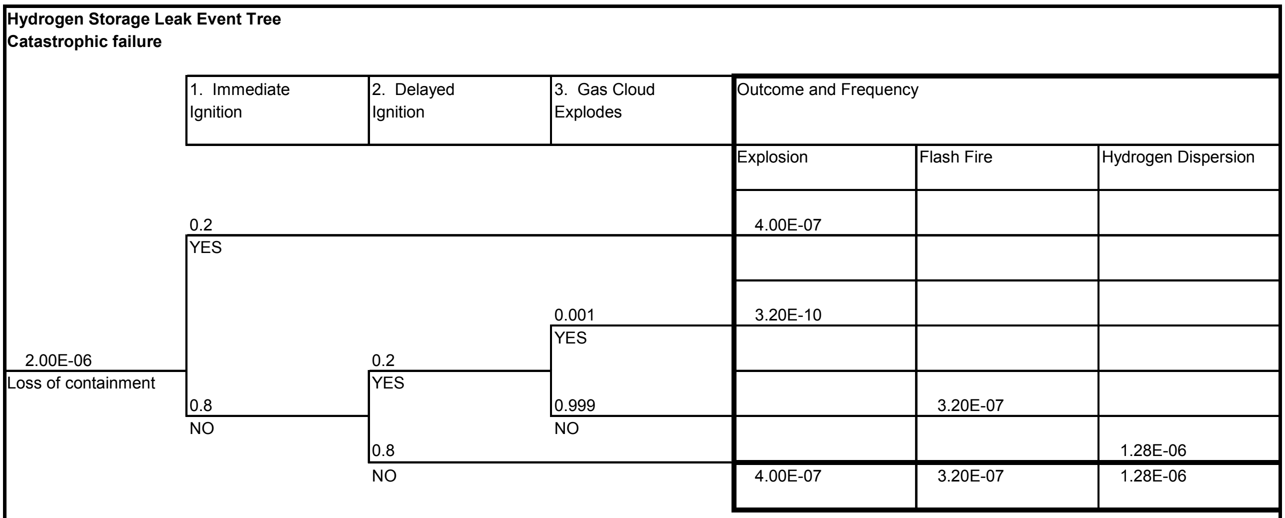
Hydrogen Storage Leak Event Tree
50 mm Hole



	1. Immediate Ignition	2. Delayed Ignition	3. Gas Cloud Explodes	Outcome and Frequency			
				Heat Radiation (Jet Fire)	Explosion	Flash Fire	Hydrogen Dispersion
6.25E-04 Loss of containment	0.2 YES			1.25E-04			
	0.8 NO	0.2 YES	0.001 YES	1.00E-07	1.00E-07		
			0.999 NO	9.99E-05		9.99E-05	
		0.8 NO					4.00E-04
				2.25E-04	1.00E-07	9.99E-05	4.00E-04

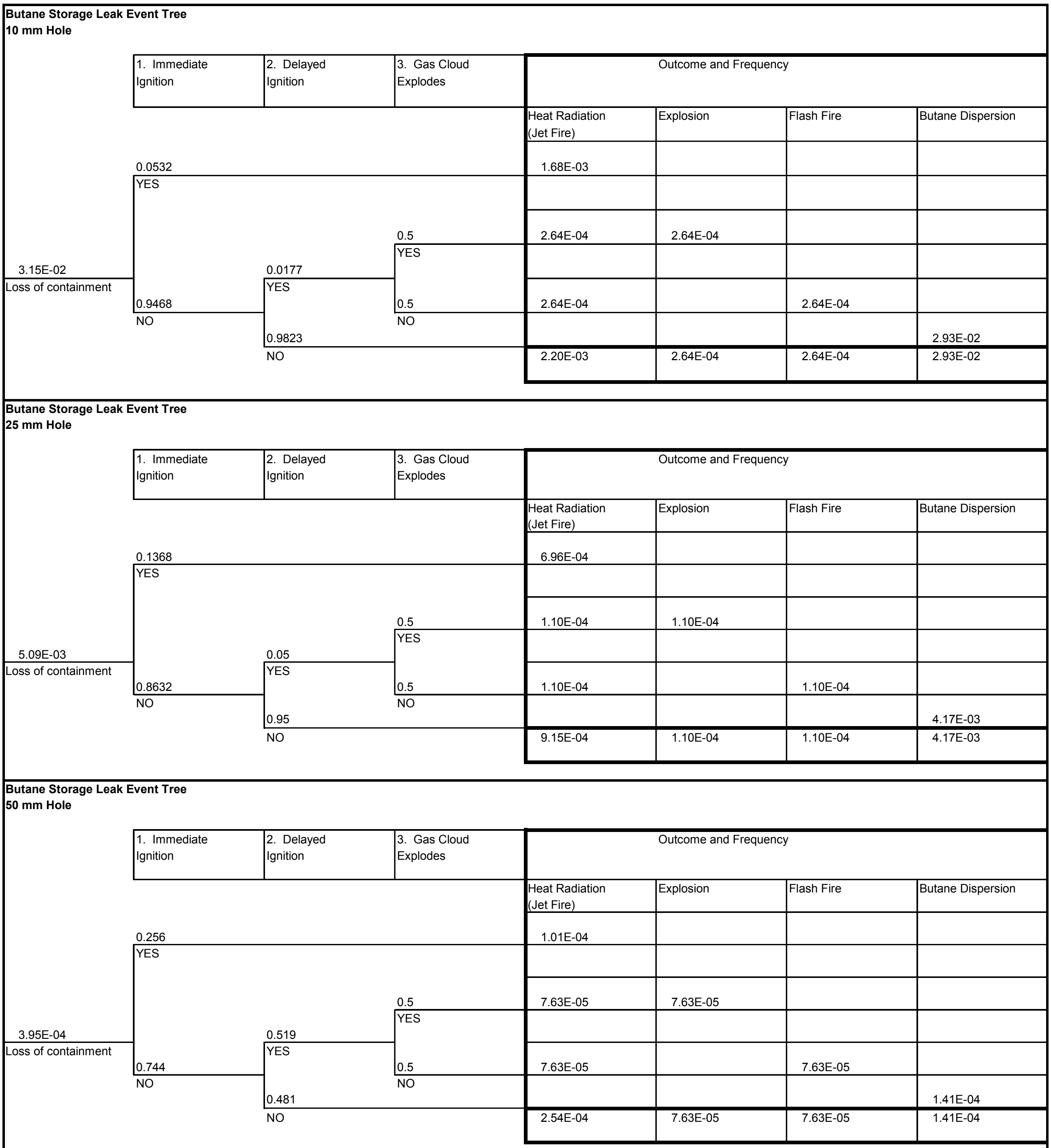
1. Ignition probability dependent on flammability characteristics, release rate and ignition sources (refer to main body of report).
2. Relative probability of delayed ignition assumed to be the same as for immediate ignition.
3. Probability of explosion is dependent on the degree of confinement, mass of flammable material in cloud, with a value of 0.001 based on mass of material being less than 1t (Lees).

Figure D.4 Event Tree for Nickel Refinery Hydrogen Storage Vessel Catastrophic Failure



1. Ignition probability dependent on flammability characteristics, release rate and ignition sources (refer to main body of report).
2. Relative probability of delayed ignition assumed to be the same as for immediate ignition.
3. Probability of explosion is dependent on the degree of confinement, mass of flammable material in cloud, with a value of 0.001 based on mass of material being less than 1t (Lees).

Figure D.5 Event Tree for Direct Reduced Iron Plant LPG, propane or butane Storage Vessel



Butane Storage Leak Event Tree
10 mm Hole

Heat Radiation (Jet Fire)	Explosion	Flash Fire	Butane Dispersion
1.68E-03			
2.64E-04	2.64E-04		
2.64E-04		2.64E-04	
			2.93E-02
2.20E-03	2.64E-04	2.64E-04	2.93E-02

Butane Storage Leak Event Tree
25 mm Hole

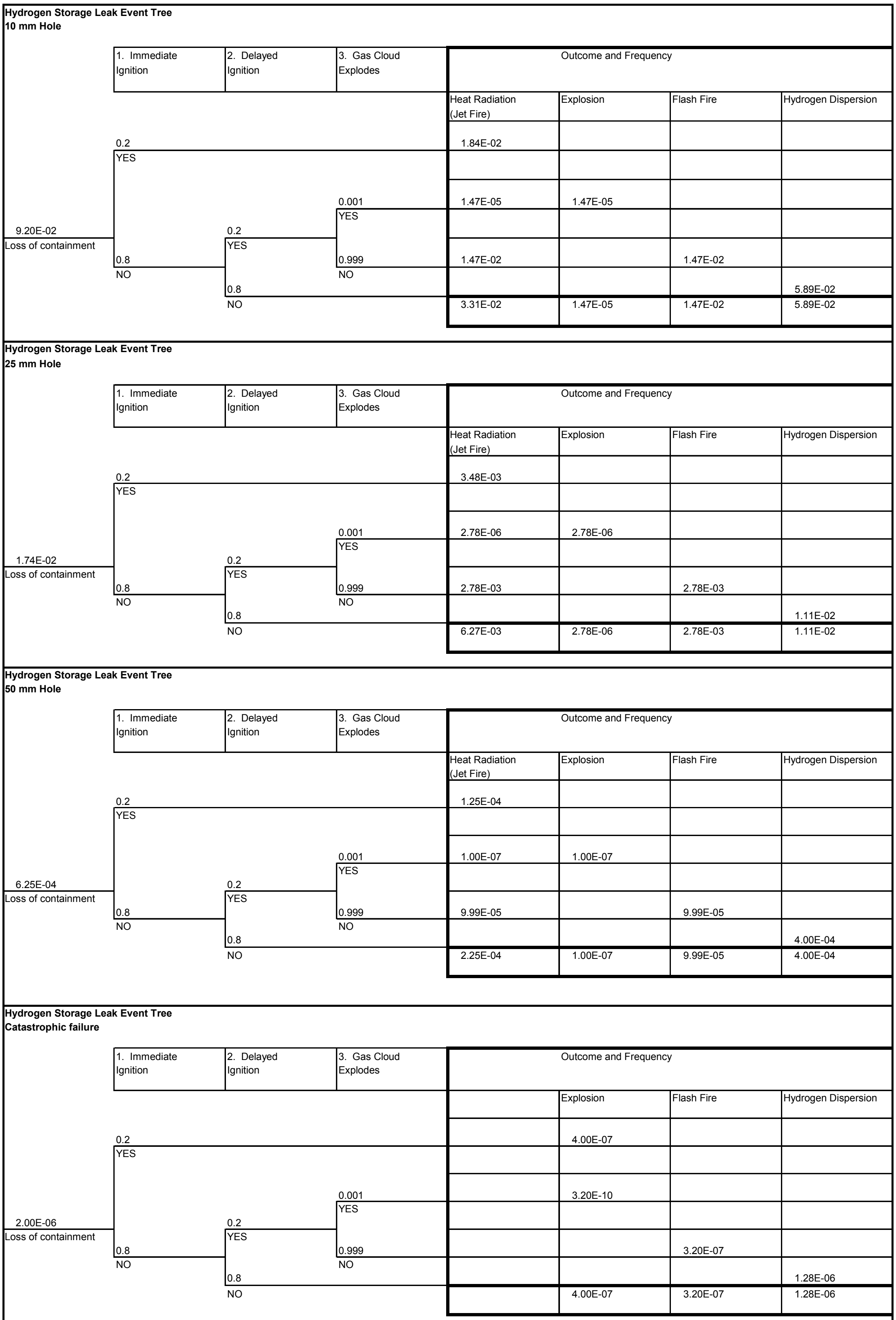
Heat Radiation (Jet Fire)	Explosion	Flash Fire	Butane Dispersion
6.96E-04			
1.10E-04	1.10E-04		
1.10E-04		1.10E-04	
			4.17E-03
9.15E-04	1.10E-04	1.10E-04	4.17E-03

Butane Storage Leak Event Tree
50 mm Hole

Heat Radiation (Jet Fire)	Explosion	Flash Fire	Butane Dispersion
1.01E-04			
7.63E-05	7.63E-05		
7.63E-05		7.63E-05	
			1.41E-04
2.54E-04	7.63E-05	7.63E-05	1.41E-04

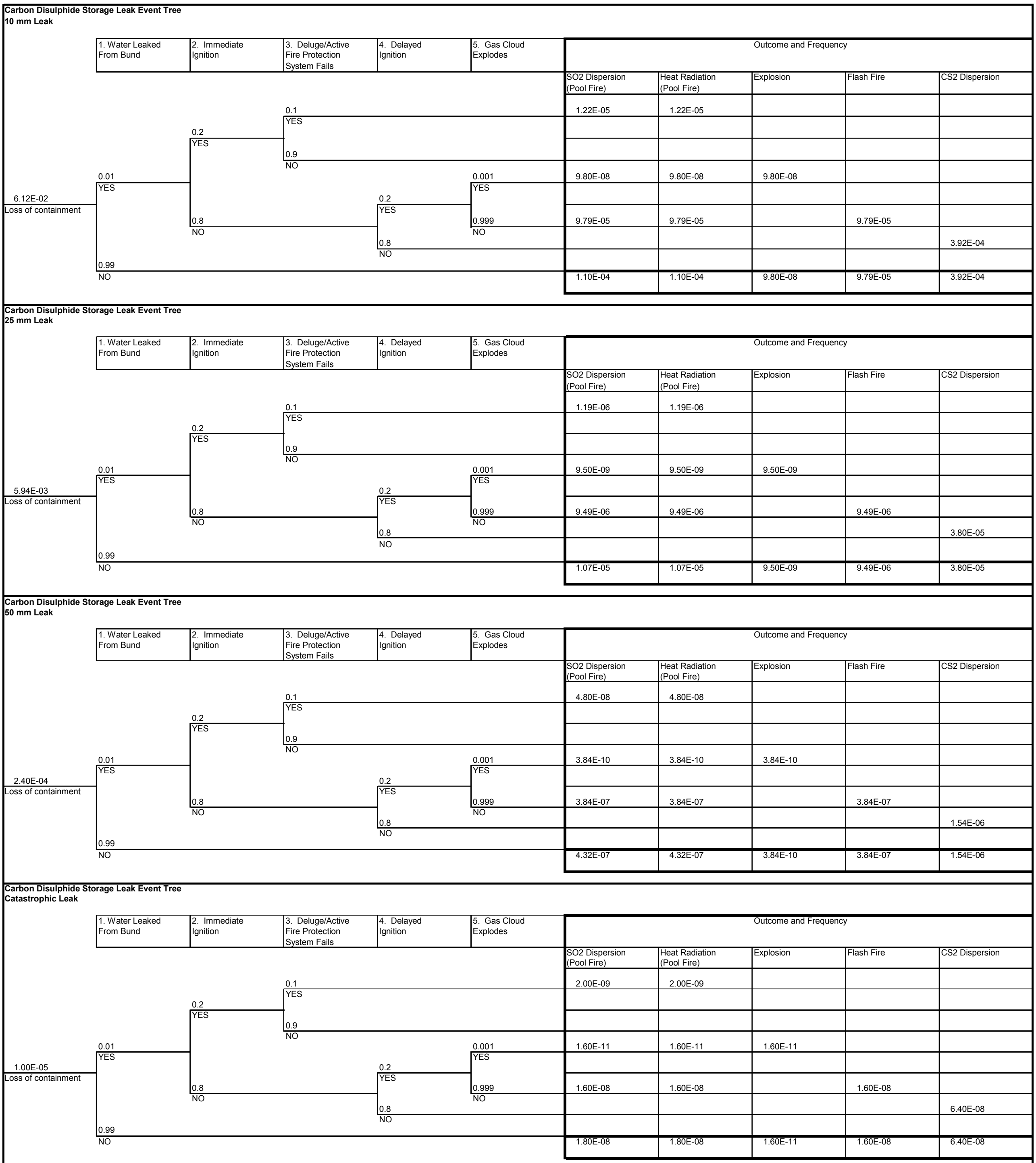
1. Ignition probability dependent on flammability characteristics, release rate and ignition sources (refer to main body of report).
2. Relative probability of delayed ignition assumed to be the same as for immediate ignition.
3. Probability of explosion is dependent on the degree of confinement, mass of flammable material in cloud, with a value of 0.001 based on mass of material being less than 1t (Lees).

Figure D.6 Event Tree for Oil Refinery Hydrogen Storage Vessel



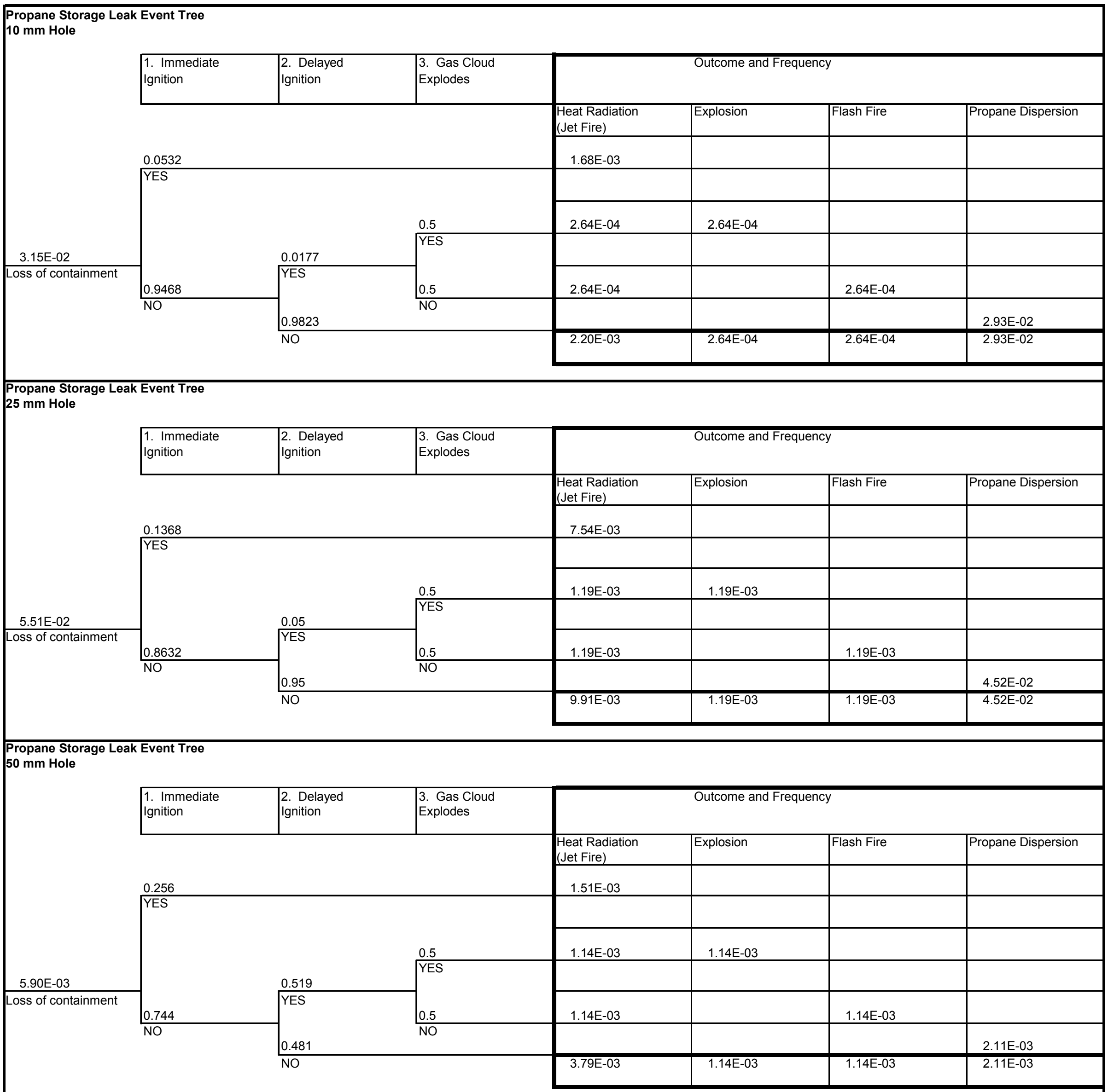
1. Ignition probability dependent on flammability characteristics, release rate and ignition sources (refer to main body of report).
2. Relative probability of delayed ignition assumed to be the same as for immediate ignition.
3. Probability of explosion is dependent on the degree of confinement, mass of flammable material in cloud, with a value of 0.001 based on mass of material being less than 1t (Lees).

Figure D.7 Event tree for Xanthate Plant Carbon Disulphide Storage



1. Water level maintained in the bund is dependent on operator action.
2. Ignition probability dependent on flammability characteristics, release rate and ignition sources (refer to main body of report).
3. Deluge system failure not analysed, 0.1 assumed (note fire water pump failure on demand is 0.0031 (OREDA)).
4. Relative probability of delayed ignition assumed to be the same as for immediate ignition.
5. Probability of explosion is dependent on the degree of confinement, mass of flammable material in cloud, with a value of 0.001 based on mass of material being less than 1t (Lees).

Figure D.8 Event tree for LPG Facility Propane Storage



Propane Storage Leak Event Tree – 10 mm Hole

Heat Radiation (Jet Fire)	Explosion	Flash Fire	Propane Dispersion
1.68E-03			
2.64E-04	2.64E-04		
2.64E-04		2.64E-04	
			2.93E-02
2.20E-03	2.64E-04	2.64E-04	2.93E-02

Propane Storage Leak Event Tree – 25 mm Hole

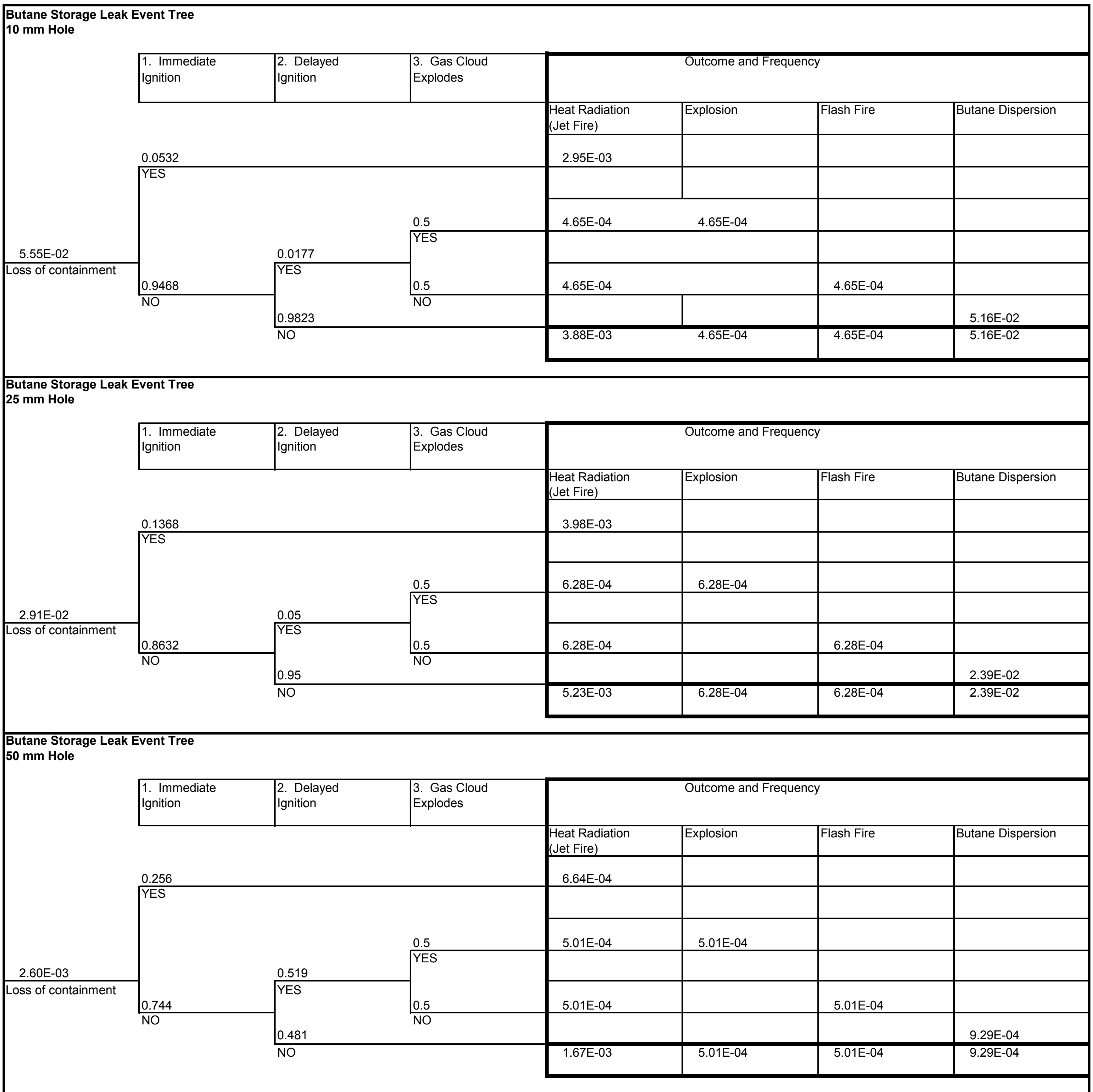
Heat Radiation (Jet Fire)	Explosion	Flash Fire	Propane Dispersion
7.54E-03			
1.19E-03	1.19E-03		
1.19E-03		1.19E-03	
			4.52E-02
9.91E-03	1.19E-03	1.19E-03	4.52E-02

Propane Storage Leak Event Tree – 50 mm Hole

Heat Radiation (Jet Fire)	Explosion	Flash Fire	Propane Dispersion
1.51E-03			
1.14E-03	1.14E-03		
1.14E-03		1.14E-03	
			2.11E-03
3.79E-03	1.14E-03	1.14E-03	2.11E-03

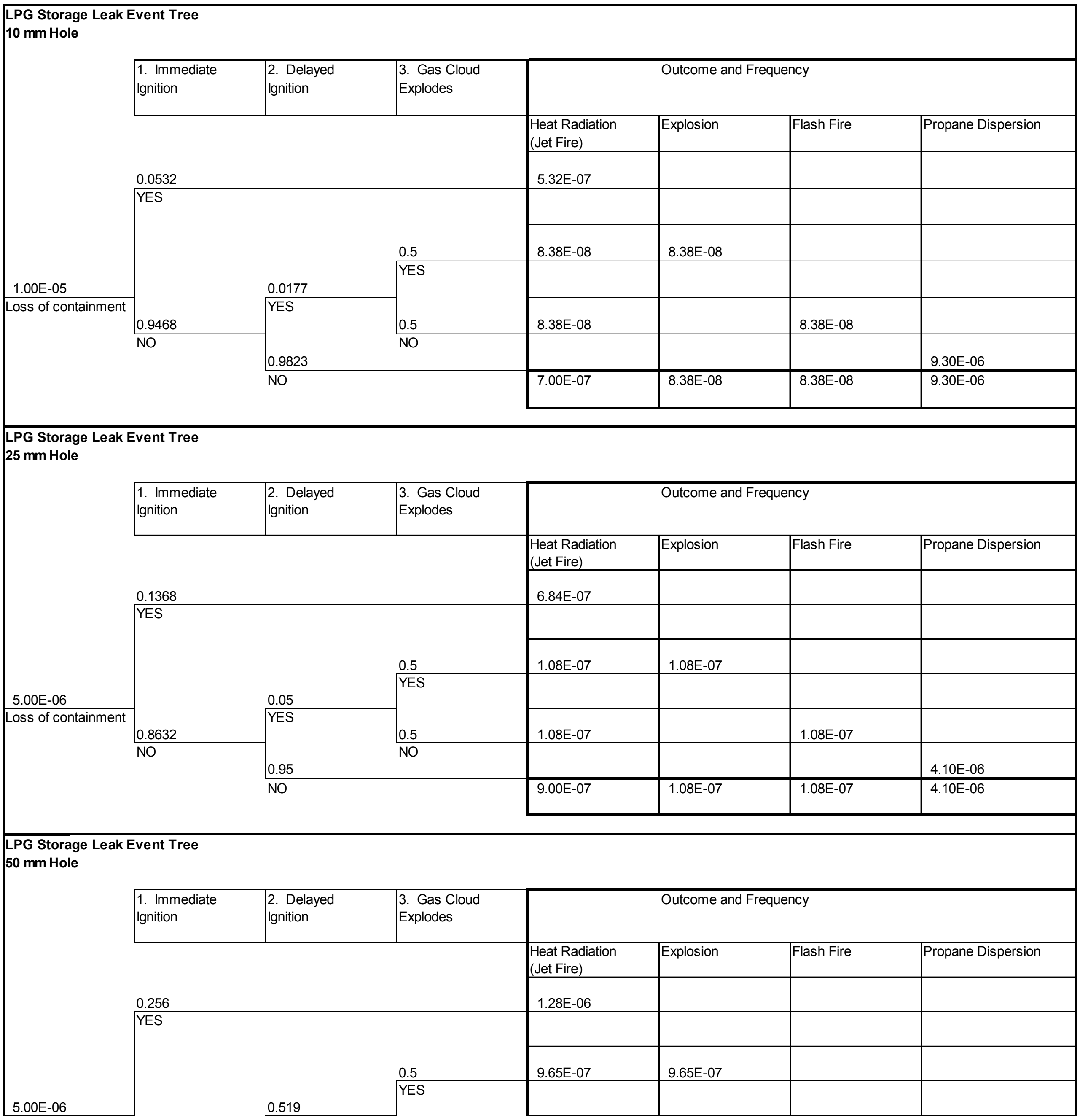
1. Ignition probability dependent on flammability characteristics, release rate and ignition sources (refer to main body of report).
2. Relative probability of delayed ignition assumed to be the same as for immediate ignition.
3. Probability of explosion is dependent on the degree of confinement, mass of flammable material in cloud, with a value of 0.001 based on mass of material being less than 1t (Lees).

Figure D.9 Event tree for LPG Facility Butane Storage



1. Ignition probability dependent on flammability characteristics, release rate and ignition sources (refer to main body of report).
2. Relative probability of delayed ignition assumed to be the same as for immediate ignition.
3. Probability of explosion is dependent on the degree of confinement, mass of flammable material in cloud, with a value of 0.001 based on mass of material being less than 1t (Lees).

Figure D.10 Event tree for LPG Storage



LPG Storage Leak Event Tree
10 mm Hole

	1. Immediate Ignition	2. Delayed Ignition	3. Gas Cloud Explodes	Heat Radiation (Jet Fire)	Explosion	Flash Fire	Propane Dispersion
	0.0532 YES			5.32E-07			
1.00E-05 Loss of containment	0.9468 NO	0.0177 YES	0.5 YES	8.38E-08	8.38E-08		
			0.5 NO	8.38E-08		8.38E-08	
		0.9823 NO					9.30E-06
				7.00E-07	8.38E-08	8.38E-08	9.30E-06

LPG Storage Leak Event Tree
25 mm Hole

	1. Immediate Ignition	2. Delayed Ignition	3. Gas Cloud Explodes	Heat Radiation (Jet Fire)	Explosion	Flash Fire	Propane Dispersion
	0.1368 YES			6.84E-07			
5.00E-06 Loss of containment	0.8632 NO	0.05 YES	0.5 YES	1.08E-07	1.08E-07		
			0.5 NO	1.08E-07		1.08E-07	
		0.95 NO					4.10E-06
				9.00E-07	1.08E-07	1.08E-07	4.10E-06

LPG Storage Leak Event Tree
50 mm Hole

	1. Immediate Ignition	2. Delayed Ignition	3. Gas Cloud Explodes	Heat Radiation (Jet Fire)	Explosion	Flash Fire	Propane Dispersion
	0.256 YES			1.28E-06			
5.00E-06		0.519	0.5 YES	9.65E-07	9.65E-07		

APPENDIX E

SCENARIO SUMMARIES

LIST OF TABLES

SCENARIO SUMMARIES

E1 Introduction

This section details all the failure event scenarios used as inputs into the *Riskcurves* modelling software package to produce the overall risk contours associated with the proposed industries for the KIP.

Table E.1 Silicon Smelter Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.										
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y				Easting	Northing
1.1	LPG Storage Vessel - 10mm	Jet Fire	LPG, Propane or Butane	L	8.37	20	501	Horizontal pressurised bullet	8	10	1.41380	2.82E-03	0.85	1.00E-05	1.0	Fig D.10	7.00E-07	369200	6330200
1.2		Flash Fire												1.00E-05		Fig D.10	8.38E-08	369200	6330200
1.3		VCE												1.00E-05		Fig D.10	8.38E-08	369200	6330200
1.4	LPG Storage Vessel - 25mm	Jet Fire	LPG, Propane or Butane	L						25	8.8351	1.76E-02	3.76	5.00E-06	1.0	Fig D.10	9.00E-07	369200	6330200
1.5		Flash Fire												5.00E-06		Fig D.10	1.08E-07	369200	6330200
1.6		VCE												5.00E-06		Fig D.10	1.08E-07	369200	6330200
1.7	LPG Storage Vessel - 50mm	Jet Fire	LPG, Propane or Butane	L						50	35.3210	7.05E-02	3.76	5.00E-06	1.0	Fig D.10	3.21E-06	369200	6330200
1.8		Flash Fire												5.00E-06		Fig D.10	9.65E-07	369200	6330200
1.9		VCE												5.00E-06		Fig D.10	9.65E-07	369200	6330200
1.10	LPG Storage Vessel - Catastrophic failure	BLEVE	Propane	L									3.76	2.00E-06	1.0	Fig D.10	1.35E-06	369200	6330200
1.11	Diesel Storage Vessel - Serious Leakage	Pool fire	Diesel	L	0.00	25	730	Horizontal tank	20	22	3.23	4.43E-03	1.94	9.60E-05	1.0		2.88E-06	369100	6330400
1.12	Bund Diesel Storage Vessel - Catastrophic failure	Pool fire	Diesel	L									14.60	6.00E-05	1.0		4.80E-06	369100	6330400

Table E.2 Pigment Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.									
					(Barg)	(°C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
2.1	Chlorine Storage Vessel 01 - 10mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L	2.99	-35	1565	Horizontal storage bullet	32	10	0.64	4.09E-04	0.38	5.20E-02	1.0	2.60E-02	370000	6330600
2.2	Chlorine Storage Vessel 01 - 10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						10	0.05	3.20E-05	0.03	5.20E-02	1.0	2.60E-02	370000	6330600
2.3	Chlorine Storage Vessel 01 - 25mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L						25	3.96	2.53E-03	2.38	8.19E-03	1.0	4.09E-03	370000	6330600
2.4	Chlorine Storage Vessel 01 - 25mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						25	0.28	1.79E-04	0.17	8.19E-03	1.0	4.09E-03	370000	6330600
2.5	Chlorine Storage Vessel 01 - 50mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L						50	15.00	9.59E-03	9.00	3.85E-04	1.0	1.93E-04	370000	6330600
2.6	Chlorine Storage Vessel 01 - 50mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						50	1.08	6.90E-04	0.65	3.85E-04	1.0	1.93E-04	370000	6330600
2.7	Chlorine Storage Vessel 01 - Catastrophic failure	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L									50.06	2.00E-06	1.0	1.00E-06	370000	6330600
2.8	Chlorine Storage Vessel 01 - Catastrophic failure	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G									50.06	2.00E-06	1.0	1.00E-06	370000	6330600
2.9	Chlorine Storage Vessel 02 - 10mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L	2.99	-35	1565	Horizontal storage bullet	32	10	0.64	4.09E-04	0.38	5.20E-02	1.0	2.60E-02	370000	6330600
2.10	Chlorine Storage Vessel 02 - 10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						10	0.05	3.20E-05	0.03	5.20E-02	1.0	2.60E-02	370000	6330600
2.11	Chlorine Storage Vessel 02 - 25mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L						25	3.96	2.53E-03	2.38	8.19E-03	1.0	4.09E-03	370000	6330600
2.12	Chlorine Storage Vessel 02 - 25mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						25	0.28	1.79E-04	0.17	8.19E-03	1.0	4.09E-03	370000	6330600
2.13	Chlorine Storage Vessel 01 - 50mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L						50	15.00	9.59E-03	9.00	3.85E-04	1.0	1.93E-04	370000	6330600
2.14	Chlorine Storage Vessel 01 - 50mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						50	1.08	6.90E-04	0.65	3.85E-04	1.0	1.93E-04	370000	6330600
2.15	Chlorine Storage Vessel 02 - Catastrophic failure	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L									50.06	2.00E-06	1.0	1.00E-06	370000	6330600
2.16	Chlorine Storage Vessel 02 - Catastrophic failure	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G									50.06	2.00E-06	1.0	1.00E-06	370000	6330600
2.17	Crude TiCl4 Storage Vessel - 10mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0.20	75	1730	Vertical fixed roof tank	405	10	0.80	4.62E-04	0.48	9.30E-02	1.0	9.30E-02	369800	6330600

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.									
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
2.18	Crude TiCl4 Storage Vessel - 25mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G						25	0.80	4.62E-04	0.48	1.60E-02	1.0	1.60E-02	369800	6330600
2.19	Crude TiCl4 Storage Vessel - 50mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G						50	0.80	4.62E-04	0.48	6.75E-04	1.0	6.75E-04	369800	6330600
2.20	Crude TiCl4 Storage Vessel - Catastrophic failure	HCl gas dispersion from a liquid TiCl4 spill	HCl	G							0.80		1.44	5.00E-06	1.0	5.00E-06	369800	6330600
2.21	Crude TiCl4Quench Vessel - 10mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0.20	75	1730	Vertical fixed roof tank	405	10	0.66	3.82E-04	0.40	9.30E-02	1.0	9.30E-02	369800	6330600
2.22	Crude TiCl4Quench Vessel - 25mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G						25	0.66	3.82E-04	0.40	1.60E-02	1.0	1.60E-02	369800	6330600
2.23	Crude TiCl4Quench Vessel - 50mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G						50	0.66	3.82E-04	0.40	6.75E-04	1.0	6.75E-04	369800	6330600
2.24	Crude TiCl4Quench Vessel - Catastrophic failure	HCl gas dispersion from a liquid TiCl4 spill	HCl	G							0.66		1.19	5.00E-06	1.0	5.00E-06	369800	6330600
2.25	Purified TiCl4 Storage Vessel - 10mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0.20	75	1730	Vertical fixed roof tank	405	10	0.07	4.05E-05	0.04	9.30E-02	1.0	9.30E-02	369800	6330600
2.26	Purified TiCl4 Storage Vessel - 25mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G						25	0.07	4.05E-05	0.04	1.60E-02	1.0	1.60E-02	369800	6330600
2.27	Purified TiCl4 Storage Vessel - 50mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G						50	0.07	4.05E-05	0.04	6.75E-04	1.0	6.75E-04	369800	6330600
2.28	Purified TiCl4 Storage Vessel - Catastrophic failure	HCl gas dispersion from a liquid TiCl4 spill	HCl	G							0.07		0.13	5.00E-06	1.0	5.00E-06	369800	6330600

Table E. 3 Chlor-Alkali Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.									
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
3.1	Chlorine Storage Vessel 01 - 10mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L	2.99	-35	1565	Horizontal pressurised bullet	32	10	0.64	4.09E-04	0.38	5.20E-02	1.0	2.60E-02	370000	6330600
3.2	Chlorine Storage Vessel 01 - 10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						10	0.05	3.20E-05	0.03	5.20E-02	1.0	2.60E-02	370000	6330600
3.3	Chlorine Storage Vessel 01 - 25mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L						25	3.96	2.53E-03	2.38	8.19E-03	1.0	4.09E-03	370000	6330600
3.4	Chlorine Storage Vessel 01 - 25mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						25	0.28	1.79E-04	0.17	8.19E-03	1.0	4.09E-03	370000	6330600
3.5	Chlorine Storage Vessel 01 - 50mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L						50	15.00	9.59E-03	9.00	3.85E-04	1.0	1.93E-04	370000	6330600
3.6	Chlorine Storage Vessel 01 - 50mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						50	1.08	6.90E-04	0.65	3.85E-04	1.0	1.93E-04	370000	6330600
3.7	Chlorine Storage Vessel 01 - Catastrophic failure	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L									50.06	2.00E-06	1.0	1.00E-06	370000	6330600
3.8	Chlorine Storage Vessel 01 - Catastrophic failure	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G									50.06	2.00E-06	1.0	1.00E-06	370000	6330600
3.9	Chlorine Storage Vessel 02 - 10mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L	2.99	-35	1565	Horizontal pressurised bullet	32	10	0.64	4.09E-04	0.38	5.20E-02	1.0	2.60E-02	370000	6330600
3.10	Chlorine Storage Vessel 02 - 10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						10	0.05	3.20E-05	0.03	5.20E-02	1.0	2.60E-02	370000	6330600
3.11	Chlorine Storage Vessel 02 - 25mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L						25	3.96	2.53E-03	2.38	8.19E-03	1.0	4.09E-03	370000	6330600
3.12	Chlorine Storage Vessel 02 - 25mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						25	0.28	1.79E-04	0.17	8.19E-03	1.0	4.09E-03	370000	6330600
3.13	Chlorine Storage Vessel 02 - 50mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L						50	15.00	9.59E-03	9.00	3.85E-04	1.0	1.93E-04	370000	6330600
3.14	Chlorine Storage Vessel 02 - 50mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						50	1.08	6.90E-04	0.65	3.85E-04	1.0	1.93E-04	370000	6330600
3.15	Chlorine Storage Vessel 02 - Catastrophic failure	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L									50.06	2.00E-06	1.0	1.00E-06	370000	6330600

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.									
					(Barg)	(°C)	(Kg/m³)		(m³)	(mm)	(Kg/s)	(m³/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
3.16	Chlorine Storage Vessel 02 - Catastrophic failure	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G									50.06	2.00E-06	1.0	1.00E-06	370000	6330600

Table E. 4 Water Treatment Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.									
					(Barg)	(°C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
5.1	Chlorine Drum 01 - 10mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L	2.99	-35	1565	Horizontal storage drum	1	10	0.23	1.47E-04	0.14	2.40E-05	1.0	1.20E-05	368300	6331100
5.2	Chlorine Drum 01 - 10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						10	0.04	2.56E-05	0.02	2.40E-05	1.0	1.20E-05	368300	6331100
5.3	Chlorine Drum 01 - 25mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L						25	1.27	8.12E-04	0.76	9.00E-06	1.0	4.50E-06	368300	6331100
5.4	Chlorine Drum 01 - 25mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						25	0.28	1.79E-04	0.17	9.00E-06	1.0	4.50E-06	368300	6331100
5.5	Chlorine Drum 01 - Catastrophic failure	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L									0.92	2.00E-06	1.0	1.00E-06	368300	6331100
5.6	Chlorine Drum 01 - Catastrophic failure	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G									0.92	2.00E-06	1.0	1.00E-06	368300	6331100
5.7	Chlorine Drum 02 - 10mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L	2.99	-35	1565	Horizontal storage drum	1	10	0.23	1.47E-04	0.14	2.40E-05	1.0	1.20E-05	368300	6331100
5.8	Chlorine Drum 02 - 10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						10	0.04	2.56E-05	0.02	2.40E-05	1.0	1.20E-05	368300	6331100
5.9	Chlorine Drum 02 - 25mm	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L						25	1.27	8.12E-04	0.76	9.00E-06	1.0	4.50E-06	368300	6331100
5.10	Chlorine Drum 02 - 25mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						25	0.28	1.79E-04	0.17	9.00E-06	1.0	4.50E-06	368300	6331100
5.11	Chlorine Drum 02 - Catastrophic failure	Chlorine gas dispersion from a liquid chlorine spill	Chlorine	L									0.92	2.00E-06	1.0	1.00E-06	368300	6331100
5.12	Chlorine Drum 02 - Catastrophic failure	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G									0.92	2.00E-06	1.0	1.00E-06	368300	6331100

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
					(Barg)	(^{o}C)	(Kg/m^3)	Tank Type	Total Vol. (m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
5.13	Chlorine tubing failure 01 -10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G	2.99	-35	1565	Tubing		10	0.04	2.56E-05	0.02	1.20E-04	1.0	1.20E-04	368300	6331100
5.14	Chlorine fitting failure 01 -10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G				Fitting		10	0.04	2.56E-05	0.02	2.19E-02	1.0	2.19E-02	368300	6331100
5.15	Regulator failure 01 - 10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G	2.99	-35	1565	Regulator		10	0.04	2.56E-05	0.02	1.00E-04	1.0	1.00E-04	368300	6331100
5.16	Regulator rupture 01 - 10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						10	0.04	2.56E-05	0.02	8.80E-05	1.0	8.80E-05	368300	6331100
5.17	Chlorine tubing failure 02-10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G	2.99	-35	1565	Tubing		10	0.04	2.56E-05	0.02	1.20E-04	1.0	1.20E-04	368300	6331100
5.18	Chlorine fitting failure 02-10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G				Fitting		10	0.04	2.56E-05	0.02	2.19E-02	1.0	2.19E-02	368300	6331100
5.19	Regulator failure 02-10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G	2.99	-35	1565	Regulator		10	0.04	2.56E-05	0.02	1.00E-04	1.0	1.00E-04	368300	6331100
5.20	Regulator rupture 02 - 10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						10	0.04	2.56E-05	0.02	8.80E-05	1.0	8.80E-05	368300	6331100
5.21	Chlorine cylinder 01-10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G	2.99	-35	1565	Chlorine Cylinder	0.04	10	0.04	2.56E-05	0.02	2.40E-05	1.0	1.20E-05	368300	6331100
5.22	Chlorine cylinder 01-10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	L						10	0.11	7.03E-05	0.07	2.40E-05	1.0	1.20E-05	368300	6331100
5.23	Chlorine cylinder 01 - 25mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						25	0.11	7.03E-05	0.07	9.00E-06	1.0	4.50E-06	368300	6331100
5.24	Chlorine cylinder 01 - 25mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	L						25	0.11	7.03E-05	0.07	9.00E-06	1.0	4.50E-06	368300	6331100
5.25	Chlorine cylinder - Catastrophic failure	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G									0.07	2.00E-06	1.0	1.00E-06	368300	6331100
5.26	Chlorine cylinder - Catastrophic failure	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	L									0.07	2.00E-06	1.0	1.00E-06	368300	6331100
5.27	Chlorine cylinder 02-10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G	2.99	-35	1565	Chlorine Cylinder	0.04	10	0.04	2.56E-05	0.02	2.40E-05	1.0	1.20E-05	368300	6331100
5.28	Chlorine cylinder 02-10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	L						10	0.30	1.92E-04	0.07	2.40E-05	1.0	1.20E-05	368300	6331100
5.29	Chlorine cylinder 02 - 25mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						25	0.33	2.11E-04	0.07	9.00E-06	1.0	4.50E-06	368300	6331100

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.									
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
5.30	Chlorine cylinder 02 - 25mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	L						25	2.70	1.73E-03	0.07	9.00E-06	1.0	4.50E-06	368300	6331100
5.31	Chlorine cylinder - Catastrophic failure	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G									0.07	2.00E-06	1.0	1.00E-06	368300	6331100
5.32	Chlorine cylinder - Catastrophic failure	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	L									0.07	2.00E-06	1.0	1.00E-06	368300	6331100

Table E. 5 Urea Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.									
					(Barg)	(°C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
8.1	Ammonia Storage Vessel - 10mm	NH3 gas dispersion from liquid NH3 spill	NH3	L	10	25	602	Horizontal pressurised bullet	10000	10	1.69	2.81E-03	1.02	3.15E-02	1.0	3.15E-02	371100	6332200
8.2	Ammonia Storage Vessel - 25mm	NH3 gas dispersion from liquid NH3 spill	NH3	L						25	10.58	1.76E-02	6.35	5.09E-03	1.0	5.09E-03	371100	6332200
8.3	Ammonia Storage Vessel - 50mm	NH3 gas dispersion from liquid NH3 spill	NH3	L						50	42.28	7.02E-02	25.37	3.95E-04	1.0	3.95E-04	371100	6332200
8.4	Ammonia Storage Vessel - Catastrophic failure	NH3 gas dispersion from liquid NH3 spill	NH3	L									6018.00	2.00E-06	1.0	2.00E-06	371100	6332200

Table E. 6 Nickel Refinery Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.											
					(Barg)	(°C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y					Easting	Northing
Ammonia Storage																				
9.1	Ammonia Storage Vessel 01 - 10mm	NH3 gas dispersion from liquid NH3 spill	NH3	L	10	25	602	Horizontal pressurised bullet	120	10	1.69	2.81E-03	1.02	1.28E-01	1.0			1.28E-01	369400	6336400
9.2	Ammonia Storage Vessel 01 - 25mm	NH3 gas dispersion from liquid NH3 spill	NH3	L						25	10.58	1.76E-02	6.35	2.31E-02	1.0			2.31E-02	369400	6336400
9.3	Ammonia Storage Vessel 01 - 50mm	NH3 gas dispersion from liquid NH3 spill	NH3	L						50	42.28	7.02E-02	25.37	1.06E-03	1.0			1.06E-03	369400	6336400
9.4	Ammonia Storage Vessel 01 - Catastrophic failure	NH3 gas dispersion from liquid NH3 spill	NH3	L									72.22	2.00E-06	1.0			2.00E-06	369400	6336400
9.5	Ammonia Storage Vessel 02 - 10mm	NH3 gas dispersion from liquid NH3 spill	NH3	L		25	602	Horizontal pressurised bullet	120	10	1.69	2.81E-03	1.02	1.28E-01	1.0			1.28E-01	369400	6336400
9.6	Ammonia Storage Vessel 02 - 25mm	NH3 gas dispersion from liquid NH3 spill	NH3	L						25	10.58	1.76E-02	6.35	2.31E-02	1.0			2.31E-02	369400	6336400
9.7	Ammonia Storage Vessel 02 - 50mm	NH3 gas dispersion from liquid NH3 spill	NH3	L						50	42.28	7.02E-02	25.37	1.06E-03	1.0			1.06E-03	369400	6336400
9.8	Ammonia Storage Vessel 02 - Catastrophic failure	NH3 gas dispersion from liquid NH3 spill	NH3	L									72.22	2.00E-06	1.0			2.00E-06	369400	6336400
H_2S Plant																				
9.9	Hydrogen sulphide Reactor and connecting pipework - 10mm	H2S gas dispersion	H2S	G	9.17	164	10	Reactor Vessel + pipeline	15	10	0.09	9.37E-03	0.05	7.60E-02	1.0			7.60E-02	369600	6336400
9.10	Hydrogen sulphide Reactor and connecting pipework - 25mm	H2S gas dispersion	H2S	G					15	25	0.45	4.76E-02	0.27	1.19E-02	1.0			1.19E-02	369600	6336400
9.11	Hydrogen sulphide Reactor and connecting pipework - 50mm	H2S gas dispersion	H2S	G					15	50	1.83	1.91E-01	1.10	5.60E-04	1.0			5.60E-04	369600	6336400
9.12	Hydrogen sulphide Reactor and connecting pipework - Catastrophic failure	H2S gas dispersion	H2S	G					15				0.14	5.00E-06	1.0			5.00E-06	369600	6336400
Acid Plant																				
9.13	Sulphur dioxide from Sulphuric acid plant and connecting pipework - 10mm	SO2 gas dispersion	SO2	G	0.45	423	2	Sulphur burner and converter	130	10	0.01	8.85E-03	0.01	7.45E-02	1.0			7.45E-02	369600	6336300
9.14	Sulphur dioxide from Sulphuric acid plant and connecting pipework - 25mm	SO2 gas dispersion	SO2	G					130	25	0.08	5.01E-02	0.05	1.36E-02	1.0			1.36E-02	369600	6336300
9.15	Sulphur dioxide from Sulphuric acid plant and connecting pipework - 50mm	SO2 gas dispersion	SO2	G					130	50	0.31	1.92E-01	0.19	8.10E-04	1.0			8.10E-04	369600	6336300

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.											
					(Barg)	(^{o}C)	(Kg/m^{3})		(m^{3})	(mm)	(Kg/s)	(m^{3}/s)	(t)	(LOC/1000 km- y) or Event/y					Easting	Northing
9.16	Sulphur dioxide from Sulphuric acid plant and connecting pipework - Catastrophic failure	SO2 gas dispersion	SO2	G					130		266.23	1.66E+02	0.21	3.13E-05	1.0			3.13E-05	369600	6336300
9.17	Sulphur trioxide from Sulphuric acid plant and connecting pipework - 10mm	SO3 gas dispersion	SO3	G	0.40	440	2	Converter and ducting	5250	10	0.01	7.65E-03	0.01	2.57E-01	1.0			2.57E-01	369600	6336300
9.18	Sulphur trioxide from Sulphuric acid plant and connecting pipework - 25mm	SO3 gas dispersion	SO3	G					5250	25	0.09	4.77E-02	0.06	3.47E-02	1.0			3.47E-02	369600	6336300
9.19	Sulphur trioxide from Sulphuric acid plant and connecting pipework - 50mm	SO3 gas dispersion	SO3	G					5250	50	0.37	1.89E-01	0.22	1.60E-03	1.0			1.60E-03	369600	6336300
9.20	Sulphur trioxide from Sulphuric acid plant and connecting pipework - Catastrophic failure	SO3 gas dispersion	SO3	G					5250		233.87	1.19E+02	10.28	1.69E-04	1.0			1.69E-04	369600	6336300
H_2 Plant																				
9.21	Hydrogen Synthesis Plant - 10mm	Jet Fire	H2	G	23.00	29	2	Synthesis plant and ancillary parts	60	10	0.06	1.18E-01	0.04	3.16E-01	1.0		Fig D.1	0.11	369500	6336300
9.22		Flash Fire												3.16E-01	1.0		Fig D.1	5.05E-02	369500	6336300
9.23		VCE												3.16E-01	1.0		Fig D.1	5.06E-05	369500	6336300
9.24	Hydrogen Synthesis Plant - 25mm	Jet Fire								25	0.31	5.78E-01	0.19	4.69E-02	1.0		Fig D.1	1.69E-02	369500	6336300
9.25		Flash Fire												4.69E-02	1.0		Fig D.1	7.50E-03	369500	6336300
9.26		VCE												4.69E-02	1.0		Fig D.1	7.50E-06	369500	6336300
9.27	Hydrogen Synthesis Plant - 50mm	Jet Fire								50	1.23	2.27E+00	0.74	6.95E-04	1.0		Fig D.1	2.50E-04	369500	6336300
9.28		Flash Fire												6.95E-04	1.0		Fig D.1	1.11E-04	369500	6336300
9.29		VCE												6.95E-04	1.0		Fig D.1	1.11E-07	369500	6336300
	Hydrogen Synthesis Plant - PSA 1 Catastrophic failure	Safe dispersion							15				0.03	5.00E-06	1.0		Fig D.2	3.20E-06	369500	6336300
9.30		Flash Fire											0.03	5.00E-06	1.0		Fig D.2	7.99E-07	369500	6336300
9.31		VCE											0.03	5.00E-06	1.0		Fig D.2	1.00E-06	369500	6336300
	Hydrogen Synthesis Plant - PSA 2 Catastrophic failure	Safe dispersion											0.03	5.00E-06	1.0		Fig D.2	3.20E-06	369500	6336300
9.32		Flash Fire											0.03	5.00E-06	1.0		Fig D.2	7.99E-07	369500	6336300
9.33		VCE											0.03	5.00E-06	1.0		Fig D.2	1.00E-06	369500	6336300
	Hydrogen Synthesis Plant - PSA 3 Catastrophic failure	Safe dispersion											0.03	5.00E-06	1.0		Fig D.2	3.20E-06	369500	6336300
9.34		Flash Fire											0.03	5.00E-06	1.0		Fig D.2	7.99E-07	369500	6336300
9.35		VCE											0.03	5.00E-06	1.0		Fig D.2	1.00E-06	369500	6336300
9.36	Hydrogen storage vessel and reticulation - 10mm	Jet Fire	H2	G	79.00	25	6.5	Horizontal pressurised bullet	100	10	0.23	0.04	0.14	9.20E-02	1.0		Fig D.3	0.03	369400	6336300
9.37		Flash Fire												9.20E-02	1.0		Fig D.3	1.47E-02	369400	6336300
9.38		VCE												9.20E-02	1.0		Fig D.3	1.47E-05	369400	6336300
9.39	Hydrogen storage vessel and reticulation - 25mm	Jet Fire								25	1.25	0.19	0.65	1.74E-02	1.0		Fig D.3	6.27E-03	369400	6336300
9.40		Flash Fire												1.74E-02	1.0		Fig D.3	2.78E-03	369400	6336300
9.41		VCE												1.74E-02	1.0		Fig D.3	2.78E-06	369400	6336300
9.42	Hydrogen storage	Jet Fire								50	4.12	0.63	0.65	6.25E-04	1.0		Fig D.3	2.25E-04	369400	6336300

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.											
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y					Easting	Northing
9.43	vessel and reticulation - 50mm	Flash Fire												6.25E-04	1.0		Fig D.3	9.99E-05	369400	6336300
9.44		VCE												6.25E-04	1.0		Fig D.3	1.00E-07	369400	6336300
	Hydrogen storage vessel and reticulation - Catastrophic failure	Safe dispersion											0.65	2.00E-06	1.0		Fig D.4	1.28E-06	369400	6336300
9.45		Flash Fire																3.20E-07	369400	6336300
9.46		VCE																4.00E-07	369400	6336300

Table E. 7 DRI Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Tree ref.	Event Frequency	GPS Co-ordinates	
					(Barg)	(^{o}C)	(Kg/m^3)	Tank Type	Total Vol. (m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y				Easting	Northing
10.1	LPG, Propane or Butane Storage Vessel 01 - 10mm	Jet Fire	LPG, Propane or Butane	L	8.37	20	579	Horizontal pressurised bullet	60	10	1.52	2.62E-03	0.91	3.15E-02	1.0	Fig D.5	2.20E-03	370200	6337100
10.2		Flash Fire												3.15E-02		Fig D.5	2.64E-04	370200	6337100
10.3		VCE												3.15E-02		Fig D.5	2.64E-04	370200	6337100
10.4	LPG, Propane or Butane Storage Vessel 01 - 25mm	Jet Fire	LPG, Propane or Butane	L						25	9.49	1.64E-02	5.69	5.09E-03	1.0	Fig D.5	9.15E-04	370200	6337100
10.5		Flash Fire												5.09E-03		Fig D.5	1.10E-04	370200	6337100
10.6		VCE												5.09E-03		Fig D.5	1.10E-04	370200	6337100
10.7	LPG, Propane or Butane Storage Vessel 01 - 50mm	Jet Fire	LPG, Propane or Butane	L						50	37.92	6.55E-02	22.75	3.95E-04	1.0	Fig D.5	2.54E-04	370200	6337100
10.8		Flash Fire												3.95E-04		Fig D.5	7.63E-05	370200	6337100
10.9		VCE												3.95E-04		Fig D.5	7.63E-05	370200	6337100
10.10	LPG, Propane or Butane Storage Vessel 01 - Catastrophic failure	BLEVE	LPG, Propane or Butane	L									34.74	2.00E-06	1.0	Fig D.5	1.35E-06	370200	6337100
10.11	LPG, Propane or Butane Storage Vessel 02 - 10mm	Jet Fire	LPG, Propane or Butane	L	8.37	20	579	Horizontal pressurised bullet	60	10	1.52	2.62E-03	0.91	3.15E-02	1.0	Fig D.5	2.20E-03	370200	6337100
10.12		Flash Fire												3.15E-02		Fig D.5	2.64E-04	370200	6337100
10.13		VCE												3.15E-02		Fig D.5	2.64E-04	370200	6337100
10.14	LPG, Propane or Butane Storage Vessel 02 - 25mm	Jet Fire	LPG, Propane or Butane	L						25	9.49	1.64E-02	5.69	5.09E-03	1.0	Fig D.5	9.15E-04	370200	6337100
10.15		Flash Fire												5.09E-03		Fig D.5	1.10E-04	370200	6337100
10.16		VCE												5.09E-03		Fig D.5	1.10E-04	370200	6337100
10.17	LPG, Propane or Butane Storage Vessel 02 - 50mm	Jet Fire	LPG, Propane or Butane	L						50	37.92	6.55E-02	22.75	3.95E-04	1.0	Fig D.5	2.54E-04	370200	6337100
10.18		Flash Fire												3.95E-04		Fig D.5	7.63E-05	370200	6337100
10.19		VCE												3.95E-04		Fig D.5	7.63E-05	370200	6337100
10.20	LPG, Propane or Butane Storage Vessel 02 - Catastrophic failure	BLEVE	LPG, Propane or Butane	L									34.74	2.00E-06	1.0	Fig D.5	1.35E-06	370200	6337100

Table E.1 Sodium Cyanide Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.									
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
11.1	Ammonia Storage Vessel - 10mm	NH3 gas dispersion from liquid NH3 spill	NH3	L	10	25	602	Horizontal pressurised bullet	5000	10	1.69	2.81E-03	1.02	3.15E-02	1.0	3.15E-02	369500	6333900
11.2	Ammonia Storage Vessel - 25mm	NH3 gas dispersion from liquid NH3 spill	NH3	L				Horizontal pressurised bullet	5000	25	10.58	1.76E-02	6.35	5.09E-03	1.0	5.09E-03	369500	6333900
11.3	Ammonia Storage Vessel - 50mm	NH3 gas dispersion from liquid NH3 spill	NH3	L				Horizontal pressurised bullet	5000	50	42.28	7.02E-02	25.37	3.95E-04	1.0	3.95E-04	369500	6333900
11.4	Ammonia Storage Vessel - Catastrophic failure	NH3 gas dispersion from liquid NH3 spill	NH3	L				Horizontal pressurised bullet	5000				3009.00	2.00E-06	1.0	2.00E-06	369500	6333900

Table E.2 Fuel Terminal Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.											
					(Barg)	(°C)	(Kg/m³)		(m³)	(mm)	(Kg/s)	(m³/s)	(t)	(LOC/1000 km- y) or Event/y					Easting	Northing
12.1	Unleaded Petrol Storage Vessel 01	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	25000				18243.75	2.40E-03	1.0	1.00		2.40E-04	371200	6335100
12.2	Unleaded Petrol Storage Vessel 01 - Serious Leakage	Pool fire	ULP	L						22	3.23	4.43E-03	1.9389	9.60E-05	1.0	0.03		2.88E-06	371200	6335100
12.3	Unleaded Petrol Storage Vessel 02	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	25000				18243.75	2.40E-03	1.0	1.00		2.40E-04	371200	6335100
12.4	Unleaded Petrol Storage Vessel 02 - Serious Leakage	Pool fire	ULP	L						22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03		2.88E-06	371200	6335100
12.5	Large Unleaded Petrol Storage Vessel - Catastrophic failure with Knock On	Pool fire	ULP	L					50000				0.00	6.00E-05	1.0	0.08	Table C.2	4.80E-06	371200	6335100
12.6	Unleaded Petrol Storage Vessel 03	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12400				9048.90	2.40E-03	1.0	1.00		2.40E-04	371200	6335100
12.7	Unleaded Petrol Storage Vessel 03 - Serious Leakage	Pool fire	ULP	L						22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03		2.88E-06	371200	6335100
12.8	Unleaded Petrol Storage Vessel 04	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12400				9048.90	2.40E-03	1.0	1.00		2.40E-04	371200	6335100
12.9	Unleaded Petrol Storage Vessel 04 - Serious Leakage	Pool fire	ULP	L						22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03		2.88E-06	371200	6335100
12.10	Unleaded Petrol Storage Vessel 05	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12400				9048.90	2.40E-03	1.0	1.00		2.40E-04	371200	6335100
12.11	Unleaded Petrol Storage Vessel 05 - Serious Leakage	Pool fire	ULP	L						22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03		2.88E-06	371200	6335100
12.12	Unleaded Petrol Storage Vessel 06	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12400				9048.90	2.40E-03	1.0	1.00		2.40E-04	371200	6335100
12.13	Unleaded Petrol Storage Vessel 06 - Serious Leakage	Pool fire	ULP	L						22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03		2.88E-06	371200	6335100
12.14	Unleaded Petrol Storage Vessel - Catastrophic failure with Knock On	Pool fire	ULP	L					49600				0.00	1.20E-04	1.0	0.08	Table C.3	9.60E-06	371200	6335100
12.15	Ethanol Storage Vessel 01	Roof fire	Ethanol	L	0	25	799	Floating roof vertical tank	5000				3993.85	2.40E-03	1.0	1.00		2.40E-04	371100	6335000
12.16	Ethanol Storage Vessel 01 - Serious Leakage	Pool fire	Ethanol	L						22	3.54	4.43E-03	2.122	9.60E-05	1.0	0.03		2.88E-06	371100	6335000
12.17	Ethanol Storage Vessel 02	Roof fire	Ethanol	L	0	25	799	Floating roof vertical tank	5000				3993.85	2.40E-03	1.0	1.00		2.40E-04	371100	6335000
12.18	Ethanol Storage Vessel 02 - Serious Leakage	Pool fire	Ethanol	L						22	3.54	4.43E-03	2.12	9.60E-05	1.0	0.03		2.88E-06	371100	6335000

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.											
					(Barg)	(°C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y					Easting	Northing
12.19	Ethanol Storage Vessel - Catastrophic failure with Knock On	Pool fire	Ethanol	L					10000				0.00	6.00E-05	1.0	0.08	Table C.4	4.80E-06	371100	6335000

Table E. 8 Titanium Metal Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.									
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
13.1	TiCl4 Storage Vessel 01 - 10mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0	25	1730	Vertical fixed roof tank	145	10	0.80	4.62E-04	0.48	1.97E-01	1.0	1.97E-01	369600	6332300
13.2	TiCl4 Storage Vessel 01 - 25mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0	25	1730			25	0.80	4.62E-04	0.48	1.98E-02	1.0	1.98E-02	369600	6332300
13.3	TiCl4 Storage Vessel 01 - 50mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0	25	1730			50	0.80	4.62E-04	0.48	4.05E-04	1.0	4.05E-04	369600	6332300
13.4	TiCl4 Storage Vessel 01 - Catastrophic failure	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0	25	1730				0.80		1.44	2.00E-06	1.0	2.00E-06	369600	6332300
13.5	TiCl4 Storage Vessel 02 - 10mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0	25	1730	Vertical fixed roof tank	145	10	0.80	4.62E-04	0.48	1.97E-01	1.0	1.97E-01	369600	6332300
13.6	TiCl4 Storage Vessel 02 - 25mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0	25	1730			25	0.80	4.62E-04	0.48	1.98E-02	1.0	1.98E-02	369600	6332300
13.7	TiCl4 Storage Vessel 02 - 50mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0	25	1730			50	0.80	4.62E-04	0.48	4.05E-04	1.0	4.05E-04	369600	6332300
13.8	TiCl4 Storage Vessel 02 - Catastrophic failure	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0	25	1730				0.80		1.44	2.00E-06	1.0	2.00E-06	369600	6332300
13.9	TiCl4 Storage Vessel 03 - 10mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0	25	1730	Vertical fixed roof tank	145	10	0.80	4.62E-04	0.48	1.97E-01	1.0	1.97E-01	369600	6332300
13.10	TiCl4 Storage Vessel 03 - 25mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0	25	1730			25	0.80	4.62E-04	0.48	1.98E-02	1.0	1.98E-02	369600	6332300
13.11	TiCl4 Storage Vessel 03 - 50mm	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0	25	1730			50	0.80	4.62E-04	0.48	4.05E-04	1.0	4.05E-04	369600	6332300
13.12	TiCl4 Storage Vessel 03 - Catastrophic failure	HCl gas dispersion from a liquid TiCl4 spill	HCl	G	0	25	1730				0.80		1.44	2.00E-06	1.0	2.00E-06	369600	6332300

Table E. 9 Oil Refinery Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
					(Barg)	(^{o}C)	(Kg/m^3)	Tank Type	Total Vol. (m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y						Easting	Northing
15.1	Unleaded Petrol Storage Vessel 01	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	200000				145950.00	2.40E-03	1.0	1.00			2.40E-04	370900	6335450
15.2	Unleaded Petrol Storage Vessel 01 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	4.31	5.90E-03	2.585	9.60E-05	1.0	0.03			2.88E-06	370900	6335450
15.3	Unleaded Petrol Storage Vessel 02	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	200000				145950.00	2.40E-03	1.0	1.00			2.40E-04	370900	6335450
15.4	Unleaded Petrol Storage Vessel 02 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	4.31	5.90E-03	2.59	9.60E-05	1.0	0.03			2.88E-06	370900	6335450
15.5	Large Unleaded Petrol Storage Vessel - Catastrophic failure with Knock on	Pool fire	ULP	L	0	25	730						291900.00	6.00E-05	1.0	0.08	Table C.5		4.80E-06	370900	6335450
15.6	Unleaded Petrol Storage Vessel 03	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335450
15.7	Unleaded Petrol Storage Vessel 03 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.939	9.60E-05	1.0	0.03			2.88E-06	371000	6335450
15.8	Unleaded Petrol Storage Vessel 04	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335450
15.9	Unleaded Petrol Storage Vessel 04 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335450
15.10	Unleaded Petrol Storage Vessel 05	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335450
15.11	Unleaded Petrol Storage Vessel 05 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335450
15.12	Unleaded Petrol Storage Vessel 06	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335450
15.13	Unleaded Petrol Storage Vessel 06 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335450
15.14	Unleaded Petrol Storage Vessel 07	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335450
15.15	Unleaded Petrol Storage Vessel 07 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335450
15.16	Unleaded Petrol Storage Vessel 08	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335450
15.17	Unleaded Petrol Storage Vessel 08 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335450
15.18	Unleaded Petrol Storage Vessel 09	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335450
15.19	Unleaded Petrol Storage Vessel 09 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335450

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.												
					(Barg)	(°C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y						Easting	Northing
15.20	Unleaded Petrol Storage Vessel 10	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335450
15.21	Unleaded Petrol Storage Vessel 10 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335450
15.22	Unleaded Petrol Storage Vessel 11	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335450
15.23	Unleaded Petrol Storage Vessel 11 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335450
15.24	Unleaded Petrol Storage Vessel 12	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335450
15.25	Unleaded Petrol Storage Vessel 12 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335450
15.26	Bund 1 Unleaded Petrol Storage Vessel - Catastrophic failure with knock on	Pool fire	ULP	L	0	25	730						91218.75	3.00E-04	1.0	0.08	Table C.6		2.40E-05	371000	6335450
15.27	Unleaded Petrol Storage Vessel 13	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335450
15.28	Unleaded Petrol Storage Vessel 13 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335450
15.29	Unleaded Petrol Storage Vessel 14	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335450
15.30	Unleaded Petrol Storage Vessel 14 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335450
15.31	Unleaded Petrol Storage Vessel 15	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335450
15.32	Unleaded Petrol Storage Vessel 15 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335450
15.33	Unleaded Petrol Storage Vessel 16	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335450
15.34	Unleaded Petrol Storage Vessel 16 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335450
15.35	Unleaded Petrol Storage Vessel 17	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335450
15.36	Unleaded Petrol Storage Vessel 17 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335450
15.37	Unleaded Petrol Storage Vessel 18	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335450
15.38	Unleaded Petrol Storage Vessel 18 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335450
15.39	Unleaded Petrol Storage Vessel 19	Roof fire	ULP	L	0	25	730	Floating roof vertical	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335450

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.												
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y						Easting	Northing
15.40	Unleaded Petrol Storage Vessel 19 - Serious Leakage	Pool fire	ULP	L	0	25	730	tank		22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335450
15.41	Unleaded Petrol Storage Vessel 20	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335450
15.42	Unleaded Petrol Storage Vessel 20 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335450
15.43	Unleaded Petrol Storage Vessel 21	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335450
15.44	Unleaded Petrol Storage Vessel 21 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335450
15.45	Unleaded Petrol Storage Vessel 22	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335450
15.46	Unleaded Petrol Storage Vessel 22 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335450
15.47	Bund 2 Unleaded Petrol Storage Vessel - Catastrophic failure with Knock on	Pool fire	ULP	L	0	25	730						91218.75	3.00E-04	1.0	0.08	Table C.6		2.40E-05	371100	6335450
15.48	Unleaded Petrol Storage Vessel 23	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371200	6335500
15.49	Unleaded Petrol Storage Vessel 23 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335500
15.50	Unleaded Petrol Storage Vessel 24	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371200	6335500
15.51	Unleaded Petrol Storage Vessel 24 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335500
15.52	Unleaded Petrol Storage Vessel 25	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371200	6335500
15.53	Unleaded Petrol Storage Vessel 25 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335500
15.54	Unleaded Petrol Storage Vessel 26	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371200	6335500
15.55	Unleaded Petrol Storage Vessel 26 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335500
15.56	Unleaded Petrol Storage Vessel 27	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371200	6335500
15.57	Unleaded Petrol Storage Vessel 27 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335500
15.58	Unleaded Petrol Storage Vessel 28	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371200	6335500
15.59	Unleaded Petrol Storage Vessel 28 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335500

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.												
					(Barg)	(°C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y						Easting	Northing
15.60	Unleaded Petrol Storage Vessel 29	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371200	6335500
15.61	Unleaded Petrol Storage Vessel 29 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335500
15.62	Unleaded Petrol Storage Vessel 30	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371200	6335500
15.63	Unleaded Petrol Storage Vessel 30 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335500
15.64	Unleaded Petrol Storage Vessel 31	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371200	6335500
15.65	Unleaded Petrol Storage Vessel 31 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335500
15.66	Unleaded Petrol Storage Vessel 32	Roof fire	ULP	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371200	6335500
15.67	Unleaded Petrol Storage Vessel 32 - Serious Leakage	Pool fire	ULP	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335500
15.68	Bund 3 Unleaded Petrol Storage Vessel - Catastrophic failure with Knock on	Pool fire	ULP	L	0	25	730						91218.75	3.00E-04	1.0	0.08	Table C.6		2.40E-05	371200	6335500
15.69	Diesel Storage Vessel 01	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	100000				72975.00	2.40E-03	1.0	1.00			2.40E-04	370900	6335600
15.70	Diesel Storage Vessel 01 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	4.31	5.90E-03	2.585	9.60E-05	1.0	0.03			2.88E-06	370900	6335600
15.71	Diesel Storage Vessel 02	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	100000				72975.00	2.40E-03	1.0	1.00			2.40E-04	370900	6335600
15.72	Diesel Storage Vessel 02 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	4.31	5.90E-03	2.59	9.60E-05	1.0	0.03			2.88E-06	370900	6335600
15.73	Large Diesel Storage Vessel - Catastrophic failure with Knock On	Pool fire	Diesel	L	0	25	730						145950.00	6.00E-05	1.0	0.08	Table C.7		4.80E-06	370900	6335600
15.74	Diesel Storage Vessel 03	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335600
15.75	Diesel Storage Vessel 03 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335600
15.76	Diesel Storage Vessel 04	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335600
15.77	Diesel Storage Vessel 04 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335600
15.78	Diesel Storage Vessel 05	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335600
15.79	Diesel Storage Vessel 05 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335600
15.80	Diesel Storage Vessel 06	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335600
15.81	Diesel Storage Vessel 06 - Serious	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335600

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
					(Barg)	(^{o}C)	(Kg/m^3)	Tank Type	Total Vol. (m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y						Easting	Northing
	Leakage																				
15.82	Diesel Storage Vessel 07	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335600
15.83	Diesel Storage Vessel 07 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335600
15.84	Diesel Storage Vessel 08	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335600
15.85	Diesel Storage Vessel 08 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335600
15.86	Diesel Storage Vessel 09	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335600
15.87	Diesel Storage Vessel 09 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335600
15.88	Diesel Storage Vessel 10	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371000	6335600
15.89	Diesel Storage Vessel 10 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371000	6335600
15.90	Bund 1 Diesel Storage Vessel - Catastrophic failure with Knock On	Pool fire	Diesel	L	0	25	730						72975.00	2.40E-04	1.0	0.08	Table C.8		1.92E-05	371100	6335600
15.91	Diesel Storage Vessel 11	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335600
15.92	Diesel Storage Vessel 11 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335600
15.93	Diesel Storage Vessel 12	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335600
15.94	Diesel Storage Vessel 12 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335600
15.95	Diesel Storage Vessel 13	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335600
15.96	Diesel Storage Vessel 13 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335600
15.97	Diesel Storage Vessel 14	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335600
15.98	Diesel Storage Vessel 14 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335600
15.99	Diesel Storage Vessel 15	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335600
15.100	Diesel Storage Vessel 15 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335600
15.101	Diesel Storage Vessel 16	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335600
15.102	Diesel Storage Vessel 16 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335600
15.103	Diesel Storage Vessel 17	Roof fire	Diesel	L	0	25	730	Floating roof vertical	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335600

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.												
					(Barg)	(^{o}C)	(Kg/m^{3})		(m^{3})	(mm)	(Kg/s)	(m^{3}/s)	(t)	(LOC/1000 km- y) or Event/y						Easting	Northing
15.104	Diesel Storage Vessel 17 - Serious Leakage	Pool fire	Diesel	L	0	25	730	tank		22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335600
15.105	Diesel Storage Vessel 18	Roof fire	Diesel	L	0	25	730	Floating roof vertical tank	12500				9121.88	2.40E-03	1.0	1.00			2.40E-04	371100	6335600
15.106	Diesel Storage Vessel 18 - Serious Leakage	Pool fire	Diesel	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371100	6335600
15.107	Bund 2 Diesel Storage Vessel - Catastrophic failure with Knock on	Pool fire	Diesel	L	0	25	730						72975.00	2.40E-04	1.0	0.08	Table C.8		1.92E-05	371100	6335600
15.108	Kerosene Storage Vessel 01	Roof fire	Kerosene	L	0	25	730	Floating roof vertical tank	20000				14595.00	2.40E-03	1.0	1.00			2.40E-04	371200	6335600
15.109	Kerosene Storage Vessel 01 - Serious Leakage	Pool fire	Kerosene	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335600
15.110	Kerosene Storage Vessel 02	Roof fire	Kerosene	L	0	25	730	Floating roof vertical tank	20000				14595.00	2.40E-03	1.0	1.00			2.40E-04	371200	6335600
15.111	Kerosene Storage Vessel 02 - Serious Leakage	Pool fire	Kerosene	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335600
15.112	Bund 1 Kerosene Storage Vessel - Catastrophic failure with Knock On	Pool fire	Kerosene	L	0	25	730						29190.00	6.00E-05	1.0	0.03	Table C.9		1.80E-06	371200	6335600
15.113	Aviation gasoline Storage Vessel 01	Roof fire	AVGAS	L	0	25	730	Floating roof vertical tank	12500				9125.00	2.40E-03	1.0	1.00			2.40E-04	371200	6335650
15.114	Aviation gasoline Storage Vessel 01 - Serious Leakage	Pool fire	AVGAS	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335650
15.115	Aviation gasoline Storage Vessel 02	Roof fire	AVGAS	L	0	25	730	Floating roof vertical tank	12500				9125.00	2.40E-03	1.0	1.00			2.40E-04	371200	6335650
15.116	Aviation gasoline Storage Vessel 02 - Serious Leakage	Pool fire	AVGAS	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335650
15.117	Aviation gasoline Storage Vessel 03	Roof fire	AVGAS	L	0	25	730	Floating roof vertical tank	12500				9125.00	2.40E-03	1.0	1.00			2.40E-04	371200	6335650
15.118	Aviation gasoline Storage Vessel 03 - Serious Leakage	Pool fire	AVGAS	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335650
15.119	Aviation gasoline Storage Vessel 04	Roof fire	AVGAS	L	0	25	730	Floating roof vertical tank	12500				9125.00	2.40E-03	1.0	1.00			2.40E-04	371200	6335650
15.120	Aviation gasoline Storage Vessel 04 - Serious Leakage	Pool fire	AVGAS	L	0	25	730			22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03			2.88E-06	371200	6335650
15.121	Bund 1 Aviation gasoline Storage Vessel - Catastrophic failure	Pool fire	AVGAS	L	0	25	730						36500.00	1.20E-04	1.0	0.08	Table C.10		9.60E-06	371200	6335650
15.122	Hydrogen storage vessel and reticulation - 10mm	Jet Fire	H2	G	79	25	6.5	Horizontal pressurised bullet	100	10	0.23	3.57E-02	0.14	9.20E-02	1.0			Fig D.6	3.31E-02	371150	6335700
15.123		Flash Fire											0.14	9.20E-02				Fig D.6	1.47E-02	371150	6335700
15.124		VCE											0.14	9.20E-02				Fig D.6	1.47E-05	371150	6335700
15.125	Hydrogen storage	Jet Fire								25	1.25	1.92E-	0.65	1.74E-02	1.0			Fig D.6	6.27E-03	371150	6335700

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.												
					(Barg)	(^{o}C)	(Kg/m^{3})		(m^{3})	(mm)	(Kg/s)	(m^{3}/s)	(t)	(LOC/1000 km- y) or Event/y						Easting	Northing
15.126	vessel and reticulation - 25mm	Flash Fire										01	0.65	1.74E-02				Fig D.6	2.78E-03	371150	6335700
15.127		VCE											0.65	1.74E-02				Fig D.6	2.78E-06	371150	6335700
15.128	Hydrogen storage vessel and reticulation - 50mm	Jet Fire								50	4.12	6.33E-01	0.65	6.25E-04	1.0			Fig D.6	2.25E-04	371150	6335700
15.129		Flash Fire											0.65	6.25E-04				Fig D.6	9.99E-05	371150	6335700
15.130		VCE											0.65	6.25E-04				Fig D.6	1.00E-07	371150	6335700
	Hydrogen storage vessel and reticulation - Catastrophic failure	Safe Dispersion											0.65	2.00E-06	1.0			Fig D.6	1.28E-06	371150	6335700
15.131		Flash Fire																Fig D.6	3.20E-07	371150	6335700
15.132		VCE																Fig D.6	4.00E-07	371150	6335700
15.133	Hydrofluoric Acid Storage Vessel 01 - 10mm	Toxic Gas dispersion	Hydrogen fluoride	G	0	15	967	Vertical - Fixed roof storage tank	10	10	0.48	4.99E-04	0.29	6.12E-02	1.0				6.12E-02	371000	6335700
15.134	Hydrofluoric Acid Storage Vessel 01 - 25mm	Toxic Gas dispersion	Hydrogen fluoride	G	0	15	967			25	3.01	3.12E-03	1.81	5.94E-03	1.0				5.94E-03	371000	6335700
15.135	Hydrofluoric Acid Storage Vessel 01 - 50mm	Toxic Gas dispersion	Hydrogen fluoride	G	0	15	967			50	12.06	1.25E-02	7.24	2.40E-04	1.0				2.40E-04	371000	6335700
15.136	Hydrofluoric Acid Storage Vessel 01 - Catastrophic failure	Toxic Gas dispersion	Hydrogen fluoride	G	0	15	967						9.67	1.00E-05	1.0				1.00E-05	371000	6335700
15.137	Hydrofluoric Acid Storage Vessel 02 - 10mm	Toxic Gas dispersion	Hydrogen fluoride	G	0	15	967	Vertical - Fixed roof storage tank	10	10	0.48	4.99E-04	0.29	6.12E-02	1.0				6.12E-02	371000	6335700
15.138	Hydrofluoric Acid Storage Vessel 02 - 25mm	Toxic Gas dispersion	Hydrogen fluoride	G	0	15	967			25	3.01	3.12E-03	1.81	5.94E-03	1.0				5.94E-03	371000	6335700
15.139	Hydrofluoric Acid Storage Vessel 02 - 50mm	Toxic Gas dispersion	Hydrogen fluoride	G	0	15	967			50	12.06	1.25E-02	7.24	2.40E-04	1.0				2.40E-04	371000	6335700
15.140	Hydrofluoric Acid Storage Vessel 02 - Catastrophic failure	Toxic Gas dispersion	Hydrogen fluoride	G	0	15	967						9.67	1.00E-05	1.0				1.00E-05	371000	6335700

Table E. 10 Xanthate Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.												
					(Barg)	(^{o}C)	(Kg/m^{3})		(m^{3})	(mm)	(Kg/s)	(m^{3}/s)	(t)	(LOC/1000 km- y) or Event/y						Easting	Northing
16.1	Alcohol storage and transfer to reactor - 10mm	Pool Fire	Isobutanol	L	0	25	802	Vertical - Fixed roof storage tank	165	10	0.4128	5.15E-04	0.25	2.00E-01	1.0	0.01	Table C.1		2.00E-03	369400	6335350
16.2	Alcohol storage and transfer to reactor - 25mm	Pool Fire	Isobutanol	L	0	25	802			25	1.590	1.98E-03	0.95	2.34E-02	1.0	0.03	Table C.1		7.01E-04	369400	6335350
16.3	Alcohol storage and transfer to reactor - 50mm	Pool Fire	Isobutanol	L	0	25	802			50	5.630	7.02E-03	3.38	7.35E-04	1.0	0.03	Table C.1		2.21E-05	369400	6335350
16.4	Alcohol storage and transfer to reactor - Catastrophic failure	Pool Fire	Isobutanol	L	0	25	802			N/A	N/A	N/A	132.33	1.00E-05	1.0	0.08	Table C.1		8.00E-07	369400	6335350
16.5	Carbon Disulphide Isotainer storage - 10mm	Pool Fire	Carbon Disulphide	L	0	25	1260	Horizontal - Isotainer	15	10	0.5579	4.43E-04	0.33	6.12E-02	1.0	0.20		Fig D.7	1.10E-04	369500	6335350
16.6	Carbon Disulphide Isotainer storage - 25mm	Pool Fire	Carbon Disulphide	L	0	25	1260			25	2.403	1.91E-03	1.44	5.94E-03	1.0	0.20		Fig D.7	1.07E-05	369500	6335350
16.7	Carbon Disulphide Isotainer 1 storage - 50mm	Pool Fire	Carbon Disulphide	L	0	25	1260			50	8.751	6.95E-03	5.25	2.40E-04	1.0	0.20		Fig D.7	4.32E-07	369500	6335350
16.8	Carbon Disulphide Isotainer 1 - Catastrophic failure	Pool Fire	Carbon Disulphide	L	0	25	1260			N/A	N/A	N/A	18.90	1.00E-05	1.0	0.20		Fig D.7	1.80E-08	369500	6335350
16.9	Carbon Disulphide Isotainer 2 storage - 10mm	Pool Fire	Carbon Disulphide	L	0	25	1260	Horizontal - Isotainer	15	10	0.5579	4.43E-04	0.33	6.12E-02	1.0	0.20		Fig D.7	1.10E-04	369500	6335350
16.10	Carbon Disulphide Isotainer 2 storage - 25mm	Pool Fire	Carbon Disulphide	L	0	25	1260			25	2.403	1.91E-03	1.44	5.94E-03	1.0	0.20		Fig D.7	1.07E-05	369500	6335350
16.11	Carbon Disulphide Isotainer 2 storage - 50mm	Pool Fire	Carbon Disulphide	L	0	25	1260			50	8.751	6.95E-03	5.25	2.40E-04	1.0	0.20		Fig D.7	4.32E-07	369500	6335350
16.12	Carbon Disulphide Isotainer 2 - Catastrophic failure	Pool Fire	Carbon Disulphide	L	0	25	1260			N/A	N/A	N/A	18.90	1.00E-05	1.0	0.20		Fig D.7	1.80E-08	369500	6335350
16.13	Carbon Disulphide Isotainer 1 storage - 10mm	SO2 Dispersion from a pool fire	Sulphur Dioxide	G	0	25	2.62	Horizontal - Isotainer	12148	10	0.9389	0.359	0.56	6.12E-02	1.0	0.20		Fig D.7	1.10E-04	369500	6335350
16.14	Carbon Disulphide Isotainer 1 storage - 25mm	SO2 Dispersion from a pool fire	Sulphur Dioxide	G	0	25	2.62			25	4.043	1.54	2.43	5.94E-03	1.0	0.20		Fig D.7	1.07E-05	369500	6335350
16.15	Carbon Disulphide Isotainer 1 storage - 50mm	SO2 Dispersion from a pool fire	Sulphur Dioxide	G	0	25	2.62			50	7.808	2.98	8.84	2.40E-04	1.0	0.20		Fig D.7	4.32E-07	369500	6335350
16.16	Carbon Disulphide Isotainer 1 - Catastrophic failure	SO2 Dispersion from a pool fire	Sulphur Dioxide	G	0	25	2.62			N/A	7.808	2.98	31.80	1.00E-05	1.0	0.20		Fig D.7	1.80E-08	369500	6335350
16.17	Carbon Disulphide Isotainer 2 storage - 10mm	SO2 Dispersion from a pool fire	Sulphur Dioxide	G	0	25	2.62	Horizontal - Isotainer	12148	10	0.9389	0.359	0.56	6.12E-02	1.0	0.20		Fig D.7	1.10E-04	369500	6335350

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
					(Barg)	(°C)	(Kg/m^3)	Tank Type	Total Vol. (m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y						Easting	Northing
16.18	Carbon Disulphide Isotainer 2 storage - 25mm	SO2 Dispersion from a pool fire	Sulphur Dioxide	G	0	25	2.62			25	4.043	1.54	2.43	5.94E-03	1.0	0.20		Fig D.7	1.07E-05	369500	6335350
16.19	Carbon Disulphide Isotainer 2 storage - 50mm	SO2 Dispersion from a pool fire	Sulphur Dioxide	G	0	25	2.62			50	7.808	2.98	8.84	2.40E-04	1.0	0.20		Fig D.7	4.32E-07	369500	6335350
16.20	Carbon Disulphide Isotainer 2 - Catastrophic failure	SO2 Dispersion from a pool fire	Sulphur Dioxide	G	0	25	2.62			N/A	7.808	2.98	31.80	1.00E-05	1.0	0.20		Fig D.7	1.80E-08	369500	6335350

Table E. 11 Ammonia Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.									
					(Barg)	(°C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
17.1	Ammonia Storage Vessel 01 - 10mm	NH3 gas dispersion from liquid NH3 spill	NH3	L	0	-33	681	Vertical - Fixed roof storage tank	29326	10	0.64	9.37E-04	0.38	6.30E-02	1.0	6.30E-02	371400	6333700
17.2	Ammonia Storage Vessel 01 - 25mm									25	3.99	5.86E-03	2.39	1.02E-02	1.0	1.02E-02	371400	6333700
17.3	Ammonia Storage Vessel 01 - 50mm									50	15.95	2.34E-02	9.57	7.90E-04	1.0	7.90E-04	371400	6333700
17.4	Ammonia Storage Vessel 01 - Catastrophic failure												19967.49	2.00E-06	1.0	2.00E-06	371400	6333700
17.5	Ammonia Storage Vessel 02 - 10mm	NH3 gas dispersion from liquid NH3 spill	NH3	L	0	-32	681	Vertical - Fixed roof storage tank	29326	10	0.64	9.37E-04	0.38	6.30E-02	1.0	6.30E-02	371400	6333700
17.6	Ammonia Storage Vessel 02 - 25mm									25	3.99	5.86E-03	2.39	1.02E-02	1.0	1.02E-02	371400	6333700
17.7	Ammonia Storage Vessel 02 - 50mm									50	15.95	2.34E-02	9.57	7.90E-04	1.0	7.90E-04	371400	6333700
17.8	Ammonia Storage Vessel 02 - Catastrophic failure												19967.49	2.00E-06	1.0	2.00E-06	371400	6333700

Table E. 12 Fertiliser Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.									
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
18.1	Ammonia Storage Vessel - 10mm	NH3 gas dispersion from liquid NH3 spill	NH3	L	0	-33	681	Vertical - Fixed roof storage tank	294	10	0.63	9.24E-04	0.38	6.30E-02	1.0	6.30E-02	371300	6332800
18.2	Ammonia Storage Vessel - 25mm									25	3.93	5.78E-03	2.36	1.02E-02	1.0	1.02E-02	371300	6332800
18.3	Ammonia Storage Vessel - 50mm									50	15.73	2.31E-02	9.44	7.90E-04	1.0	7.90E-04	371300	6332800
18.4	Ammonia Storage Vessel - Catastrophic failure												199.84	2.00E-06	1.0	2.00E-06	371300	6332800

Table E. 13 LPG Facility Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.												
					(Barg)	(°C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y						Easting	Northing
19.1	Propane Storage Vessel 01 - 10mm	Jet Fire	Propane	L	8	20	501	Horizontal pressurised bullet	120	10	1.41380	2.82E-03	0.85	3.15E-02	1.0	0.07		Fig D.8	2.20E-03	370500	6331700
19.2		Flash Fire												3.15E-02		0.07		Fig D.8	2.64E-04	370500	6331700
19.3		VCE												3.15E-02		0.07		Fig D.8	2.64E-04	370500	6331700
19.4	Propane Storage Vessel 01 - 25mm	Jet Fire	Propane	L						25	8.8351	1.76E-02	5.30	5.51E-02	1.0	0.18		Fig D.8	9.91E-03	370500	6331700
19.5		Flash Fire												5.51E-02		0.18		Fig D.8	1.19E-03	370500	6331700
19.6		VCE												5.51E-02		0.18		Fig D.8	1.19E-03	370500	6331700
19.7	Propane Storage Vessel 01 - 50mm	Jet Fire	Propane	L						50	35.3210	7.05E-02	21.19	5.90E-03	1.0	0.64		Fig D.8	3.79E-03	370500	6331700
19.8		Flash Fire												5.90E-03		0.64		Fig D.8	1.14E-03	370500	6331700
19.9		VCE												5.90E-03		0.64		Fig D.8	1.14E-03	370500	6331700
19.10	Propane Storage Vessel 01 - Catastrophic failure	BLEVE	Propane	L									60.12	2.00E-06	1.0			Fig D.8	1.35E-06	370500	6331700
19.11	Propane Storage Vessel 02 - 10mm	Jet Fire	Propane	L	8	20	501	Horizontal pressurised bullet	120	10	1.41380	2.82E-03	0.85	3.15E-02	1.0	0.07		Fig D.8	2.20E-03	370500	6331700
19.12		Flash Fire												3.15E-02		0.07		Fig D.8	2.64E-04	370500	6331700
19.13		VCE												3.15E-02		0.07		Fig D.8	2.64E-04	370500	6331700
19.14	Propane Storage Vessel 02 - 25mm	Jet Fire	Propane	L						25	8.8351	1.76E-02	5.30	5.51E-02	1.0	0.18		Fig D.8	9.91E-03	370500	6331700
19.15		Flash Fire												5.51E-02		0.18		Fig D.8	1.19E-03	370500	6331700
19.16		VCE												5.51E-02		0.18		Fig D.8	1.19E-03	370500	6331700
19.17	Propane Storage Vessel 02 - 50mm	Jet Fire	Propane	L						50	35.3210	7.05E-02	21.19	5.90E-03	1.0	0.64		Fig D.8	3.79E-03	370500	6331700
19.18		Flash Fire												5.90E-03		0.64		Fig D.8	1.14E-03	370500	6331700
19.19		VCE												5.90E-03		0.64		Fig D.8	1.14E-03	370500	6331700
19.20	Propane Storage Vessel 02 - Catastrophic failure	BLEVE	Propane	L									60.12	2.00E-06	1.0			Fig D.8	1.35E-06	370500	6331700
19.21	Propane Storage Vessel 03 - 10mm	Jet Fire	Propane	L	8	20	501	Horizontal pressurised bullet	120	10	1.41380	2.82E-03	0.85	3.15E-02	1.0	0.07		Fig D.8	2.20E-03	370500	6331700
19.22		Flash Fire												3.15E-02		0.07		Fig D.8	2.64E-04	370500	6331700
19.23		VCE												3.15E-02		0.07		Fig D.8	2.64E-04	370500	6331700
19.24	Propane Storage Vessel 03 - 25mm	Jet Fire	Propane	L						25	8.8351	1.76E-02	5.30	5.51E-02	1.0	0.18		Fig D.8	9.91E-03	370500	6331700
19.25		Flash Fire												5.51E-02		0.18		Fig D.8	1.19E-03	370500	6331700
19.26		VCE												5.51E-02		0.18		Fig D.8	1.19E-03	370500	6331700
19.27	Propane Storage Vessel 03 - 50mm	Jet Fire	Propane	L						50	35.3210	7.05E-02	21.19	5.90E-03	1.0	0.64		Fig D.8	3.79E-03	370500	6331700
19.28		Flash Fire												5.90E-03		0.64		Fig D.8	1.14E-03	370500	6331700
19.29		VCE												5.90E-03		0.64		Fig D.8	1.14E-03	370500	6331700
19.30	Propane Storage Vessel 03 - Catastrophic failure	BLEVE	Propane	L									60.12	2.00E-06	1.0			Fig D.8	1.35E-06	370500	6331700
19.31	Butane Storage Vessel 01 - 10mm	Jet Fire	Butane	L	8	20	579	Horizontal pressurised bullet	60	10	1.52	2.62E-03	0.91	5.55E-02	1.0	0.07		Fig D.9	3.88E-03	370700	6331700
19.32		Flash Fire												5.55E-02		0.07		Fig D.9	4.65E-04	370700	6331700
19.33		VCE												5.55E-02		0.07		Fig D.9	4.65E-04	370700	6331700
19.34	Butane Storage Vessel 01 - 25mm	Jet Fire	Butane	L						25	9.49	1.64E-02	5.69	2.91E-02	1.0	0.18		Fig D.9	5.23E-03	370700	6331700
19.35		Flash Fire												2.91E-02		0.18		Fig D.9	6.28E-04	370700	6331700

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Fault Tree ref.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.												
					(Barg)	(°C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y						Easting	Northing
19.36		VCE												2.91E-02		0.18		Fig D.9	6.28E-04	370700	6331700
19.37	Butane Storage Vessel 01 - 50mm	Jet Fire	Butane	L						50	37.92	6.55E-02	22.75	2.60E-03	1.0	0.64		Fig D.9	1.67E-03	370700	6331700
19.38		Flash Fire												2.60E-03		0.64		Fig D.9	5.01E-04	370700	6331700
19.39		VCE												2.60E-03		0.64		Fig D.9	5.01E-04	370700	6331700
19.40	Butane Storage Vessel 01 - Catastrophic failure	BLEVE	Butane	L									34.74	2.00E-06	1.0			Fig D.9	1.35E-06	370700	6331700
19.41	Butane Storage Vessel 02 - 10mm	Jet Fire	Butane	L	8	20	579	Horizontal pressurised bullet	60	10	1.52	2.62E-03	0.91	5.55E-02	1.0	0.07		Fig D.9	3.88E-03	370700	6331700
19.42		Flash Fire												5.55E-02		0.07		Fig D.9	4.65E-04	370700	6331700
19.43		VCE												5.55E-02		0.07		Fig D.9	4.65E-04	370700	6331700
19.44	Butane Storage Vessel 02 - 25mm	Jet Fire	Butane	L						25	9.49	1.64E-02	5.69	2.91E-02	1.0	0.18		Fig D.9	5.23E-03	370700	6331700
19.45		Flash Fire												2.91E-02		0.18		Fig D.9	6.28E-04	370700	6331700
19.46		VCE												2.91E-02		0.18		Fig D.9	6.28E-04	370700	6331700
19.47	Butane Storage Vessel 02 - 50mm	Jet Fire	Butane	L						50	37.92	6.55E-02	22.75	2.60E-03	1.0	0.64		Fig D.9	1.67E-03	370700	6331700
19.48		Flash Fire												2.60E-03		0.64		Fig D.9	5.01E-04	370700	6331700
19.49		VCE												2.60E-03		0.64		Fig D.9	5.01E-04	370700	6331700
19.50	Butane Storage Vessel 02 - Catastrophic failure	BLEVE	Butane	L									34.74	2.00E-06	1.0			Fig D.9	1.35E-06	370700	6331700
19.51	Butane Storage Vessel 03 - 10mm	Jet Fire	Butane	L	8	20	579	Horizontal pressurised bullet	60	10	1.52	2.62E-03	0.91	5.55E-02	1.0	0.07		Fig D.9	3.88E-03	370700	6331700
19.52		Flash Fire												5.55E-02		0.07		Fig D.9	4.65E-04	370700	6331700
19.53		VCE												5.55E-02		0.07		Fig D.9	4.65E-04	370700	6331700
19.54	Butane Storage Vessel 03 - 25mm	Jet Fire	Butane	L						25	9.49	1.64E-02	5.69	2.91E-02	1.0	0.18		Fig D.9	5.23E-03	370700	6331700
19.55		Flash Fire												2.91E-02		0.18		Fig D.9	6.28E-04	370700	6331700
19.56		VCE												2.91E-02		0.18		Fig D.9	6.28E-04	370700	6331700
19.57	Butane Storage Vessel 03 - 50mm	Jet Fire	Butane	L						50	37.92	6.55E-02	22.75	2.60E-03	1.0	0.64		Fig D.9	1.67E-03	370700	6331700
19.58		Flash Fire												2.60E-03		0.64		Fig D.9	5.01E-04	370700	6331700
19.59		VCE												2.60E-03		0.64		Fig D.9	5.01E-04	370700	6331700
19.60	Butane Storage Vessel 03 - Catastrophic failure	BLEVE	Butane	L									34.74	2.00E-06	1.0			Fig D.9	1.35E-06	370700	6331700

Table E. 14 Hydrogen Peroxide Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.										
					(Barg)	(°C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y				Easting	Northing
20.1	Hydrogen Synthesis Plant - 10mm	Jet Fire	H2	G	23	29	2	Synthesis plant and ancillary parts	60	10	0.06	1.18E-01	0.04	3.16E-01	1.0	Fig D.1	0.11	369800	6335800
20.2		Flash Fire												3.16E-01	1.0	Fig D.1	5.05E-02	369800	6335800
20.3		VCE												3.16E-01	1.0	Fig D.1	5.06E-05	369800	6335800
20.4	Hydrogen Synthesis Plant - 25mm	Jet Fire								25	0.31	5.78E-01	0.19	4.69E-02	1.0	Fig D.1	1.69E-02	369800	6335800
20.5		Flash Fire												4.69E-02	1.0	Fig D.1	7.50E-03	369800	6335800
20.6		VCE												4.69E-02	1.0	Fig D.1	7.50E-06	369800	6335800
20.7	Hydrogen Synthesis Plant - 50mm	Jet Fire								50	1.23	2.27E+00	0.74	6.95E-04	1.0	Fig D.1	2.50E-04	369800	6335800
20.8		Flash Fire												6.95E-04	1.0	Fig D.1	1.11E-04	369800	6335800
20.9		VCE												6.95E-04	1.0	Fig D.1	1.11E-07	369800	6335800
	Hydrogen Synthesis Plant - PSA 1 Catastrophic failure	Safe dispersion							15				0.03	5.00E-06	1.0	Fig D.2	3.20E-06	369800	6335800
20.10		Flash Fire											0.03	5.00E-06	1.0	Fig D.2	7.99E-07	369800	6335800
20.11		VCE											0.03	5.00E-06	1.0	Fig D.2	1.00E-06	369800	6335800
	Hydrogen Synthesis Plant - PSA 2 Catastrophic failure	Safe dispersion							15				0.00	5.00E-06	1.0	Fig D.2	3.20E-06	369800	6335800
20.12		Flash Fire											0.00	5.00E-06	1.0	Fig D.2	7.99E-07	369800	6335800
20.13		VCE											0.00	5.00E-06	1.0	Fig D.2	1.00E-06	369800	6335800
	Hydrogen Synthesis Plant - PSA 3 Catastrophic failure	Safe dispersion							15				0.00	5.00E-06	1.0	Fig D.2	3.20E-06	369800	6335800
20.14		Flash Fire											0.00	5.00E-06	1.0	Fig D.2	7.99E-07	369800	6335800
20.15		VCE											0.00	5.00E-06	1.0	Fig D.2	1.00E-06	369800	6335800
20.16	Hydrogen storage vessel and reticulation - 10mm	Jet Fire	H2	G	79	25	6.5	Horizontal pressurised bullet	100	10	0.23	0.04	0.14	9.20E-02	1.0	Fig D.3	0.03	369700	6335800
20.17		Flash Fire												9.20E-02	1.0	Fig D.3	1.47E-02	369700	6335800
20.18		VCE												9.20E-02	1.0	Fig D.3	1.47E-05	369700	6335800
20.19	Hydrogen storage vessel and reticulation - 25mm	Jet Fire								25	1.25	0.19	0.00	1.74E-02	1.0	Fig D.3	6.27E-03	369700	6335800
20.20		Flash Fire												1.74E-02	1.0	Fig D.3	2.78E-03	369700	6335800
20.21		VCE												1.74E-02	1.0	Fig D.3	2.78E-06	369700	6335800
20.22	Hydrogen storage vessel and reticulation - 50mm	Jet Fire								50	4.12	0.63	0.00	6.25E-04	1.0	Fig D.3	2.25E-04	369700	6335800
20.23		Flash Fire												6.25E-04	1.0	Fig D.3	9.99E-05	369700	6335800
20.24		VCE												6.25E-04	1.0	Fig D.3	1.00E-07	369700	6335800
	Hydrogen storage vessel and reticulation - Catastrophic failure	Safe dispersion											0.00	2.00E-06	1.0	Fig D.4	1.28E-06	369700	6335800
20.25		Flash Fire															3.20E-07	369700	6335800
20.26		VCE															4.00E-07	369700	6335800

Table E. 15 Lithium Metal Facility Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.									
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y			Easting	Northing
21.1	Chlorine Release - 10mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G	2	300	3.7	Gas Release from Process	270	10	0.03	6.76E-03	0.02	5.20E-02	1.0	5.20E-02	369800	6332900
21.2	Chlorine Release - 25mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						25	0.16	4.32E-02	0.096	8.19E-03	1.0	8.19E-03	369800	6332900
21.3	Chlorine Release - 50mm	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G						50	0.63	1.70E-01	0.38	3.85E-04	1.0	3.85E-04	369800	6332900
21.4	Chlorine Release - Catastrophic failure	Chlorine gas dispersion from a gaseous chlorine release	Chlorine	G									1.00	2.00E-06	1.0	2.00E-06	369800	6332900

Table E. 16 Timber Products Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.										
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y				Easting	Northing
22.1	Methanol Storage Vessel	Roof fire	Methanol	L	0	25	788	Floating roof vertical tank	130				102.44	2.40E-03	1.0	1.00	2.40E-04	370800	6336700
22.2	Methanol Storage Vessel - Serious Leakage	Pool fire	Methanol	L	0	25	788			22	3.54	4.49E-03	2.122	9.60E-05	1.0	0.03	2.88E-06	370800	6336700
22.3	Methanol Storage Vessel - Catastrophic failure with Knock On	Pool fire	Methanol	L	0	25	788						102.44	6.00E-05	1.0	0.08	4.80E-06	370800	6336700

Table E. 17 Tantalum Refining Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.										
					(Barg)	(^oC)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y				Easting	Northing
23.1	Cyclohexane Storage Vessel	Roof fire	Cyclohexane	L	0	25	779	Floating roof vertical tank	130				101.27	2.40E-03	1.0	1.00	2.40E-04	369400	6333200
23.2	Cyclohexane Storage Vessel - Serious Leakage	Pool fire	Cyclohexane	L	0	25	779			22	3.43	4.40E-03	2.058	9.60E-05	1.0	0.03	2.88E-06	369400	6333200
23.3	Cyclohexane Storage Vessel - Catastrophic failure	Pool fire	Cyclohexane	L	0	25	779						101.27	6.00E-05	1.0	0.08	4.80E-06	369400	6333200

Table E. 18 Synthetic Rutile Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.											
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y					Easting	Northing
25.1	LPG Storage Vessel - 10mm	Jet Fire	Propane	L	8	20	501	Horizontal pressurised bullet	8	10	1.41380	2.82E-03	0.85	1.00E-05	1.0	0.07	Fig D.10	7.00E-07	369500	6331100
25.2		Flash Fire												1.00E-05		0.07	Fig D.10	8.38E-08	369500	6331100
25.3		VCE												1.00E-05		0.07	Fig D.10	8.38E-08	369500	6331100
25.4	LPG Storage Vessel - 25mm	Jet Fire	Propane	L						25	8.8351	1.76E-02	3.76	5.00E-06	1.0	0.18	Fig D.10	9.00E-07	369500	6331100
25.5		Flash Fire												5.00E-06		0.18	Fig D.10	1.08E-07	369500	6331100
25.6		VCE												5.00E-06		0.18	Fig D.10	1.08E-07	369500	6331100
25.7	LPG Storage Vessel - 50mm	Jet Fire	Propane	L						50	35.3210	7.05E-02	3.76	5.00E-06	1.0	0.64	Fig D.10	3.21E-06	369500	6331100
25.8		Flash Fire												5.00E-06		0.64	Fig D.10	9.65E-07	369500	6331100
25.9		VCE												5.00E-06		0.64	Fig D.10	9.65E-07	369500	6331100
25.10	LPG Storage Vessel - Catastrophic failure	BLEVE	Propane	L									3.76	2.00E-06	1.0		Fig D.10	1.35E-06	369500	6331100
25.11	Diesel Storage Vessel - Serious Leakage	Pool fire	Diesel	L	0	25	730	Horizontal tank	20	22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03		2.88E-06	369400	6331100
25.12	Bund Diesel Storage Vessel - Catastrophic failure	Pool fire	Diesel	L	0	25	730						14.60	6.00E-05	1.0	0.08		4.80E-06	369400	6331100

Table E. 19 Vanadium Refining Plant Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.											
					(Barg)	(^{o}C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y					Easting	Northing
26.1	LPG Storage Vessel - 10mm	Jet Fire	Propane	L	8	20	501	Horizontal pressurised bullet	8	10	1.41380	2.82E-03	0.85	1.00E-05	1.0	0.07	Fig D.10	7.00E-07	369300	6331900
26.2		Flash Fire												1.00E-05		0.07	Fig D.10	8.38E-08	369300	6331900
26.3		VCE												1.00E-05		0.07	Fig D.10	8.38E-08	369300	6331900
26.4	LPG Storage Vessel - 25mm	Jet Fire	Propane	L						25	8.8351	1.76E-02	3.76	5.00E-06	1.0	0.18	Fig D.10	9.00E-07	369300	6331900
26.5		Flash Fire												5.00E-06		0.18	Fig D.10	1.08E-07	369300	6331900
26.6		VCE												5.00E-06		0.18	Fig D.10	1.08E-07	369300	6331900
26.7	LPG Storage Vessel - 50mm	Jet Fire	Propane	L						50	35.3210	7.05E-02	3.76	5.00E-06	1.0	0.64	Fig D.10	3.21E-06	369300	6331900
26.8		Flash Fire												5.00E-06		0.64	Fig D.10	9.65E-07	369300	6331900
26.9		VCE												5.00E-06		0.64	Fig D.10	9.65E-07	369300	6331900
26.10	LPG Storage Vessel - Catastrophic failure	BLEVE	Propane	L									3.76	2.00E-06	1.0		Fig D.10	1.35E-06	369300	6331900
26.11	Diesel Storage Vessel - Serious Leakage	Pool fire	Diesel	L	0	25	730	Horizontal tank	20	22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03		2.88E-06	369200	6331900
26.12	Bund Diesel Storage Vessel - Catastrophic failure	Pool fire	Diesel	L									14.60	6.00E-05	1.0	0.08		4.80E-06	369200	6331900

Table E. 20 Aluminium Smelter Scenario Summaries

Scenario ID	Hazard Description	Consequence	Material	Phase	P	T	Fluid Density at Process Conditions	Tank		Hole Size	Release Rate		Total Mass Released	Base Failure/ Event Freq.	Fraction of Time in Op. Mode	Ignit. Prob.	Event Tree ref.	Event Frequency	GPS Co-ordinates	
								Tank Type	Total Vol.											
					(Barg)	(°C)	(Kg/m^3)		(m^3)	(mm)	(Kg/s)	(m^3/s)	(t)	(LOC/1000 km- y) or Event/y					Easting	Northing
28.1	LPG Storage Vessel - 10mm	Jet Fire	Propane	L	8	20	501	Horizontal pressurised bullet	8	10	1.41380	2.82E-03	0.85	1.00E-05	1.0	0.07	Fig D.10	7.00E-07	370700	6332900
28.2		Flash Fire												1.00E-05		0.07	Fig D.10	8.38E-08	370700	6332900
28.3		VCE												1.00E-05		0.07	Fig D.10	8.38E-08	370700	6332900
28.4	LPG Storage Vessel - 25mm	Jet Fire	Propane	L						25	8.8351	1.76E-02	3.76	5.00E-06	1.0	0.18	Fig D.10	9.00E-07	370700	6332900
28.5		Flash Fire												5.00E-06		0.18	Fig D.10	1.08E-07	370700	6332900
28.6		VCE												5.00E-06		0.18	Fig D.10	1.08E-07	370700	6332900
28.7	LPG Storage Vessel - 50mm	Jet Fire	Propane	L						50	35.3210	7.05E-02	3.76	5.00E-06	1.0	0.64	Fig D.10	3.21E-06	370700	6332900
28.8		Flash Fire												5.00E-06		0.64	Fig D.10	9.65E-07	370700	6332900
28.9		VCE												5.00E-06		0.64	Fig D.10	9.65E-07	370700	6332900
28.10	LPG Storage Vessel - Catastrophic failure	BLEVE	Propane	L									3.76	2.00E-06	1.0		Fig D.10	1.35E-06	370700	6332900
28.11	Diesel Storage Vessel - Serious Leakage	Pool fire	Diesel	L	0	25	730	Horizontal tank	20	22	3.23	4.43E-03	1.94	9.60E-05	1.0	0.03		2.88E-06	370600	6332900
28.12	Bund Diesel Storage Vessel - Catastrophic failure	Pool fire	Diesel	L									14.60	6.00E-05	1.0	0.08		4.80E-06	370600	6332900

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APPENDIX F

TANK BUND AND LIQUID POOL AREA CALCULATIONS

LIST OF FIGURES

LIST OF TABLES

F1 FUEL TERMINAL

F1.1 Fires

Roof fires

For calculation of the burning pool areas for Liquid Hydrocarbon Fuel roof fires, a conservative assumption that the entire surface area of the roof represented the surface area of the pool was used. The tank roof surface areas are indicated in **Table F.1** below.

Pool fires

The calculation of burning pool areas for Liquid Hydrocarbon Fuel pool fires resulting from serious leaks are detailed below. All release rates were calculated using the TNO software Effects. Actual values calculated for each scenario are detailed in the Scenario Summaries **Table E.7** in **Appendix E**.

F1.2 Burning Pool Area Calculation

The maximum burning pool area occurs when the pool fire has developed to the stage when the discharge rate equals the burning rate, as given by:

$m = \nu_\infty \text{ (m / s) . SA (m}^2\text{) . } \rho \text{ (kg / m}^3\text{)}$

Where: m = mass discharge rate = 3.2315 kg / s
ν_∞ = liquid burning rate of a pool of infinite diameter (m / s)
SA = surface area (m^2)
ρ = density = 740 kg / m^3

rearranging for SA yields

$\text{SA (m}^2\text{) = (3.2315 kg / s) / (740 kg / m}^3 \text{ . } \nu_\infty)$

To calculate ν_∞ the following equation is used:

$m_\infty \text{ (kg / m}^2\text{ s) = } \nu_\infty \text{ (m / s).} \rho_1 \text{ (kg / m}^3\text{)}$

rearranging for ν_∞ yields

$\nu_\infty \text{ (m / s) = } m_\infty \text{ (kg / m}^2\text{ s) / } \rho_1 \text{ (kg / m}^3\text{)}$

Where:
m_∞ = mass liquid burning rate for a pool of infinite diameter = 0.055 kg / m^2 s
ν_∞ = burning rate (m / s)
ρ_1 = density = 740 kg / m^3

Therefore:

$\nu_\infty \text{ = (0.055 kg / m}^2\text{ s) / (740 kg / m}^3\text{) = 7.432 x 10}^{-5}\text{ m / s}$

$\text{SA = (3.2315 kg / s) / (740 kg / m}^3\text{ . 7.432 x 10}^{-5}\text{ m / s) = 59.586 m}^2$

Note, Calculations in this example are representative only and do not consider the effects of rounding error

Table F.1 Assumed Fuel Storage Terminal Tank Farm Inventories

Tank Number	Material	Tank Height (m)	Tank Diameter (m)	Tank Roof Area (m^2)	Storage Capacity (m^3)
01 - 02	ULP	18	42	1389	25,000
03 - 06	ULP	18	30	689	12,400
01 - 02	Ethanol	18	19	278	5,000

Table F.2 Large ULP Tank Bund

Bund Area calculation (assume 1 m bund height)		
Total volume of tanks = 25000 x 2 kL	50000	kL
Design is 110% of total vol.	55000	kL
:. L x W x H =	55000	m^3
:. L x W x 1 =	55000	m^2
:. L or W =	234.5	m
or Diameter =	264.6	m

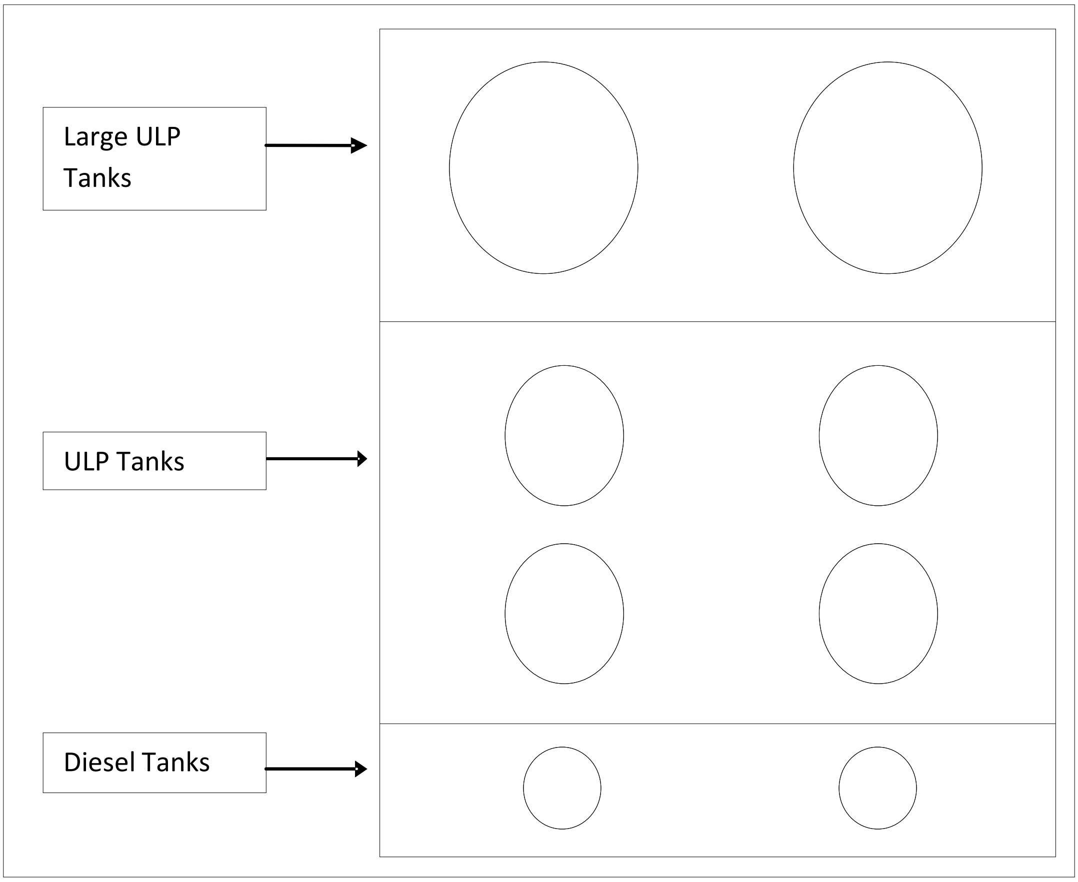
Table F.3 ULP Tank Bund

Bund Area calculation (assume 1 m height)		
Total volume of tanks = 12400 x 4 kL	49600	kL
Design is 110% of total vol.	54560	kL
L x W x H =	54560	m^3
:. L x W x 1 =	54560	m^2
:. L or W =	233.6	m
or Diameter =	263.6	m

Table F.4 Ethanol Tank Bund

Bund Area calculation (assume 1 m height)		
Total volume of tanks = 5000 x 2 kL	10000	kL
Design is 110% of total vol.	11000	kL
L x W x H =	11000	m^3
:. L x W x1 =	11000	m^2
:. L or W =	104.9	m
or Diameter =	118.3	m

Figure F.1 Storage Tank Layout Assumption for Fuel Tank Terminal



F2 OIL REFINERY

F2.1 Fires

Pool fires

For calculation of the burning pool areas for Liquid Hydrocarbon Fuel roof fires, a conservative assumption that the entire surface area of the roof represented the surface area of the pool was used. The tank roof surface areas are indicated in **Table F.5**.

Pool fires

The calculation of burning pool areas for Liquid Hydrocarbon Fuel pool fires resulting from serious leaks are detailed below. All release rates were calculated using the TNO software Effects. Actual values calculated for each scenario are detailed in the Scenario Summaries **Table E.10** in **Appendix E**.

F2.2 Burning Pool Area Calculation

The maximum burning pool area occurs when the pool fire has developed to the stage when the discharge rate equals the burning rate, as given by:

$m = .\nu_\infty \text{ (m / s) . SA (m}^2\text{) . } \rho \text{ (kg / m}^3\text{)}$

Where: m = mass discharge rate = 4.3088 kg / s
ν_∞ = liquid burning rate of a pool of infinite diameter (m / s)
SA = surface area (m^2)
ρ = density = 740 kg / m^3

Rearranging for SA yields

$\text{SA (m}^2\text{) = (4.3088 kg / s) / (740 kg / m}^3 \text{ . } \nu_\infty)$

To calculate ν_∞ the following equation is used:

$m_\infty \text{ (kg / m}^2 \text{ s) = } \nu_\infty \text{ (m / s).} \rho_1 \text{ (kg / m}^3\text{)}$

Rearranging for $\nu\infty$ yields

$\nu_\infty \text{ (m / s) = } m_\infty \text{ (kg / m}^2 \text{ s) / } \rho_1 \text{ (kg / m}^3\text{)}$

Where:
m_∞ = mass liquid burning rate for a pool of infinite diameter = 0.055 kg / m^2 s
ν_∞ = burning rate (m / s)
ρ_1 = density = 740 kg / m^3

Therefore:

$\nu_\infty \text{ = (0.055 kg / m}^2 \text{ s) / (740 kg / m}^3\text{) = 7.432 x 10}^{-5} \text{ m / s}$

$\text{SA = (4.3088 kg / s) / (740 kg / m}^3 \text{ . 7.432 x 10}^{-5} \text{ m / s) = 79.450 m}^2$

Note, Calculations in this example are representative only and do not consider the effects of rounding error.

Table F.5 Assumed Oil Refinery Liquid Hydrocarbon Fuel Inventories

Tank Number	Material	Tank Height (m)	Tank Diameter (m)	Tank Roof Area (m^2)	Storage Capacity (m^3)
01 - 02	ULP	32	89	6250	200,000
03 - 12	ULP	18	30	694	12,500
13 - 22	ULP	18	30	694	12,500
23 - 32	ULP	18	30	694	12,500
01 - 02	Diesel	32	63	3125	100,000
03 - 10	Diesel	18	30	694	12,500
11 - 18	Diesel	18	30	694	12,500
01 - 02	Kerosene	18	38	1111	20,000
01 - 04	Aviation Gasoline	18	30	694	12,500

Table F.6 Large ULP Tank Bund

Bund Area calculation (assume 1.5m height)		
200000 x 2 kL	400000	kL
design 110% of vol.	440000	kL
L x W x H =	440000	m^3
:. L x W =	293333.3	m^2
:. L or W =	541.6	m
or Diameter =	611.1	m

Table F.7 ULP Tank Bund

Bund Area calculation (assume 1 m height)		
12500 x 10 kL	125000	kL
design 110% of vol.	137500	kL
L x W x H =	137500	m^3
:. L x W =	137500	m^2
:. L or W =	370.8	m
or Diameter =	418.4	m

Table F.8 Large Diesel Tank Bund

Bund Area calculation (assume 1 m height)		
100000 x 2 kL	200000	kL
design 110% of vol.	220000	kL
L x W x H =	220000	m^3
:. L x W =	220000	m^2
:. L or W =	469.0	m
or Diameter =	529.3	m

Table F.9 Diesel Tank Bund

Bund Area calculation (assume 1 m height)		
12500 x 8 kL	100000	kL
design 110% of vol.	110000	kL
L x W x H =	110000	m^3
:. L x W =	110000	m^2
:. L or W =	331.7	m
or Diameter =	374.2	m

Table F.10 Kerosene Tank Bund

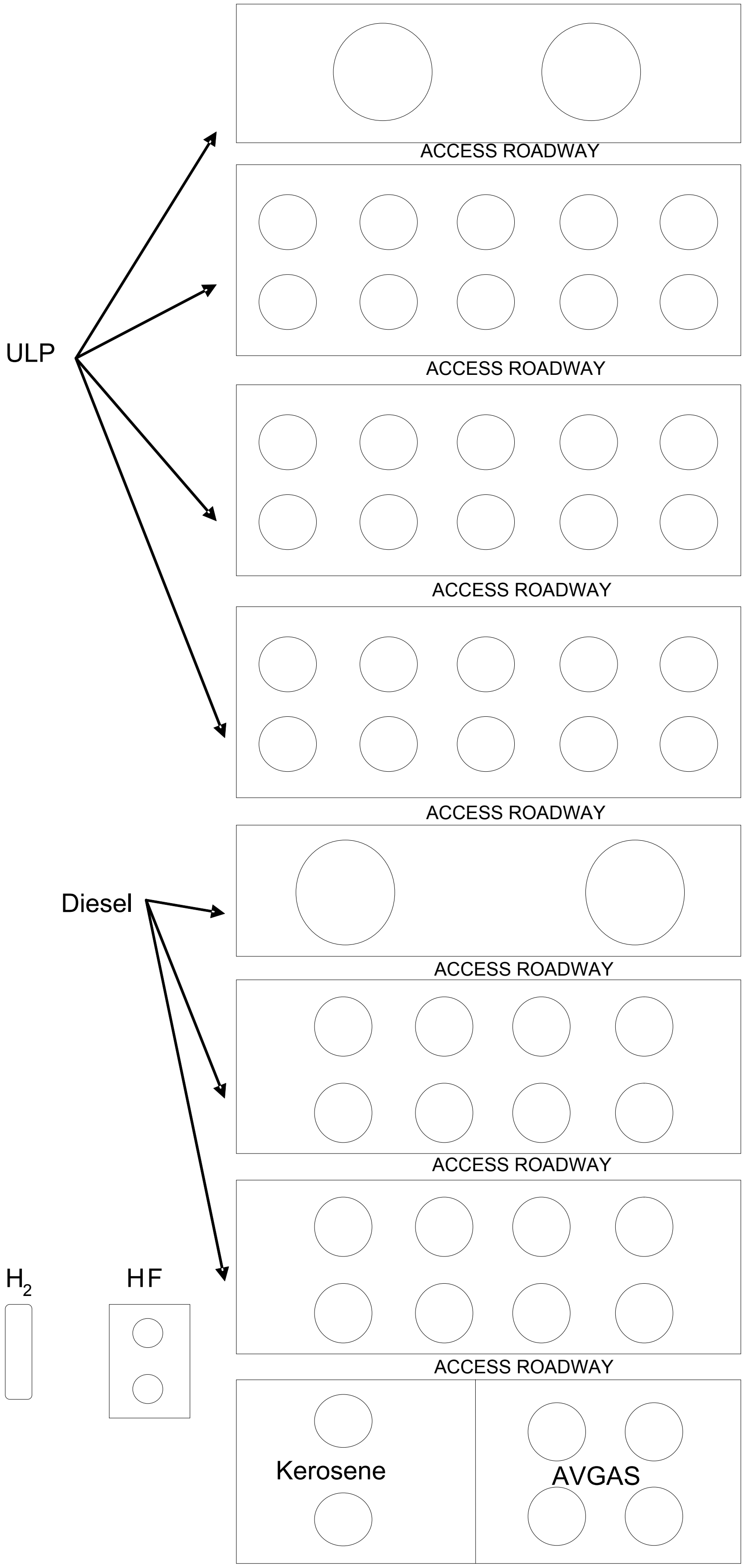
Bund Area calculation (assume 1 m height)		
20000 x 2 kL	40000	kL
design 110% of vol.	44000	kL
L x W x H =	44000	m^3
:. L x W =	44000	m^2
:. L or W =	209.8	m
or Diameter =	236.7	m

Table F.11 AVGAS Tank Bund

Bund Area calculation (assume 1 m height)		
12500 x 4 kL	50000	kL
design 110% of vol.	55000	kL
L x W x H =	55000	m^3
:. L x W =	55000	m^2
:. L or W =	234.5	m
or Diameter =	264.6	m

Figure F.2 illustrates the Oil Refinery bund layout assumed for this study. Note, the diagram is not drawn to scale and is used only as an indication of the layout modelled.

Figure F.2 Storage Tank Layout Assumption for Oil Refinery



F3 XANTHATE PLANT

F3.1 Burning Rate

The burning rate of CS_2 has been calculated using the following formula (Ref. 11),

$$\upsilon_\infty = k_2 \left(\frac{-\Delta H_c}{\Delta H_v}\right)$$

Where: k_2 = 0.0076
ΔH_c = is the net heat of combustion (negative) (kJ / kg-mol)
ΔH_v = is the total heat of vapourisation (kJ / kg-mol)
υ_∞ = liquid burning rate for a pool of infinite diameter (cm / min)

$$\upsilon_\infty = 0.0076 \left(\frac{13.6}{0.363}\right)$$

$$\upsilon_\infty = 0.29 \text{ cm / min } (0.061 \text{ kg / m}^2\text{ / s})$$

(Note: for comparison the burning rates of methanol and benzene are 0.17 and 0.6 cm / min respectively, and for LPG, propane or butane 0.078 kg / m^2 / s (Ref. 11)

F3.2 Burning Pool Area Calculation

The maximum burning pool area occurs when the pool fire has developed to the stage when the discharge rate equals the burning rate, as given by:

$$m = .\nu_\infty \text{ (cm/min)}. \tfrac{1}{60} \text{ (min/s)}. \tfrac{1}{100} \text{ (m/cm)} . SA \text{ (m}^2\text{)}.\rho \text{ (kg / m}^3\text{)}$$

Where: m = mass discharge rate (kg / s)
ν_∞ = burning rate (cm / min)
SA = surface area (m^2)
ρ = density (kg / m^3) = 800 kg / m^3

$$m = 0.133 . \nu_\infty . SA$$

Burning pool areas calculated are provided in the Scenario Summaries **Table E.11** in **Appendix E**.

F3.3 Pool Size Diameter

The maximum pool diameter, and hence maximum burning rate, occurs when the pool fire has developed to the stage when the discharge rate equals the burning rate, as given by:

$$\dot{m} = v_{\infty} \cdot \frac{1}{60} \text{min}/\text{s} \cdot \frac{1}{100} \text{m}/\text{cm} \cdot \frac{\pi . D^2}{4} \text{m}^2 . 1{,}260 \, \text{kg}/\text{m}^3$$

Where: D = liquid pool diameter (m)

$\dot{m}$ = mass discharge rate (kg / s)

υ_{∞} = liquid burning rate for a pool of infinite diameter (cm / min)

$$D = \left(\frac{6.1 . \dot{m}}{v_{\infty}}\right)^{1/2}$$

F3.4 Consequences Of An Ignited Spill Of CS_2

F3.4.1 General

CS_2 when ignited results in the generation of SO_2, the oxidation reaction being:

$$CS_2 + 3O_2 \rightarrow CO_2 + 2SO_2$$

The SO_2 emission rate is dependent on the size of the pool and the burning rate of CS_2. For different size release rates there will be an equilibrium diameter at which the release rate equals the burning rate.

F3.4.2 Mass Emission Rate of SO_2

For stoichiometric combustion there are two moles of SO_2 in the combustion gases for each mole of CS_2 burnt. The mass emission rate per kilogram of CS_2 burnt is given by:

$$\dot{m}_{SO_2} = 2 . \dot{m}_{CS_2} . \frac{MW_{SO_2}}{MW_{CS_2}}$$

Where: $\dot{m}_{SO_2}$ = emission rate of SO_2 kg / s

$\dot{m}_{CS_2}$ = burning rate of CS_2 kg / s

MW_{SO_2} = molecular weight of SO_2 kg / kg-mol

MW_{CS_2} = molecular weight of CS_2 kg / kg-mol

Table A1 shows the mass emission rate of SO_2 for various ignited release rates.

Table F.12 CS_2 Leakage Rates, Pool Fire Diameter, Burning Rates and SO_2 Emission Rates

Scenario	Hole Size (mm)	Mass Discharge Rate (kg / s)	Pool Fire Diameter (m)	CS_2 Burning Rate (kg / s)	SO_2 Emission Rate (kg / s)
Storage Tank Catastrophic Failure	N / A	N / A	9.77	4.64	7.80
System Leak(2)	50	8.75	9.77	4.64	7.80
	25	2.40	7.17	2.40	4.04
	10	0.55	3.46	0.55	0.94

Notes:
1. Bund dimensions assumed to be 15 m x 5 m for the CS_2 storage bund (from past experience with similar facility).
2. Based on a liquid head height of 4 m. A driving pressure of 4 m liquid head has been assumed.

F4 TIMBER PRODUCTS PLANT

F4.1 Pool Size Diameter

The maximum pool diameter, and hence maximum burning rate, occurs when the pool fire has developed to the stage when the discharge rate equals the burning rate, as given by:

$$\dot{m} = v_{\infty} \cdot \frac{1}{60} \, {}^{\text{min}}\!/_{s} \cdot \frac{1}{100} \, {}^{\text{m}}\!/_{\text{cm}} \cdot \frac{\pi . \text{D}^{2}}{4} \text{m}^{2} . 788 \, {}^{\text{kg}}\!/_{\text{m}^{3}}$$

Where: D = liquid pool diameter (m)
$\dot{m}$ = mass discharge rate (kg / s)
υ_{∞} = liquid burning rate for a pool of infinite diameter (cm / min)

For methanol, υ_{∞} is 0.17 cm/min.

$$\text{D} = \left(\frac{9.7 . \dot{m}}{v_{\infty}}\right)^{1/2}$$

For catastrophic failure, the pool is assumed to be the volume of the bund. A bund dimension of 12m x 12m x 1m (L x W x H) is assumed for 130 kL storage of methanol (bund volume is assumed at 110% of tank volume). The pool surface area is then derived from a simple mathematical calculation.

F5 TANTALUM REFINING PLANT

F5.1 Pool Size Diameter

The maximum pool diameter, and hence maximum burning rate, occurs when the pool fire has developed to the stage when the discharge rate equals the burning rate, as given by:

$$\dot{m} = v_{\infty} \cdot \frac{1}{60} \,{}^{\text{min}}\!/\!_{s} \cdot \frac{1}{100} \,{}^{\text{m}}\!/\!_{\text{cm}} \cdot \frac{\pi . \text{D}^2}{4} \text{m}^2 . 779 \,{}^{\text{kg}}\!/\!_{\text{m}^3}$$

Where: D = liquid pool diameter (m)
$\dot{m}$ = mass discharge rate (kg / s)
υ_{∞} = liquid burning rate for a pool of infinite diameter (cm / min)

For cyclohexane υ_{∞} is 0.17 cm/min.

$$\text{D} = \left(\frac{9.8 . \dot{m}}{v_{\infty}}\right)^{1/2}$$

For catastrophic failure, the pool is assumed to be the volume of the bund. A bund dimension of 12m x 12m x 1m (L x W x H) is assumed for 130 kL storage of cyclohexane (bund volume is assumed at 110% of tank volume). The pool surface area is then derived from a simple mathematical calculation.

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APPENDIX G

CONSEQUENCE ASSUMPTIONS

LIST OF FIGURES

LIST OF TABLES

G1 CONSEQUENCE CALCULATIONS

Upon a release of hazardous materials consequences may occur caused by the effects of a fire, an explosion or a toxic gas cloud. There are four different consequences distinguished within the Quantitative Risk Assessment (QRA):

- Fire (or direct flame contact);
- Heat radiation;
- Explosion (Blast); and
- Toxic inhalation.

The consequence models used in Riskcurves and assumptions used are described below under respective headings with most of the information derived directly from the Riskcurves manual except for the additional information on the modelling of a titanium tetrachloride ($TiCl_4$) release which, due to its properties, converts to hydrogen chloride (HCl) and hence has been modelled as a HCl release.

G2 FIRE (DIRECT FLAME CONTACT)

It is assumed that all people present within the dimensions of a fire, pool fire, jet fire, fire ball or flash fire, will be lethally injured (100% lethality) due to direct flame contact or suffocation.

Outside the fire, lethality may occur due to heat radiation. For a flash fire no consequences are considered outside the flash fire or the burning vapour cloud. This is due to the fact that exposure to the radiation caused by the ignition of the cloud of flammable gas is practically instantaneous.

G3 HEAT RADIATION

For the exposure to heat radiation the vulnerability model (probit function) as described in the Green Book (Ref. 33) has been used in this study:

$$Pr = -36.38 + 2.56\ln(q^{4/3} * t)$$

Where:

Pr = probit value

q = the heat radiation level (W/m^2); and

t = the exposure duration in [sec]

The probit value is transferred to a fraction of mortality afterwards. This is described in the last paragraph of this chapter.

G4 EXPLOSION (BLAST)

In the case of a vapour cloud explosion (a flash fire with generation of a pressure wave) the consequences to people in the cloud is the same as in the case of a flash fire. This means a 100% lethality (see above).

The pressure wave can destroy the confined area and also buildings in the surroundings.

Consequences to people outside the cloud can occur mainly due to fragments from the explosion area and as a result of secondary damage, due to collapsed buildings (falling walls, glass fragments, etc.). For the pressure wave effects the following lethality criterion from (Ref. 9) is used:

Peak overpressure of 0.1 bar: 1.25% lethality for people due to the collapse of buildings.

Peak overpressure of >0.3 bar probability of fatality is 100%.

G5 TOXIC GAS RELEASE

G5.1 General

The consequences of toxic materials for people depend on the toxic dose to which a person is exposed. The toxic dose (or load) is a function of gas concentration and exposure duration. A probit (probability unit) function relates the toxic dose to the proportion of affected people:

$Pr = a + b \ln(C^n * t)$

where:

Pr =	Probit Value. This is the value obtained from the probabilistic probit function that relates the percentage of death to the probit value.
C =	Concentration of the toxic gas in the air (mg/m^3).
t =	Duration of exposure to the concentration C (min).
Cn * t =	Toxic dose (mg/m^3)^n.min).
a, b, n =	Specific constants of the chemical.

To convert the probit value to a percentage of mortality, the table below is used.

The probit values are listed within the table itself. From the side and the top of the table, the percentage of mortality can be read. For example: A probit value of 4.01 (second row) corresponds to a value of 16% mortality.

Table G.13 Probit vs Mortality Conversion

%	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	0	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.92	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5,25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33
99	7.33	7.37	7.41	7.46	7.51	7.58	7.65	7.75	7.88	8.09

G5.2 Probit values for specific chemicals

Table G.2 details the probit values for chemicals modelled.

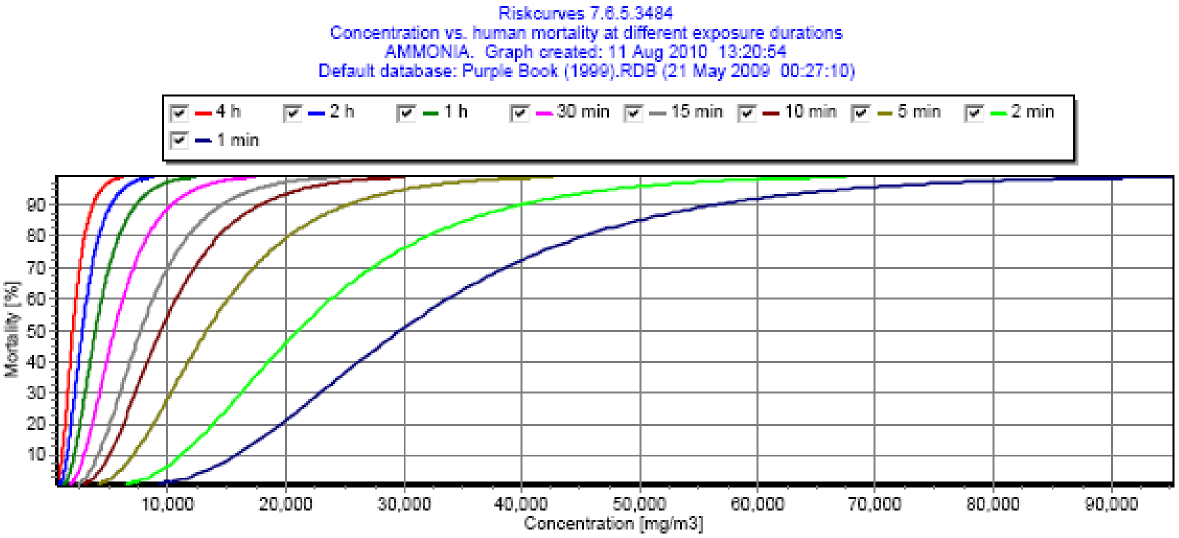
Table G.14 Probit Constants Based on Concentration of mg/m^3 and Exposure in Minutes

Chemical	**a**	**b**	**n**
Ammonia(1)	-16.6	1	2
Chlorine(1)	-6.35	0.5	2.75
Hydrogen chloride(1)	-37.3	3.69	1
Hydrogen fluoride(1)	-8.4	1	1.5
Hydrogen sulphide(1)	-11.5	1	1.9
Sulphur dioxide(1)	-19.2	1	2.4
Sulphur trioxide(2)	-12.2	1	2
Sulphur trioxide (future studies) (3)	-14.2	1.6	1.3

Notes:
1. ‘Purple Book’ (Ref. 9)
2. 1998 probit – conservative value used in QRA
3. 2009 probit proposed for more detailed/future QRA

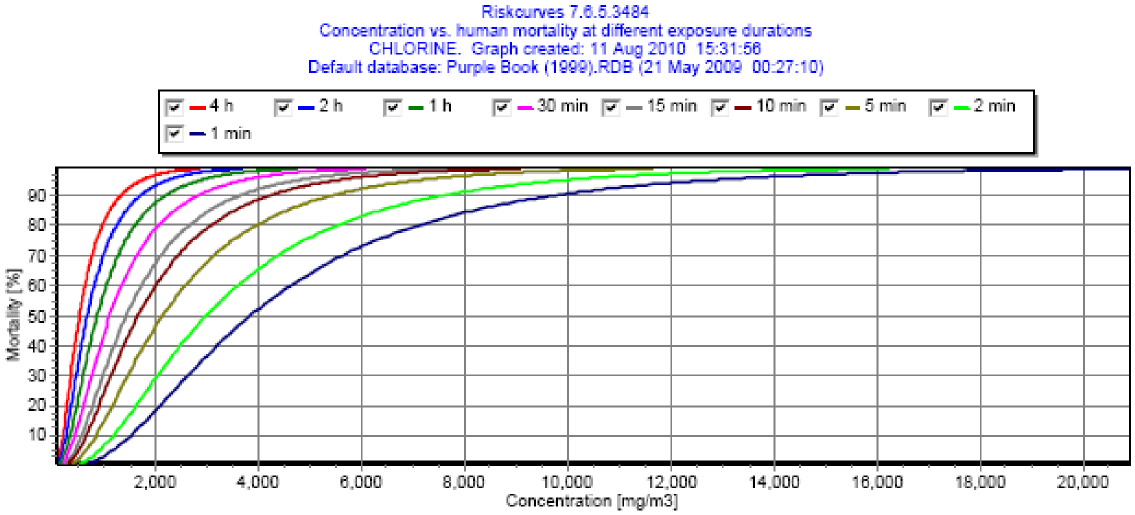
G5.2.1 Ammonia

Figure G.3 Ammonia – Concentration vs Human Mortality at Different Exposure Concentrations


Riskcurves 7.6.5.3484
Concentration vs. human mortality at different exposure durations
AMMONIA. Graph created: 11 Aug 2010 13:20:54
Default database: Purple Book (1999).RDB (21 May 2009 00:27:10)

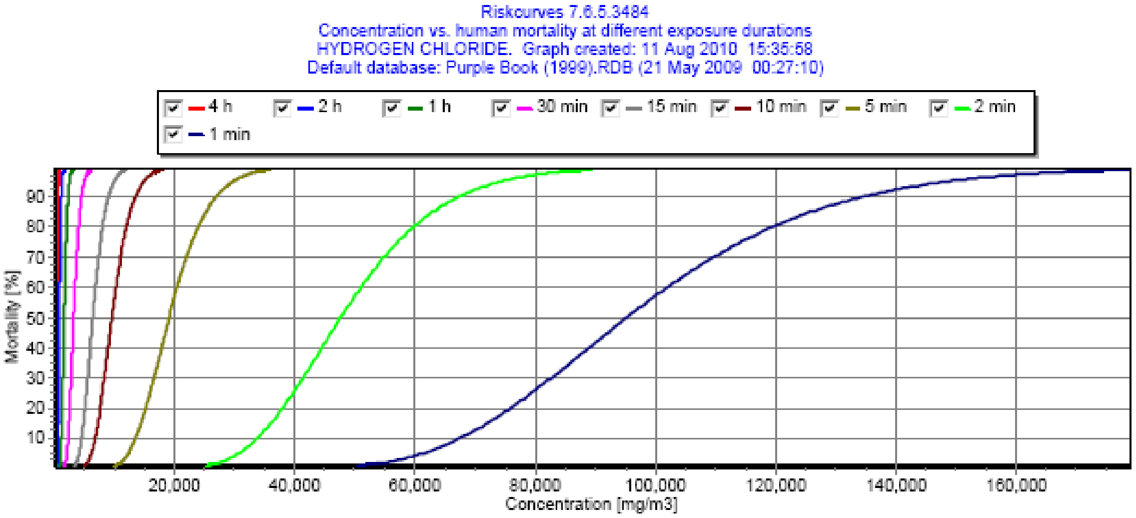
G5.2.2 Chlorine

Figure G.4 Chlorine – Concentration vs Human Mortality at Different Exposure Concentrations


Riskcurves 7.6.5.3484
Concentration vs. human mortality at different exposure durations
CHLORINE. Graph created: 11 Aug 2010 15:31:56
Default database: Purple Book (1999).RDB (21 May 2009 00:27:10)

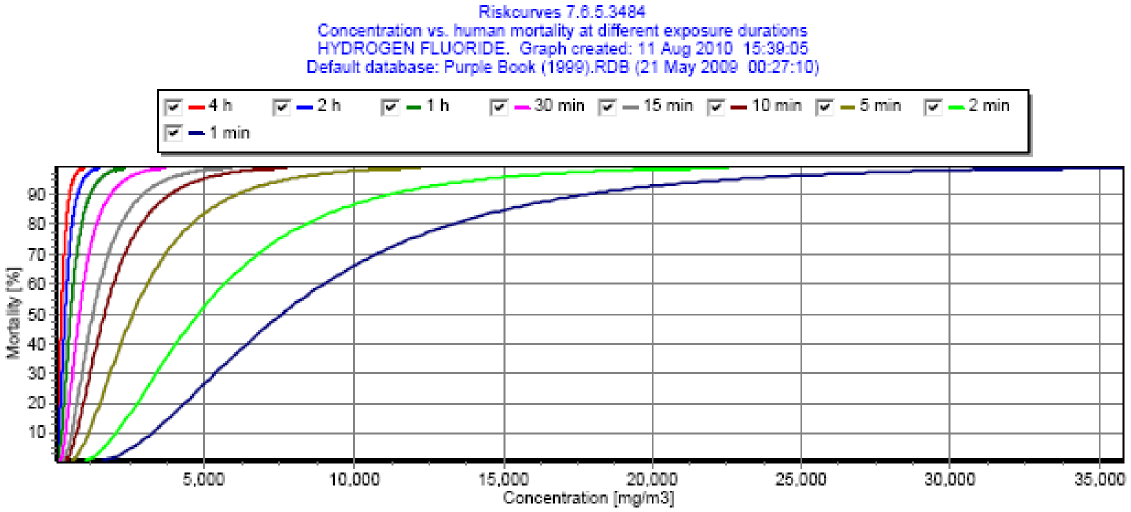
G5.2.3 Hydrogen Chloride

Figure G.5 Hydrogen Chloride – Concentration vs Human Mortality at Different Exposure Concentrations



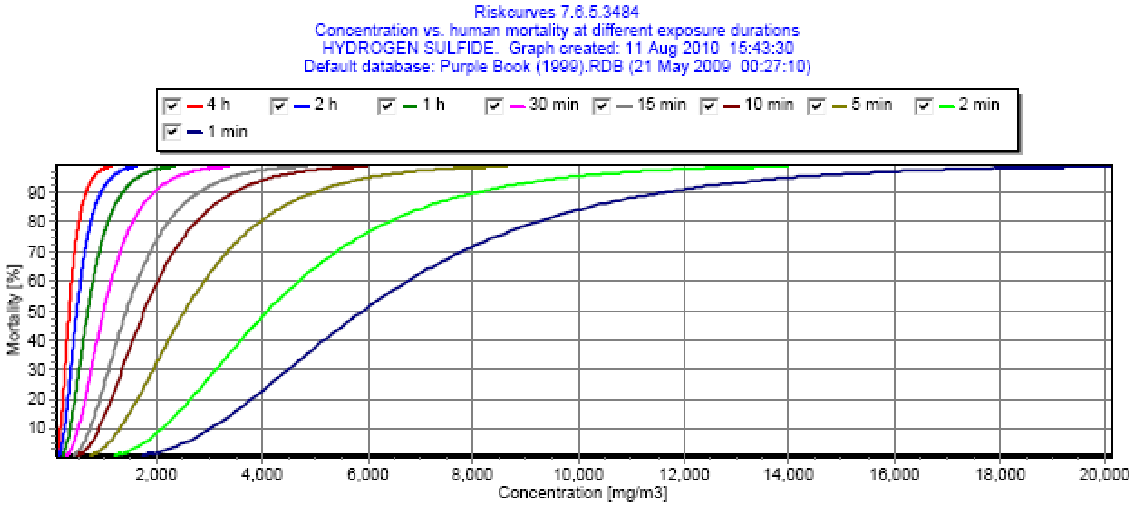
G5.2.4 Hydrogen Fluoride

Figure G.6 Hydrogen Fluoride – Concentration vs Human Mortality at Different Exposure Concentrations



G5.2.5 Hydrogen Sulphide

Figure G.7 Hydrogen Sulphide – Concentration vs Human Mortality at Different Exposure Concentrations



G5.2.6 Sulphur Dioxide

Figure G.8 Sulphur Dioxide – Concentration vs Human Mortality at Different Exposure Concentrations

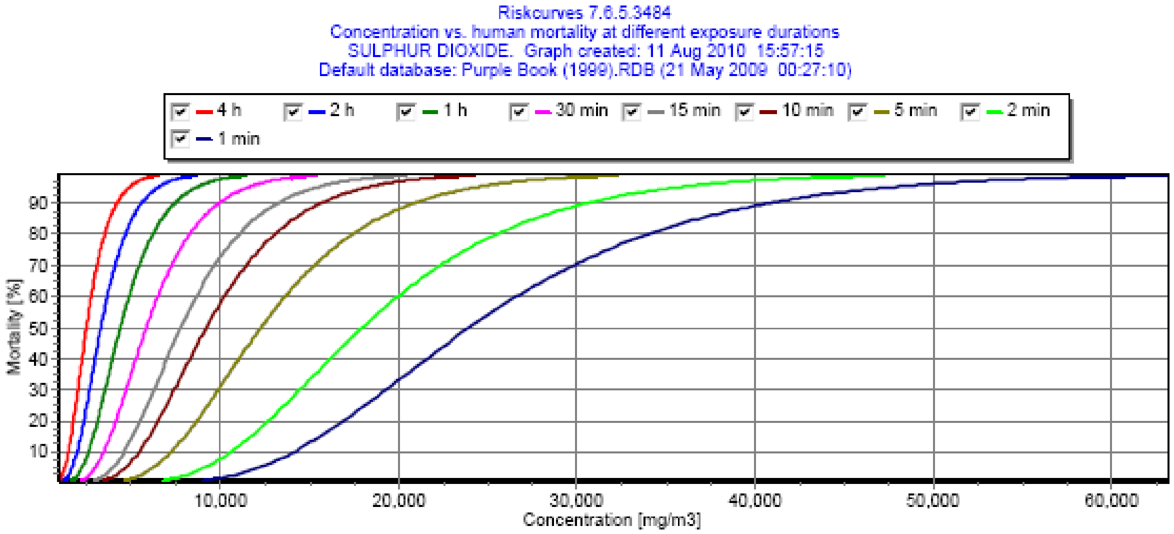


Figure G.9 Sulphur Trioxide – Concentration vs Human Mortality at Different Exposure Concentrations Based On Probit Of H_2SO_4 (1998 Probit)

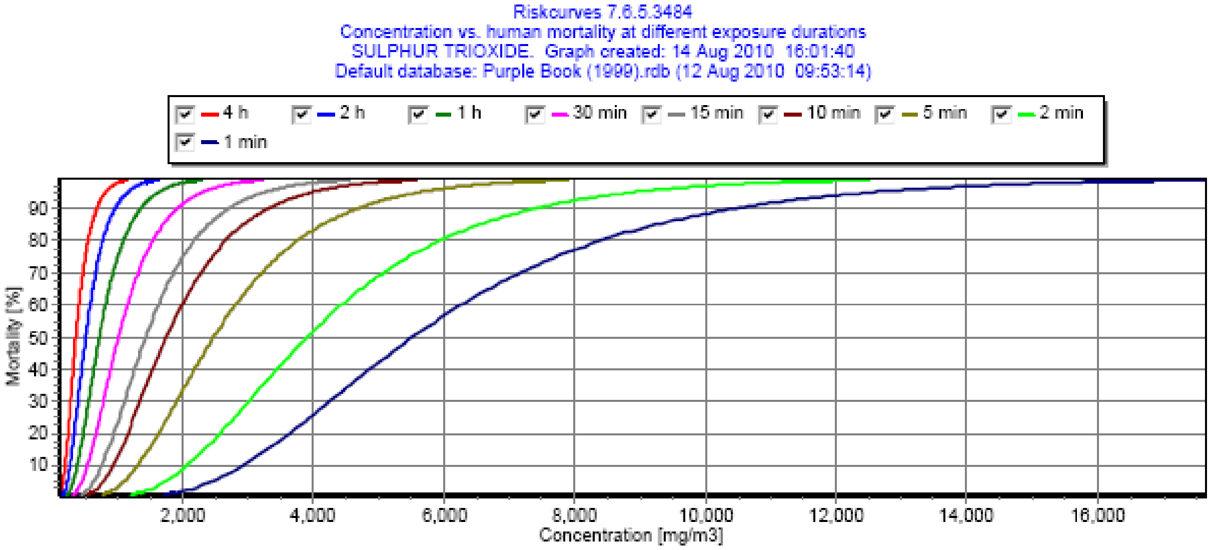
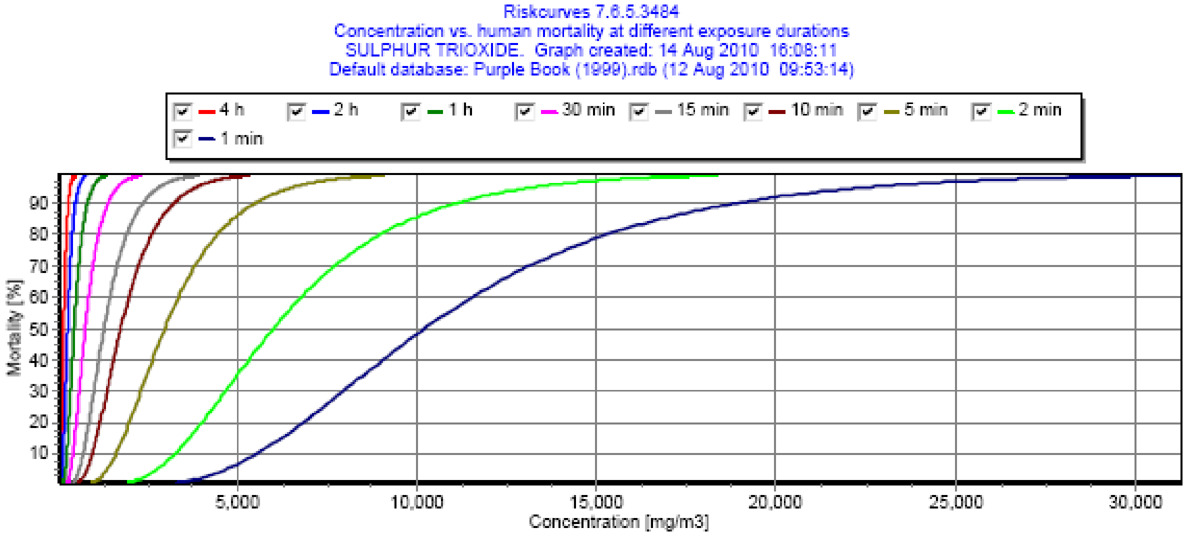


Figure G.10 Sulphur Trioxide – Concentration vs Human Mortality at Different Exposure Concentrations Based On Probit Of H_2SO_4 (2009 Probit)



G6 MODELLING OF WATER REACTIVE MATERIALS – $TiCl_4$ AND SO_3

$TiCl_4$ and sulphur trioxide (SO_3) are regarded as water reactive chemicals which when released to the atmosphere react readily with any free ground water, substrate water and atmospheric water.

For example, the Netherlands National Institute of Public Health and the Environment (RIVM), (Ref. 31), has reported that studies of the thermodynamics of clouds generated from spills of SO_3 and oleum (sulphuric acid (H_2SO_4) containing up to 80% free SO_3) found that while the conversion from SO_3 to H_2SO_4 is very fast, the content of atmospheric moisture immediately above the pool is insufficient for complete and rapid reaction to H_2SO_4 mist. Typically, some 50-100 m downwind from the source only $H2SO_4$ will be present in the aerosol cloud.

Based on the findings of the RIVM (Ref. 31), a recommendation is made that the probit function for application in a QRA for an airborne release of H_2SO_4, SO_3 or oleum should be that for H_2SO_4. The proposed probit is:

$Pr = -14.2 + 1.6\ln(C^{1.3} \times t)$ with C in mg/m^3 and t in min.

This probit is less conservative that the one that has been used in the QRA that was based on an older reference source (Ref. 30), namely:

$Pr = -12.2 + 1.\ln(C^2 \times t)$ with C in mg/m^3 and t in min.

For future risk assessments the newer probit, which is less conservative, is proposed to be used.

Similarly, $TICl_4$ is a highly aggressive material that hydrolyses rapidly in air to form a dense white cloud containing titanium dioxide (TiO_2), oxychloride/hydroxide particulates and hydrogen chloride (HCl) gas (Ref. 32). Therefore HCl has been used in the consequence modelling.

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