

Jet Zero™



**FIRE AND EXPLOSION
ANALYSIS**



T.EN Australia and New Zealand Pty Ltd
1 William St, Perth WA 6000
Tel: +61 8 6371 9100
ACN 066 996 060 | ABN 20 636 996 060



Jet Zero Australia
Project Ulysses

216651C

Document Title

Fire and Explosion Analysis

Document Number

216651C-000-RT-1950-0002

Jet Zero Document Number

28011007-HSE-REP-00006

0	11-01-25	Issued for Design	WPL	PB	PT	RH
A	21-11-24	Issued for Review	AS/WPL	PB	PT	RH
A1	18-11-24	Issued for Inter-Discipline Check	AS/WPL	PB	PT	
Rev.	Date	Reason for Issue	Prepared by	Discipline Check	Technical Integrity	Project Approval

JET ZERO RETURN CODE



- ☒ 1 Reviewed & Accepted (Final & Certified)
- ☐ 2 Reviewed & Accepted (As Noted)
- ☐ 3 Reviewed & Returned (Correct & Resubmit)
- ☐ 4 Information Only (Not Reviewed)
- ☐ 5 Reviewed & Accepted (Comments to be included in next stage)

Work May Proceed

Work May Proceed
Revise and Resubmit numerical rev

Work Should Not Proceed
Revise and Resubmit alpha rev for review

Work May Proceed
Information Only

Date: 25/2/25

Rev

Rob Venables

Digitally signed by
Rob Venables
Date: 2025.02.25
09:40:06+10'00'

This document is CONFIDENTIAL and issued in accordance with Contract 216651C001 and this document is considered Confidential Information under the General Conditions of Contract, Section 18.

Record of Amendment	
Section	Description of changes

Hold Status Sheet	
No.	Description

Contents

EXECUTIVE SUMMARY	8
1.0 INTRODUCTION AND BATTERY LIMITS.....	11
1.1 Background	11
1.2 Document Objective	11
1.3 Battery Limits.....	11
2.0 ABBREVIATIONS	13
3.0 METHODOLOGY OVERVIEW	15
3.1 Failure Case Definition.....	15
3.2 Consequence Analysis	15
4.0 FACILITY DESCRIPTION	16
4.1 Overview	16
5.0 FAILURE CASES	17
5.1 Process Events.....	17
5.2 Escalation Events	17
5.3 Non Process Fires	18
6.0 CONSEQUENCE MODELLING	19
6.1 Introduction.....	19
6.2 Source term.....	19
6.2.1 Event and Process Conditions	19
6.2.2 Inventory sizing	19
6.2.3 Representative hole size	20
6.2.4 Release duration	20
6.3 Physical Effect Modelling	20
6.3.1 General Parameters.....	20
6.3.2 Dispersion Analysis.....	21
6.3.3 Jet and Pool Fires Analysis	21
6.3.4 Explosion Analysis	21
6.3.5 Domino Effects.....	22
6.4 Impact and Impairment Criteria.....	22
6.4.1 Effect of Thermal Radiation	22
6.4.2 Effect of Flash Fire	23
6.4.3 Effect of Explosion	23
6.4.4 Effect of Toxic	24
7.0 RESULTS.....	25

7.1	Module IS1 (ETE)	25
7.1.1	Jet Fire Thermal radiation	25
7.1.2	Pool Fire Thermal Radiation	28
7.1.3	Flammable Dispersion	29
7.1.4	Explosion	31
7.1.5	Toxic Dispersion	32
7.2	Module IS2 (ETJ)	34
7.2.1	Jet Fire Thermal radiation	34
7.2.2	Pool fire thermal radiation	36
7.2.3	Flammable Dispersion	38
7.2.4	Explosion	39
7.3	Module IS3	40
7.3.1	Jet Fire Thermal radiation	40
7.3.2	Pool Fire Thermal Radiation	42
7.3.3	Flammable Dispersion	43
7.3.4	Explosion	44
7.3.5	Toxic	45
7.4	Module OS4	45
7.4.1	Thermal radiation	45
7.4.2	Explosion	46
7.4.3	Flammable Dispersion	47
7.5	OSBL Module	48
7.5.1	Storage Tanks	48
7.5.2	Tanker Loading	50
7.5.3	OS5 Module	51
7.5.4	OS1 Module	53
7.6	Escalation events	53
8.0	CONCLUSION AND RECOMMENDATIONS	57
8.1	Conclusions	57
8.2	Recommendations	61
9.0	REFERENCES	63
	APPENDIX A: OVERALL PLOT PLAN	64
	APPENDIX B: FAILURE CASES SUMMARY	66
	APPENDIX C: MARKED-UP PFDS AND UFDS	70
	APPENDIX D: CONSEQUENCE RESULTS	71
	D.1 Jet Fire results	72

D.2 Pool Fire results	84
D.3 Explosion Results	90
D.4 Flammable Dispersion Results.....	91
D.5 Toxic Dispersion Results.....	102
D.6 Escalation Event Results	106

Figures & Tables

Figures

Figure 4-1: Overall Site Layout.....	16
Figure 6-1: Mark-up of congested areas.....	21
Figure 7-1: Jet fire Thermal Radiation from FC36, 5D wind, 23mm release	26
Figure 7-2: Jet fire Thermal Radiation from FC52, 5D wind, 23mm release	27
Figure 7-3: Pool fire Thermal Radiation from FC02, 5D wind, 23mm release	28
Figure 7-4: Flammable dispersion from FC52, 5D wind, 23mm release	30
Figure 7-5: Explosion Overpressure from worst case 23mm release (IS1 Module), 5D wind.....	32
Figure 7-6: Toxic 340 ppm dispersion from FC28 5D wind, 23mm release.....	33
Figure 7-7: Jet fire Thermal Radiation from FC95, 5D wind, 23mm release	35
Figure 7-8: Jet fire Thermal Radiation from FC96, 5D wind, 23mm release	35
Figure 7-9: Pool fire Thermal Radiation from FC95, 5D wind, 23mm release	37
Figure 7-10: Flammable dispersion from FC96, 5D wind, 23mm release	38
Figure 7-11: Explosion Overpressure from worst case 23mm release, 5D wind	40
Figure 7-12: FC12 Jet fire Thermal Radiation 23mm release, 5D wind	41
Figure 7-13: Pool fire Thermal Radiation from FC107, 5D wind, 23mm release	42
Figure 7-14: Flammable dispersion from FC145, 5D wind, 23mm release	43
Figure 7-15: Explosion Overpressure from worst case 23mm release, 5D wind	45
Figure 7-16: Jet Fire Thermal Radiation from F140B Hydrogen storage vessel 23mm release, 5D wind.....	46
Figure 7-17: Explosion Overpressure from F140 Electrolyser building, 30% filled.	47
Figure 7-18: Hydrogen dispersion from F140B Hydrogen Storage Tank, 23mm release 5D wind.	48
Figure 7-19: Ethanol Storage Tank bund fire, 5D wind.	49
Figure 7-20: SAF Storage Tank bund fire, 5D wind	49
Figure 7-21: Tanker Loading module pool fire, 5D wind	50
Figure 7-22: Tanker pool fire, 5D wind	51
Figure 7-23: FC150 pool fire, 23mm release, 5D wind	52
Figure 7-24: FC138 Toxic Dispersion, 23mm release, 5D wind	52
Figure 7-25: LPG Tank BLEVE	54
Figure 7-26: Refrigeration Package Z-3400 BLEVE	54
Figure 7-27: Hydrogen Storage Tank Catastrophic Rupture.....	55
Figure 7-28: Olig 1 HP Separator BLEVE.....	55
Figure 7-29: Ethylene Refinement Column Reflux Drum BLEVE.....	56

Tables

Table 5-1: Escalation Scenarios.....	17
Table 6-1: General Parameters Basis	20
Table 6-2: Explosion Modelling Basis.....	22
Table 6-3: Thermal Radiation Criteria	23
Table 6-4: Reported Overpressures	23
Table 6-5: Concentration to AEGL-2, Ref [7] and [8]	24
Table 7-1: Selected Jet Fire Results - Module IS1	27
Table 7-2: Selected Pool Fire Results - Module IS1	29
Table 7-3: Selected Flammable Dispersion Results - Module IS1	30
Table 7-4: Selected Explosion Results - Module IS1	31
Table 7-5: Selected Toxic Dispersion Results - Module IS1	33
Table 7-6: Selected Jet Fire Results - Module IS2	36
Table 7-7: Selected Pool Fire Results - Module IS2	37

Table 7-8: Selected Flammable Dispersion Results - Module IS2	39
Table 7-9: Explosion Results - Module IS2.....	39
Table 7-10: Selected Jet Fire Results - Module IS3	41
Table 7-11: Selected Pool Fire Results - Module IS3	43
Table 7-12: Selected Flammable Dispersion Results - Module IS3	44
Table 7-13: Explosion Results - Module IS3.....	44
Table 7-14: Jet Fire Results - Module OS4	46
Table 7-15: Explosion Results - Module OS4	47
Table 7-16: Flammable Dispersion Results - Module OS4	48
Table 7-17: Selected Pool Fire Results - Tanks	50
Table 7-18: Escalation Results.....	56
Table 8-1: Recommended Separation Distances	60
Table B-0-1: Failure Case Summary	66
Table D-0-1: Jet fire Thermal Radiation result (at release height)	72
Table D-0-2: Pool fire Thermal Radiation result.....	84
Table D-0-3: Explosion Results.....	90
Table D-0-4: Flammable Dispersion result	91
Table D-0-5: Toxic Dispersion result (Acetaldehyde)	102
Table D-0-6: Escalation Results	106

EXECUTIVE SUMMARY

Fire and Explosion Analysis (FEA) was carried out for the Alcohol to Jet Fuel (ATJ) plant converting ethanol feedstock to Sustainable Aviation Fuel (SAF). The plant will be constructed in Townsville, Queensland and will produce 100 ML of SAF and 10 ML of renewable diesel per annum. The plant consists of 2 main elements: Inside Battery Limits (ISBL) and Outside Battery Limits (OSBL). The study covered both the ISBL and OSBL of the facility, which is a combination of Alcohol To Jet (ATJ) - (Ethanol-to-Ethylene (ETE) and Ethylene-to-Jet (ETJ) units) and OSBL consisting of tank farm with loading/ unloading gantry, hydrogen generation, utilities, tanker loading and services.

The objective of the Fire and Explosion Analysis (FEA) is to identify Loss of Containment (LOC) scenarios from the ATJ facility and estimate the maximum credible events for all release types as input to the layout development and regulatory consent requirement. The consequence results will also be used as a high-level assessment of potential escalation events in the facility.

Major hazards of this facility were found to be from the ETE (IS1) and ETJ (IS2) modules. These modules are 4-5 storeys high and contain large amount of process equipment within a small space and a high level of congestion. Thermal radiation resulting from jet and pool fire, toxic (Acetaldehyde) and flammable dispersion from these modules were found to be largely confined within the site for small to medium releases due to the separation distance to the site boundary. For explosion events the 0.07 bar overpressure contour from both modules and small section of 0.14 bar contour from ETJ module and was found to encroach to offsite areas. At these overpressure, fatality of personnel outdoors is expected to be minimum.

Loss of containment events from the IS3 module could lead to offsite thermal radiation from jet fire and pool fire events due to location of the module close to the site boundary. Although the IS3 module is much smaller compared to the ETE and ETJ module, the credible VCE event was found to lead to offsite impact from the 0.07 bar explosion contour. The Liquid Hydrocarbon Storage Vessel in OS5 could give rise to pool fire and also toxic dispersion (97m for 23mm release) due to presence of Acetaldehyde which could impact offsite areas.

Fire and toxic events from small and medium process loss of containment events were not found to impact the manned buildings towards the east of the facility. Credible explosion overpressure to the manned buildings was evaluated to be less than 0.14 bar (from IS2 module). The manned buildings (i.e. control room and admin building is impacted by approximately 0.10 bar explosion overpressure, which could cause windows breakage and damage to the building but not to a level that leads to its failure, causing fatality of operators within. Design of the buildings will need to consider the credible explosion load (i.e. windows facing away from process area/ no windows and strengthening of the structure may be required).

Pool fire thermal radiation arising from the storage tanks and tanker loading area could result in a larger pool fire with thermal radiation that could extend offsite towards the plant access road at the South Boundary.

Several escalation events were also considered in this assessment. Events such as BLEVE of the LPG tank and catastrophic rupture of the hydrogen storage tanks could lead to explosion overpressure that could have a larger impact compared to the primary event. Escalation events can be minimised with separation distance, provision of active fire protection and inventory reduction.

The major hazard arising from the hydrogen module is explosion overpressure as hydrogen has the propensity for detonation. Worst case explosion overpressure from the H2 generation area is expected to be from the electrolyser building due to the congestion and confinement of the building. The 0.21 bar explosion contour from the electrolyser building could impact the

H2 storage tanks and the H2 separation and purification skids located within the module. Due to the large separation distance provided in the OS4 module, thermal radiation from jet fire and flammable dispersion was found to be confined within the module.

As the basis for isolation is 10 minutes, most of the thermal radiation resulting from loss of containment event arising from modules IS1, IS2 and IS3 could lead to impairment and subsequently escalation to neighbouring equipment and structures within the module and to adjacent modules due to the close proximity of equipment in ISBL. Hence rapid detection and isolation is key to minimise escalation events, particularly for the modules whereby separation distance is difficult to achieve, as the release for medium, large and full-bore ruptures would typically deplete quickly after isolation.

The 0.35 bar and 0.21 bar explosion overpressure arising from explosion within IS1, IS2 and IS3 modules could impact neighbouring modules and extend to the utilities area. 0.21 bar explosion overpressure arising from the ETJ module could impact critical emergency equipment (i.e. flare KOD, firewater tanks and Firewater Pumps leading to escalation. However, the manned buildings, storage tanks and the hydrogen generation module are outside of the 0.14 bar overpressure contour.

The following recommendations are raised to reduce the escalation risk within the facility and to the public:

- The basis of this study is manual isolation (assumed to take 10 minutes), meaning that if ignited, most releases could have the potential to cause escalation due to the modular design of the plant. Modularisation of plants tend to have a greater safety cost due to greater congestion which increases the risk of escalation and explosions. Rapid detection and isolation (i.e. with automatic isolation and blowdown upon confirmed detection) would reduce the duration of release, such that escalation is less likely to happen. Provision of automatic shutdown would be most beneficial for the IS1, IS2 and IS3 modules whereby there are large number of process equipment with limited separation distances.
- It should be noted that even small releases can impair adjacent modules due to limited separation between modules. Acceptability of escalations due to jet/pool fires and explosions between modules should be considered and recommended for separation distances to be reviewed based on COMPANY escalation acceptance criteria.
- Most large and full-bore releases are anticipated to exceed offsite and lead to escalation, it is recommended to evaluate frequencies of these releases in future QRA studies to ensure the risk to offsite is acceptable.
- Explosion with the IS1, IS2 and IS3 modules could give rise to large explosion overpressure. Equipment containing significant ethylene and hydrogen inventory that can give rise to large explosive cloud (e.g. Hydrogenation HP Separator, hydrogenation reactor, ethylene separation and refinement columns) should be located whereby the ventilation is maximised to disperse any released flammable vapour (i.e. edge of module, at the top elevation) or be sited outside of the module in a more open location to reduce the resulting explosion overpressure.
- Computational Fluid Dynamics (CFD) explosion analysis is recommended during FEED design phase for more accurate explosion overpressure prediction due to the high confinement and congestion within the IS1, IS2, IS3 modules and electrolyser building.
- Suitable containment and drainage should be provided for process vessels containing large amounts of liquid inventory and at the tanker loading area to limit the spread of any liquid release and the resulting pool fire.

- Required fire and explosion design accidental loads should be evaluated during FEED design phase to evaluate passive fire/blast protection for critical process/ emergency equipment and structure to avoid catastrophic escalation events.
- Provision of active fire protection for the storage tanks and other critical process vessel containing significant quantities of flammable liquid inventory could provide cooling, reducing likelihood of escalation.
- Critical utilities required during emergency such as the firewater system, flare KOD, nitrogen unit should be located in a safe area, preferably upwind from process releases and protected from fire and explosion hazards. In addition, critical process equipment that could lead to catastrophic escalation events (i.e. Hydrogen Storage Tank, LPG tank) should be located away/ protected from process hazards.
- Although the manned buildings were found to be outside the 0.14 bar explosion overpressure threshold, the buildings could still be subjected to explosion overpressure of around 0.1 bar. Design of the buildings will need to consider the credible explosion load (i.e windows facing away from process area/ no windows and strengthening of the structure may be required). Risk to operators working within the facility and offsite personnel should be evaluated to ensure the risk is acceptable.

1.0 INTRODUCTION AND BATTERY LIMITS

1.1 Background

Jet Zero Australia (JZA) has requested Technip Energies (T.EN) to help it develop Project Ulysses project via the completion of pre-FEED engineering services.

The proposed facility will be Australia's first Alcohol to Jet Fuel (ATJ) plant converting ethanol feedstock into Sustainable Aviation Fuel (SAF). The plant will be constructed in Townsville, Queensland and will produce 100 ML of SAF and 10 ML of renewable diesel per annum. The plant consists of 2 main elements: Inside Battery Limits (ISBL) and Outside Battery Limits (OSBL).

JZA has partnered with technology provider and licensor LJT to deliver the ATJ facility ISBL scope up to basic engineering design. This design is based off Lanza Jet's Freedom Pines 38 ML commercial demonstration plant currently under construction within Georgia, USA, with operations due to commence in Q4 2024.

LJT as licensor, shall provide Process Design Package (PDP), also known as the Basic Engineering Package (BEP) for the ISBL plant and continue to support T.EN in progressing the ISBL design during FEED, Detail Design, fabrication, construction, commissioning and start-up. The facility is configured to minimise energy consumption and as a result minimise its greenhouse gas emissions.

The proposed site location is a greenfield site located approximately 10 kms south from the Port of Townsville with B-Double and Triple Road train access between site and the port. The site is approximately 16 hectares in size. The site is registered as a State Development Area (SDA), owned by the Queensland Government, administered through the Co-Ordinator General (CoG) within the Department of State Development, Infrastructure, Local Government and Planning (DSILGP)

Following the completion of the pre-FEED, it is expected that JZA will award a contract for the FEED and EPC phases to design and build the project.

1.2 Document Objective

The objective of the Fire and Explosion Analysis (FEA) is to identify Loss of Containment (LOC) scenarios from the ATJ facility and estimate the maximum credible events for all release types as input to the layout development and regulatory consent requirement.

The consequence results will also be used as a high-level assessment of potential escalation events in the facility.

1.3 Battery Limits

The studies are to cover both the ISBL and OSBL of the facility, which is a combination of Alcohol To Jet (ATJ) - (Ethanol-to-Ethylene (ETE) and Ethylene-to-Jet (ETJ) units) and OSBL consisting of tank farm with loading/ unloading gantry, hydrogen generation, utilities, tanker loading and services.

Main ATJ and OSBL module comprises:

- Feed Pre-treatment,
- Vaporisation and Dehydration Reaction,

- Primary Separation and Compression,
- Low Pressure Separation and Water Recovery,
- Dewatering,
- Ethylene Polishing,
- Product Finishing,
- OLIG-1 Reaction, High & Low Pressure Separation,
- OLIG-2 Reaction and Stabilization,
- Hydrogenation, Post-Hydrogenation Separation & Fractionation,
- Hydrogen generation package,
- Steam system,
- Refrigeration Package,
- Air compressor package and plant air receiver,
- Instrument air system,
- Liquid nitrogen system,
- Fuel gas system,
- Liquid hydrocarbon storage,
- Utility and cooling water systems,
- Demin water system,
- Firewater system,
- Boilers,
- Ethanol storage tanks,
- Jet product storage tanks.
- Diesel storage tank,
- Utility and services storage tanks (i.e. suspect condensate, caustic, sulphuric acid, etc),
- HP, LP and Cold flare system.

2.0 ABBREVIATIONS

AEGL	Acute exposure guideline
ATJ	Alcohol-to-Jet
BEP	Basic Engineering Package
BLEVE	Boiling Liquid Expanding Vapour Explosion
CA	Consequence Analysis
CFD	Computational Fluid Dynamics
CoG	Co-Ordinator General
DNV	Det Norske Veritas
DSILGP	Department of State Development, Infrastructure, Local Government and Planning
EPC	Engineering Procurement and Construction
ETE	Ethanol-to-Ethylene
ETJ	Ethylene to Jet Fuel
FB	Full Bore
FC	Failure Case
FEA	Fire and Explosion Analysis
FEED	Front End Engineering Design
GE	General
HMB	Heat and Material Balance
IDLH	Immediately Dangerous to Life and Health
ISBL	Inside Battery Limit
JZA	Jet Zero Australia
LFL	Lower Flammability Limit
LJT	Lanzajet
LOC	Loss of Containment
MLPY	Million Litres-Per-Year

NR	Not Reached
OSBL	Outside Battery Limit
PDP	Process Design Package
PFD	Process Flow Diagram
PHAST	Process Hazard Analysis Software Tool
ppm	Parts per Million
RD	Renewable Diesel
SAF	Sustainable Aviation Fuel
SDA	State Development Area
T.EN	Technip Energies
TNO	Toegepast. Natuurwetenschappelijk Onderzoek
UFD	Utility Flow Diagram
UK	United Kingdom
VCE	Vapour Cloud Explosion

3.0 METHODOLOGY OVERVIEW

This section of the report is to:

- Provide the methodology and basis for calculating the scale, intensity and duration of potential fires, explosions and toxic releases.
- Identify impact criteria to personnel and equipment.
- Provide basis to inform the design of the facilities in respect of equipment layout and impact to offsite areas. The results can be used to ensure effective risk reduction measures are identified and implemented as appropriate.

Further details about the overall approach for the FEA are presented in the Assumption Register [1].

The FEA consists in evaluating the consequence of fire and explosion accidental events only. No frequency analysis will be carried out.

3.1 Failure Case Definition

The FEA is performed based on a set of defined initiating events. These will be defined according to isolation sections or in case of significant change in the fluid composition and/or conditions. Since at this stage of the project provision of isolation valves have not been confirmed, sections within the facility will be segregated based on major equipment and associated inventories.

Extent of the failure cases will be shown on marked-up PFDs and UFDs (Appendix B). Assumed release locations from the failure cases will be based on the pre-FEED Conceptual plot plan (Appendix A) [2].

Sections containing non-hazardous fluids (i.e. water, air) will not be considered in the assessment.

The full initiating events list, including their derivation, is given in the Assumption Register [1].

3.2 Consequence Analysis

All Physical Effect Modelling for the identified process releases has been undertaken using DNV PHAST 9.0. This includes jet fire, flammable and toxic dispersion and explosion modelling.

Det Norske Veritas (DNV) PHAST is an industry standard consequence analysis tool used for the evaluation of accidental release rates, flammable and toxic gas dispersion, and fire, explosion. The individual physical effects models incorporated into DNV PHAST have been validated by the program's publishers and are considered to be appropriate in the context of the current project.

4.0 FACILITY DESCRIPTION

4.1 Overview

The overall site layout is shown in Figure 4-1 below and is the basis for this analysis. The main hazard locations are highlighted in red squares. Manned buildings are shown in green.

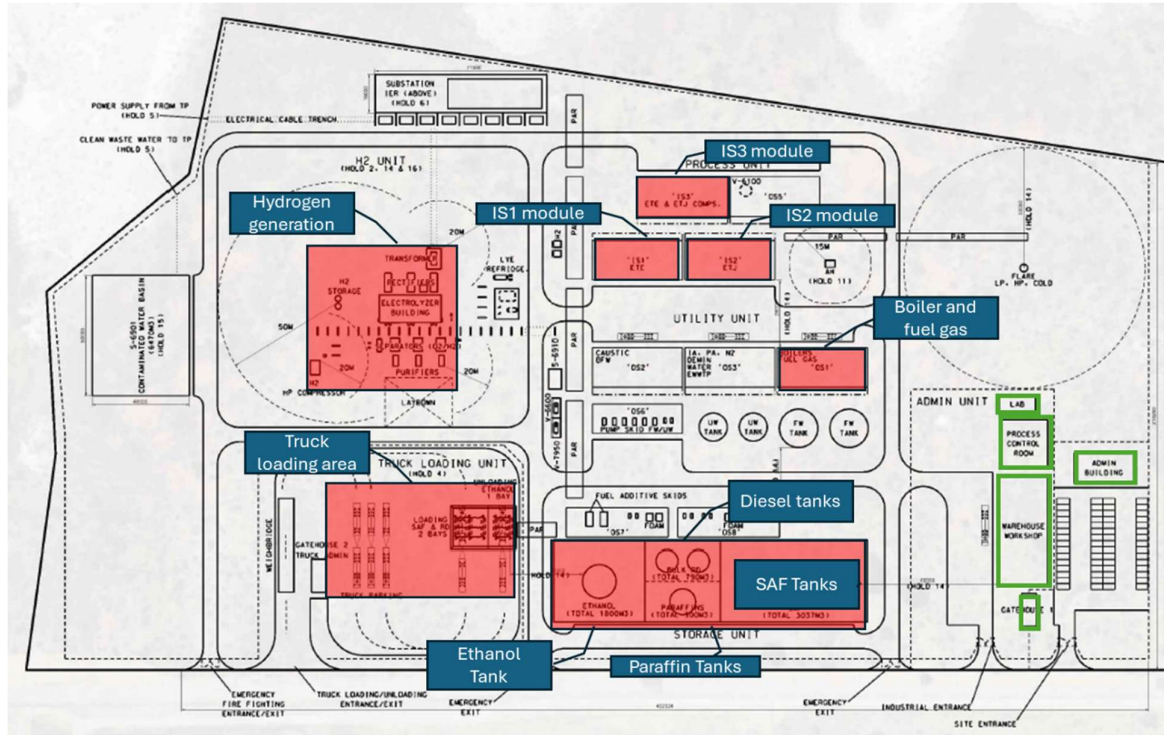


Figure 4-1: Overall Site Layout

Key features shown on the layout related to consequence modelling include:

- The ETE and ETJ process forms part of ISBL modules IS1, IS2 and IS3. The separation distance between IS1 and IS2 is approximately 1m. The separation distance between IS1/2 and IS3 is approximately 10m,
- IS1 is a 4 storey module comprise of the ETE process with approximate dimensions of 36m x 17m x 24m,
- IS2 is a 5 storey module comprise of the ETJ process with approximate dimensions of 36m x 17m x 30m,
- IS3 is a single storey module housing the compressors, dryer and guard beds with approximate dimensions of 36m x 17m x 6m,
- Manned buildings are located to the east, with the main entrance and exit from the site located to the South.

Each level of the modules is assumed to be 6m high. The layout referenced is presented in Appendix A.

5.0 FAILURE CASES

5.1 Process Events

During the development of the Assumption Register [1], the failure case definition was performed. The definition of the failure case scenarios has been completed using the rules outlined in Assumptions Sheet FC-1 and has been achieved by considering process sections, equipment location, and process conditions.

The format / numbering for each failure case follows the following convention as per Assumption Sheet FC-2 [1]:

Area-Elevation-FCi-Phase

Where:

- Module number & Deck Level: IS1.1-4, IS2.1-5, IS3.1, OS1.1-4, OS2.1-4, OS3.1-3, OS4, OS5, OSBL.
- FCi: Failure case number
- Phase: Vapor, Liquid or 2-Phase respectively

The full list of failure cases is presented in Appendix B, with the marked-up PFDs and UFDs showing the extent of the sections included in Appendix C.

5.2 Escalation Events

The above failure cases cover mostly the primary hazardous scenarios arising from loss of containment events. However, depending on the characteristic of the events (e.g. calorific value of the jet fire, duration, direction, location in relation to other equipment, equipment survival time) further escalation could occur.

Escalation could take multiple forms such as secondary releases of flammable or toxic fluids, Boiling Liquid Expanding Vapour Explosion (BLEVE), failure of structural elements, etc. It is to be noted it is not practicable to model all potential escalation mechanisms and some simplifying assumptions are necessary. The consequences of secondary escalation are therefore modelled as far as possible using engineering judgement (potential worst case inventory loss will be assumed).

These are identified in the below table by the failure case ID Domino_1 to Domino_5 following a review of the consequence analysis results of the primary events. The escalations events have been selected based on the predicted severity extent within a given module.

Table 5-1: Escalation Scenarios

Failure Case ID	Description	Escalation event
Domino_1	LPG Tank T-7500	Boiling Liquid Evaporating Vapour Explosion (BLEVE)
Domino_2	Hydrogen Storage Tank V-4351/2	Catastrophic Rupture
Domino_3	IS1 module escalation (Ethylene Refinement Column Reflux Drum)	Boiling Liquid Evaporating Vapour Explosion (BLEVE)
Domino_4	IS2 module escalation (Olig 1 HP Separator)	Boiling Liquid Evaporating Vapour Explosion (BLEVE)
Domino_5	IS3 module escalation (Refrigeration Package Z-3400)	Boiling Liquid Evaporating Vapour Explosion (BLEVE)

5.3 Non Process Fires

Non-process fires include those fires involving electrical equipment, small quantities of flammable oils (i.e lube oils), chemical storage, hazardous goods and ordinary combustible cellulosic materials in the facility.

While non process fires could occur anywhere in the plant, it is considered that the majority would occur within enclosures or bunds which would be localised in nature. Consequently the risks to individuals and of escalation would be minimal. As part of this study, the extent and intensity of these types of fires will not be subject to specific consequence modelling.

6.0 CONSEQUENCE MODELLING

6.1 Introduction

Consequence assessment describes the basis and process by which the final hazardous outcomes resulting from a loss of containment event are quantified in terms of their resultant severity and extent. Input data for the consequence analysis includes:

- Inventory (including volume, composition, pressure and temperature); and
- Release conditions (including hole sizes and weather conditions).

The following fire and dispersion consequences are identified as possible should a release event occur.

- **Jet fires:** A jet or spray fire is a turbulent diffusion flame resulting from the combustion of a fuel continuously released with some significant momentum in a particular direction or directions.
- **Pool fires:** A pool fire is a turbulent diffusion fire burning above a horizontal pool of vaporising flammable fuel where the fuel has zero or low initial momentum.
- **Flash fires / Flammable dispersion:** A flash fire is a sudden, intense fire caused by ignition of a mixture of air and a dispersed flammable substance such as combustible liquid (such as an aerosol or fine mist), or a flammable gas.
- **Explosions:** A flammable gas or a flashing liquid released to atmosphere, if not immediately ignited, can develop into a Vapour Cloud Explosion (VCE), if the burning velocity of the cloud is increased due to the turbulence generated by obstacles present in the cloud. Hazardous effects are associated with levels of overpressure generated by pressure wave to some extent of structure damage or failure.
- **Toxic dispersion:** Dispersion of toxic Acetaldehyde and Acetonitrile that could cause adverse health effects to people.

The consequence modelling results are calculated in terms of distance to a specified level of severity.

6.2 Source term

6.2.1 Event and Process Conditions

Sources are the flammable gas and liquid phases of the failure cases listed in Section 5.0 .

The consequence effects are calculated based on normal steady state operating conditions. Pressures, temperatures and compositions for each release event is taken from the heat and material balance [3] and [4]. Where process conditions are not available at this stage of the project, best engineering judgement is used based on previous projects.

6.2.2 Inventory sizing

In line with Assumption Sheet FC-3 [1], the inventory size of the individual sections is estimated based on the main equipment volumes from the equipment list, with 20% contingency added to the total volume to allow for piping. Where vessel contains two or more phases, then the normal liquid level is used to ensure correct inventories are estimated.

6.2.3 Representative hole size

A set of discrete release hole sizes that are used to derive the extent of the consequences for each failure case. The selected hole sizes are taken to be representative of the full range of hole sizes that could occur.

Four leak sizes are considered in this study as per Assumption Sheet FC-4 [1] as follows:

- Small: 6 mm,
- Medium: 23 mm,
- Large: 87 mm,
- Full bore (FB) / Rupture.

6.2.4 Release duration

The base case considers that there is no automatic isolation, and that isolation and blowdown would occur manually after 10 minutes.

On the whole all releases are taken to continue for at least 10 minutes either from the primary inventory or from the incoming flow before isolation occurs. The consequences results used for fatalities arising from the initial release rates and for the escalation potential might differ as the release duration from the primary inventory might not be sufficiently long. This will be assessed on a case-by-case basis in the FEA.

6.3 Physical Effect Modelling

6.3.1 General Parameters

The general parameters stipulated within the Assumption Sheet GE-1 for PHAST modelling have been applied as indicated in the tables below [1].

Table 6-1: General Parameters Basis

PARAMETER	Value
Atmospheric pressure	1.013 bar
Atmospheric temperature	+22.7 degC
Surface temperature	+22.7 degC
Relative humidity	62%
Solar radiation	6.7 kWh/m ²
Ground surface roughness	50cm

Two combination of wind speeds and ambient weather conditions (which follow the Pasquill-Gifford naming scheme for defining atmospheric stability) will be considered in the analysis and are described below.

- 5D (neutral stability, 5 m/s wind speed), representative of typical daytime conditions.
- 2F (very stable, 2 m/s wind speed), representative of low wind speed conditions found during nighttime.

6.3.2 Dispersion Analysis

All releases have been assumed to occur horizontally which is conservative since releases that have a vertical component in their orientation would result in shorter downwind consequence distances.

Release occurring within the ISBL area are assumed to be impinged to reflect loss of momentum due to jet impingement on structures and equipment nearby. Releases located OSBL are unimpinged.

Downwind distances for flash fire events are reported for each failure case, hole size and weather condition. The extents are that of the fully developed cloud.

6.3.3 Jet and Pool Fires Analysis

The jet fire and pool fire models within PHAST have been used to generate the downwind and crosswind for each relevant failure case detailed in Section 5.1. Jet fire will be modelled as horizontal unimpinged to give the maximum downwind distance of the jet fire for escalation analysis.

6.3.4 Explosion Analysis

Explosion analysis is undertaken to determine the effects of explosions when a congested region of the plant is filled or partially filled with dispersing flammable gases and ignited.

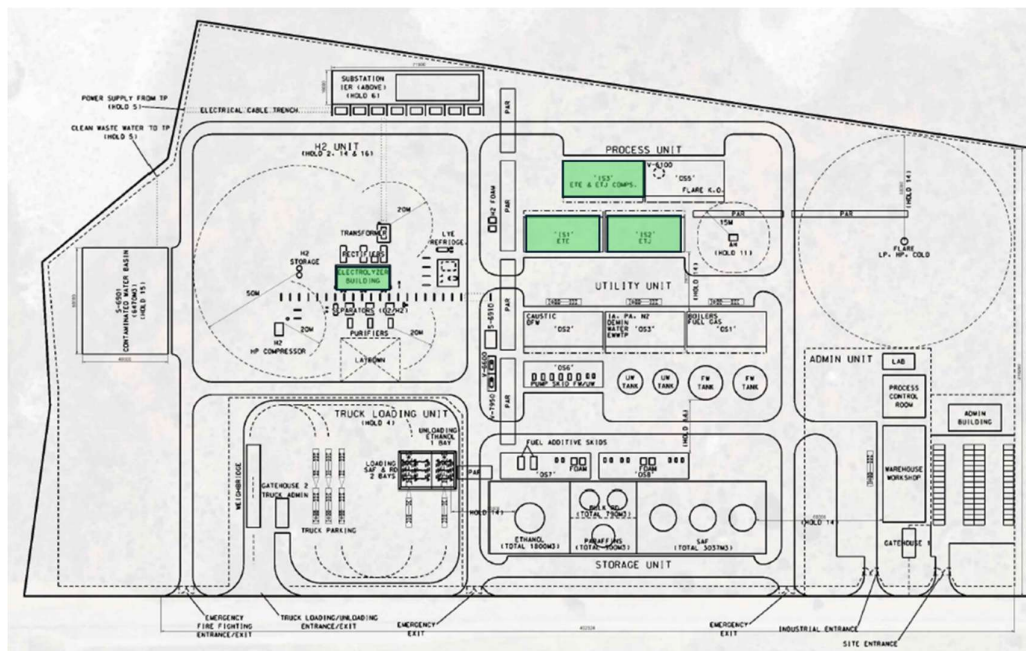


Figure 6-1: Mark-up of congested areas

Overpressure analysis is performed via the TNO multi-energy model available within the PHAST consequence suite.

The following methodology is employed to model explosion hazards:

- Potentially congested plant areas are identified from the equipment layouts. These corresponds to Modules IS1, IS2, IS3 and electrolyser building, marked up in Figure 6-1. These regions are to be viewed as representative of possible congested facility areas; their volume has been calculated measuring the area on the plot plan.

- A single representative stream is considered per area and is selected based on the highest volatile streams circulating within the area. At this stage, this has been selected as the stream with the highest concentration of Ethylene or Hydrogen. These streams are considered worst case scenarios compared with all potential streams that might give rise to explosion overpressures.
- Each region is assumed fractionally filled with flammable gases. The largest flammable cloud size from a 23mm release is also considered for each congested area to obtain the credible explosion overpressure.
- TNO multi-energy model requires that a value should be taken for the source strength. Typically, a value of 7 is indicative of a moderately strong degree of congestion and typical of process modules onshore. Explosion strength 8 will be used to model ethylene explosion to take into consideration the higher reactivity of the gas.
- For an explosion resulting from hydrogen (i.e. H₂ Electrolyser building), explosion strength 10 is used to model explosion within congested areas to take into consideration hydrogen's propensity for detonation.
- Distances to defined overpressure levels are then determined.

Table 6-2: Explosion Modelling Basis

CONGESTED AREA	Dimension (m)	Total Volume (m ³)	Representative HMB Stream	Congestion	Confinement	TNO Curve
IS1	36x17x24	14688	1500	High	NO	8
IS2	36x17x30	18360	2205	High	NO	8
IS3	36x17x6	3672	1306	High	NO	8
H ₂ Electrolyser Building	26x10x5	1300	100% H ₂	High	YES	10

6.3.5 Domino Effects

The domino effects considered as part of the analysis consist of BLEVE and catastrophic rupture of vessels. PHAST has been used to estimate the extent of the explosion overpressure effects from these events. See Section 5.2 for more detail on domino effects.

6.4 Impact and Impairment Criteria

The impact and impairment criteria associated with the release scenarios are given with reference to industry accepted standards and Queensland planning guideline [5]. The selected criteria summarised below and are in line with those presented in the Assumption Register [6].

6.4.1 Effect of Thermal Radiation

In line with Assumption Sheet CA-2 [1], for fire events, (pool and jet) thermal radiation are reported to levels shown in Table 6-3 alongside the probability of fatalities for people within the effect zone.

Table 6-3: Thermal Radiation Criteria

THERMAL RADIATION LEVELS (KW/M ²)	Criteria
4.7	Criteria for impact to offsite public
12.6	Criteria for impact to offsite industrial land
37.5	20min to failure of equipment
100	3 min to failure of equipment and 10 min for structure

The flame length and pool diameter will also be reported.

6.4.2 Effect of Flash Fire

In line with Assumption Sheet CA-3 [1], the dispersion of flammable clouds is reported to the conditions where the cloud edge reaches 100% and 50% of the lower flammability limit (LFL).

Flash fires are taken to not cause escalation.

6.4.3 Effect of Explosion

In line with Assumption Sheet CA-5 [1], distances to the following explosion overpressures are reported to enable correlation of explosion results the damage criteria.

Table 6-4: Reported Overpressures

OVERPRESSURE	Damage Criteria
7 kPa (1 psi / 0.07 bar)	Damage to internal partitions and joinery but can be repaired. Probability of injury is 10%. No fatality.
14 kPa (2 psi / 0.14 bar)	House uninhabitable and badly cracked.
21 kPa (3 psi / 0.21 bar)	Reinforced structures distort. Storage tanks fail. 20% chance of fatality to a person in a building.
35 kPa (5 psi / 0.35 bar)	House uninhabitable. Wagons and plants items overturned. Threshold of eardrum damage. 50% chance of fatality for a person in a building and 15% chance of fatality for a person in the open.

Escalation resulting from a vapour cloud explosion is possible and the reaction of the plant element to the overpressure created by the blast will vary. 0.14 bar is the lower limit of severe structural damage to buildings, and it is expected that minor damage to the plant would occur. Serious damage to plant and equipment are typically quoted as 0.35 bar.

Equipment under load may damage itself, its supports and other piping connected to it. Secondary leakage or failure could then lead to subsequent hazardous effect such as jet fires. The overpressure incurred by the ignition of a flammable gas within a congested area is uncertain and should be subject to CFD analysis to accurately predict the peak overpressure.

6.4.4 Effect of Toxic

In line with Assumption Sheet CA-7 [1], toxic material identified as part of the ETE stream is Acetaldehyde and Acetonitrile. Concentrations in the stream based on the HMB was found to be higher than the Acute exposure guideline levels (AEGL).

The following AEGL-2 concentrations will be applied to determine the toxic dispersion based on Queensland Hazardous Chemical criteria [5].

Table 6-5: Concentration to AEGL-2, Ref [7] and [8]

CHEMICAL	AEGL-2 Concentration based on exposure duration
	10 - 30 min
Acetaldehyde	340 ppm
Acetonitrile	80 ppm

7.0 RESULTS

The Physical Effect Modelling was performed for each of the failure case shown in Section 5.

Results for 6mm and 23mm release for a number of representative events for the 2F and 5D weather condition are presented per area in the following sections. The 23mm release will be used to represent the credible consequence case, as typically leak frequency for small to medium hole sizes encompass majority of the total event frequency compared with larger hole sizes. Full results are available in Appendix D.

The below results are based on a series of failure cases and associated releases deemed a good representation of the hazards. For some large releases, the selected representative consequence results had been adjusted/capped to 150% of the flowrate, particularly for failure cases with limited inventory (i.e. compressors, pumps, heat exchangers). For vessels, the release is a combination of the inventory (static inventory) and plant throughput (dynamic inventory). For large releases, the static inventory would deplete within 10-15s, and thereafter the release rate will be driven by the dynamic inventory. For conservatism, contours for fatality and offsite impact from thermal radiation, including flash fire from flammable dispersion will be based on the peak release rate for these cases. For toxic releases, the capped release rate will be used for determining the effect distance as the exposure duration for toxic effect at AEGL-2 concentration is 10 min or more.

Note that the downwind effect distances presented in this report are the ones resulting from a release at equipment height. This shows the full extent of the hazard. Contours for offsite impairment is reported at 1m height, for impact to personnel at ground level.

7.1 Module IS1 (ETE)

The ETE module spans over 4 levels, consisting of the Ethanol to Ethylene process. The main equipment located in this module are the Ethanol Pre-Treatment Column, associated Reactors, Columns including Ethylene Refinement, Water Separation and various Flash Drums. Releases were modelled at the lowest points for each failure cases, as this would give the largest consequence contour at 1m height to evaluate impact to personnel.

7.1.1 Jet Fire Thermal radiation

The operating pressure of equipment in this module range from 0.3 barg for the Pre-treatment Column Reflux Drum to over 27 barg. The high-pressure systems in this module consists of Ethylene Separation Column, Ethylene Refinement Column and their associated Reflux Drums. The jet fire from these systems will give rise to the larger jet fire thermal radiation result, particular for liquid releases.

Small (6mm) liquid release could result in jet fire flame length of over 10m downwind distance with release duration of over 30 minutes, due to the inventory within the vessels. For majority of small releases, the maximum thermal radiation from the flame is less than 100 kW/m² (approximately 50 kW/m²) taking into consideration effects of the wind. However these releases could still cause impairment and escalation due to the long release duration. Medium (23mm) releases could be over 66m and 45m in downwind distance to radiation levels of 37.5kW/m² and 100kW/m² respectively while large and full-bore releases could lead to jet fires of over 100m in downwind distance to radiation levels of 100kW/m². Vapour releases results in jet fires that are approximately 50% smaller compared with liquid releases, due to the lower mass release rate.

As the basis for isolation is 10 minutes, most of the thermal radiation resulting from loss of containment event in this module could lead to impairment and subsequently escalation to

neighbouring equipment and structures within the module and to adjacent modules (IS2 and IS3) due to the close proximity of equipment and module.

It should be noted that , the majority of the medium releases cannot be sustained more than 3 minutes after isolation, with the exception of some equipment with a large liquid inventory that could sustain a release for more than 10 minutes after isolation (i.e. Ethanol Pre-Treatment Column, Vaporiser Feed Drum, Water Separation Column Reflux Drum). A leak from the Cation Guard Bed Package could sustain release for over 30 minutes due to a substantial amount of inventory. For large and full-bore rupture, most of the releases cannot be sustained and would deplete within 1 minute after isolation.

Figure 7-1 and Figure 7-2 present the radiation contour at 1m height from the Ethylene Separation Column Reflux Drum and Dee & Ethanol Recovery KO Drum, which represents the credible worst case jet fires (f23mm release) from Module IS1. Due to the Dee & Ethanol Recovery Pump being located at ground level (and assuming a release from this section), jet fires from the scenario with the Dee & Ethanol Recovery KO Drum would have the greatest impact to personnel and public at ground level as compared to the Ethanol Recovery KO Drum release scenario which is located on the second level of the module. As per thermal radiation contour, the 4.7kW/m² radiation level remains within the site boundary, and not expected to impact offsite locations. The 100Kw/m² radiation level contour is shown to impact the utility unit and modules IS2 and IS3. It should be noted that this is considered conservative, as with shielding and impingement of equipment within the IS1 module, the jet fire is expected to be reduced.

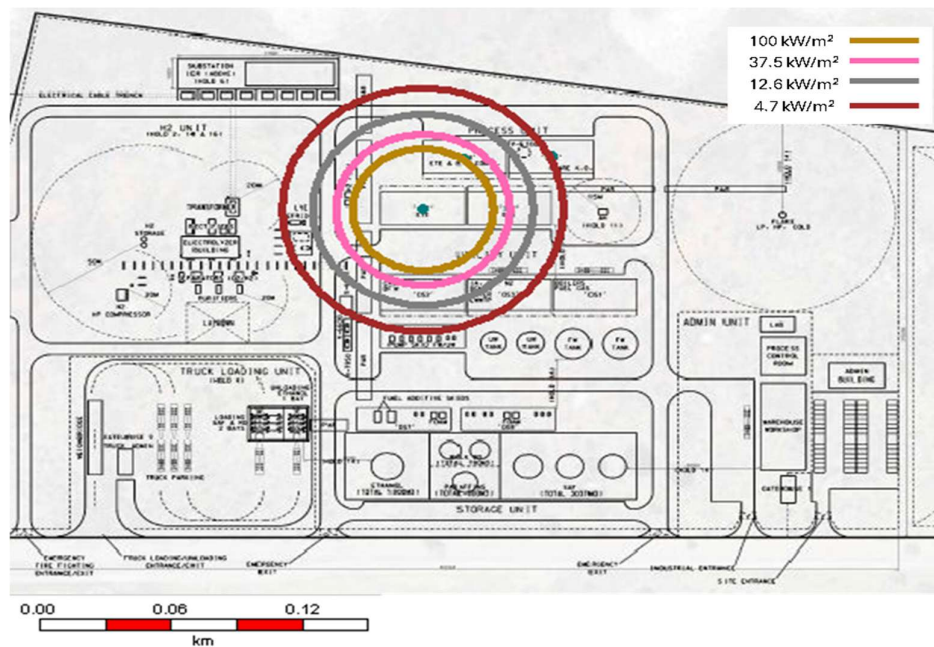


Figure 7-1: Jet fire Thermal Radiation from FC36, 5D wind, 23mm release

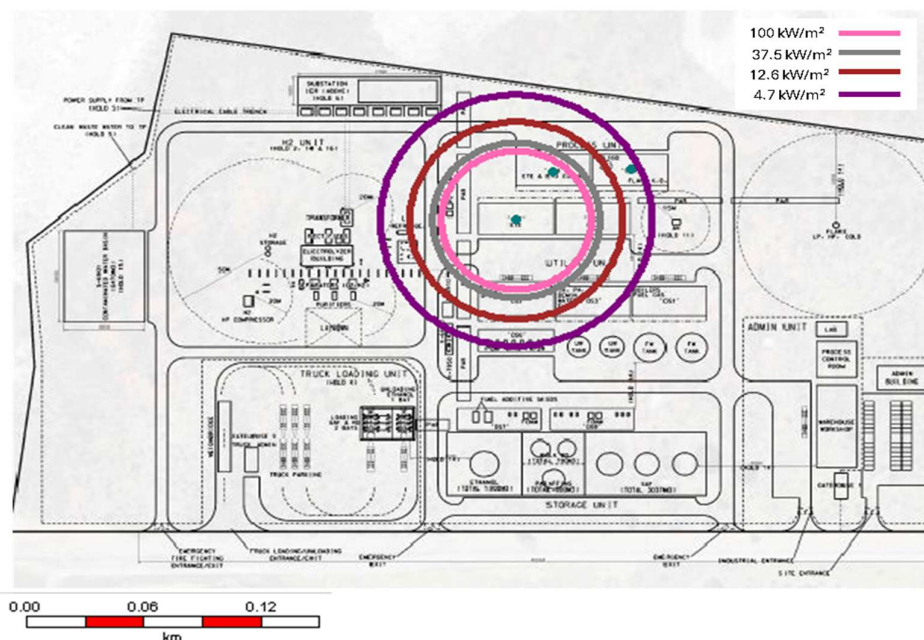


Figure 7-2: Jet fire Thermal Radiation from FC52, 5D wind, 23mm release

The consequence results for the below failure cases, which represents the worst-case jet fire scenario have been selected for illustration of the hazards present in the area:

- Primary Separation Column C-1350 liquid release (FC27).
- Primary Separation Column Reflux Drum V-1361 liquid release (FC28).
- Ethylene Separation Column C-1410 liquid release (FC33).
- Ethylene Separation Column Reflux Drum V-1421 liquid release (FC36).
- Ethylene Refinement Column Reflux Drum V-1561 liquid release (FC41).
- Dee and Ethanol Recovery KO Drum V-1631 liquid release (FC52).
- Ethylene Refinement Column Condenser (Shell-side) HE-1560 liquid release (FC147).

Table 7-1: Selected Jet Fire Results - Module IS1

FAILURE CASE	Hole size	Release rate (kg/s)	Release duration (mins)	Jet Fire thermal radiation Downwind (m) 5D wind			
				4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
FC27-Liquid	6mm	0.6	>30.0	17	14	12	NR*
	23mm	8.6	11.6	56	47	40	NR*
FC28-Liquid	6mm	0.5	26.2	18	14	11	9
	23mm	7.9	11.1	59	46	37	31
FC33-Liquid	6mm	0.8	11.4	20	15	13	11
	23mm	11.9	10.1	67	52	42	36
FC36-Liquid	6mm	0.8	16.8	19	15	13	11
	23mm	12.4	10.5	65	52	42	37
FC41-Liquid	6mm	0.8	19.3	18	15	13	11
	23mm	12.4	10.6	62	51	42	37
FC52-Liquid	6mm	0.8	>30.0	21	17	14	NR*

FAILURE CASE	Hole size	Release rate (kg/s)	Release duration (mins)	Jet Fire thermal radiation Downwind (m) 5D wind			
				4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
	23mm	11.2	13.4	69	54	43	38
FC147-Liquid	6mm	0.2	30.0	13	10	8	NR*
	23mm	3.1	13.2	43	34	28	24

* No thermal radiation at this value expected

7.1.2 Pool Fire Thermal Radiation

Liquid release from vessels such as Ethanol Pre-Treatment Column, Pre-Treatment Column Reflux Drum, Water Separation Reflux Drum, Dee and Ethanol Recovery KO Drum and other inventories containing liquids could form a pool upon release and subsequently lead to pool fires on ignition.

Small (6mm) release could lead to pool fires between 2m – 4m in diameter while medium release (23mm) could be up to 15m in diameter for release from the Ethanol FEED Preheaters as shown in Figure 7-9. The pool formation has assumed no bunding provision within the module. Maximum thermal radiation from the pool fire was estimated to be less than 100 kW/m² (approximately 50 kW/m²). Provision of bunding and drainage would limit the size of the pool formed and the resulting pool fire size, preventing escalation.

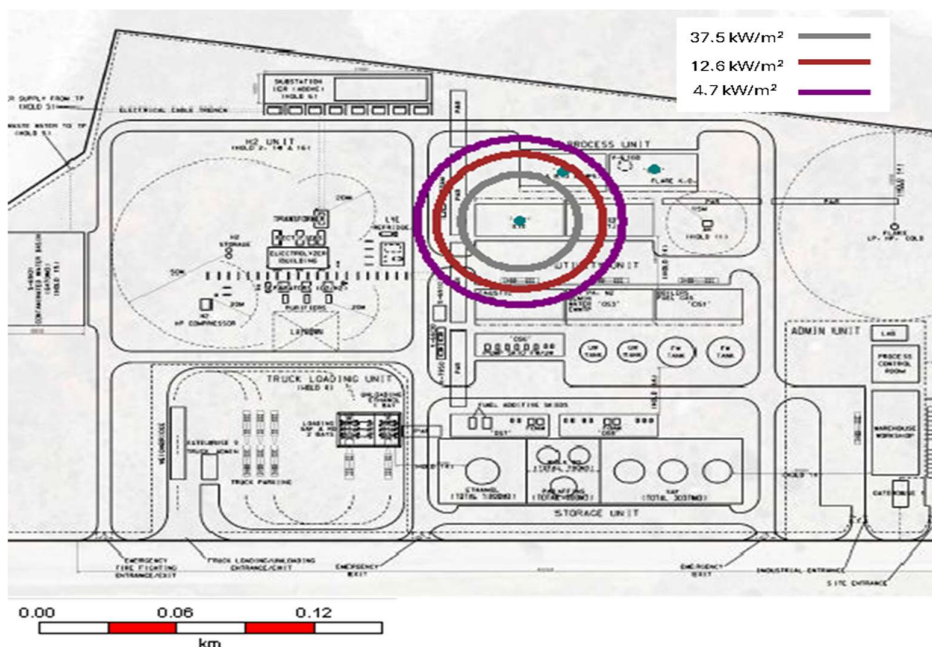


Figure 7-3: Pool fire Thermal Radiation from FC02, 5D wind, 23mm release

The consequence results for the below failure cases, which represents the worst-case pool fire scenario have been selected for illustration of the hazards present in the area:

- Ethanol FEED Pre-heaters HE-1101/2 (FC02).
- Ethanol Pre-Treatment Column C-1100 (FC04).
- Pre-Treatment Column Reflux Drum V-111 (FC08)
- Water Separation Column Reflux Drum V-1621 (FC49).

- Dee and Ethanol Recovery KO Drum V-1631 (FC52).

Table 7-2: Selected Pool Fire Results - Module IS1

FAILURE CASE	Hole size	Release rate (kg/s)	Pool diameter (m)	Pool Fire thermal radiation Downwind (m) 5D wind			
				4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
FC02-Liquid	6mm	0.4	3	31	29	27	NR*
	23mm	6.1	15	45	36	25	NR*
FC04-Liquid	6mm	0.3	-	-	-	-	-
	23mm	4.7	9	48	42	34	NR*
FC08-Liquid	6mm	0.2	3	12	11	NR*	NR*
	23mm	2.3	10	23	19	NR*	NR*
FC49-Liquid	6mm	0.3	2	22	20	19	NR*
	23mm	4.0	9	34	28	19	NR*
FC52-Liquid	6mm	0.8	3	16	13	9	NR*
	23mm	11.2	14	47	35	22	NR*

* No thermal radiation at this value expected

7.1.3 Flammable Dispersion

Flammable dispersion from the ETE module from small releases (6mm) ranges from 1m to 16m to ½ LFL concentrations, to over 70m and 25m from a medium (23mm) release to ½ LFL and LFL concentrations respectively. The worst-case dispersion tends to occur for the 2F weather condition, whereby the calm condition leads to less mixing of the plume with air and subsequently greater hazard distances. At 5D weather condition, the dispersion downwind distance is less, due to the increased mixing. The larger distance distances are typically from liquid releases, due to the large mass being released which vaporises and forms a flammable cloud. Based on the worst-case dispersion from a 23mm release both ½ LFL and LFL concentrations do not exceed the facility boundary.

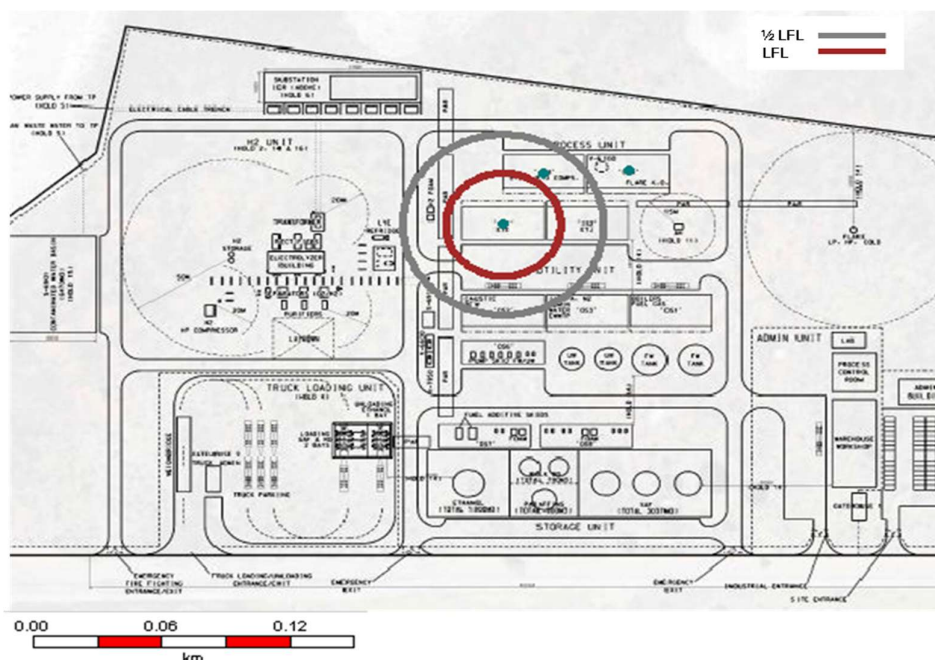


Figure 7-4: Flammable dispersion from FC52, 5D wind, 23mm release

With respect to the liquid releases, they would form a pool upon release and vaporisation from the pool leads to flammable gas dispersion. It should be noted release durations from large to full-bore releases cannot be sustained for longer than approximately 1 minute after isolation with the exception of releases from large inventories (i.e. Ethanol Pre-Treatment Column, Reactor 1 R-1260) which can last for 3 minutes after isolation. Ignition of a flammable gas cloud results in a flash fire and could lead to immediate fatality of personnel within the gas cloud. It is important to also note that leak frequencies for large and full-bore releases are however generally much lower.

The consequence results for the below failure cases, which represents the worst-case flammable dispersion scenarios have been selected for illustration of the hazards present in the area:

- Ethylene Separation Column Reflux Drum V-1421 vapour release (FC38).
- Ethylene Refinement Column C-1550 vapour release (FC40).
- Ethylene Refinement Column Reflux Drum V-1561 liquid release (FC41).
- Ethylene Refinement Column Reflux Drum V-1561 vapour release (FC43a)
- Dee and Ethanol Recovery KO Drum V-1631 liquid release (FC52).

Selected consequence results are presented in the following table.

Table 7-3: Selected Flammable Dispersion Results - Module IS1

FAILURE CASE	Hole size	Release rate (kg/s)	Flammable dispersion downwind distance (m)			
			2F		5D	
			1/2 LFL	LFL	1/2 LFL	LFL
FC38-Vapour	6mm	0.2	9	6	8	5
	23mm	2.6	29	19	24	17
FC40-Liquid	6mm	0.2	11	7	11	7
	23mm	2.6	31	21	30	20

FAILURE CASE	Hole size	Release rate (kg/s)	Flammable dispersion downwind distance (m)			
			2F		5D	
			1/2 LFL	LFL	1/2 LFL	LFL
FC41-Vapour	6mm	0.8	16	12	15	11
	23mm	12.4	39	31	41	30
FC43a-Liquid	6mm	0.2	9	6	8	5
	23mm	2.6	28	19	24	17
FC52-Liquid	6mm	0.8	6	5	7	5
	23mm	11.2	73	38	47	27

7.1.4 Explosion

The most reactive material in the IS1 module is Ethylene (stream 1500 containing 100% Ethylene), this was considered for IS1 module explosion.

The size of the congested area is taken as the size of the module. IS1 is the second largest module on the site, consisting of 4 levels (6m was assumed as height of each level). Different fill fraction was modelled for the module, representing different flammable cloud size within the congested area.

The scenarios modelled are as follows:

Table 7-4: Selected Explosion Results - Module IS1

FAILURE CASE	Flammable Volume (m ³)	Fill Fraction	Material	Explosion Overpressure Radii (m)			
				0.07 bar	0.14 bar	0.21 bar	0.35 bar
IS1 Module Explosion	14688	100%	Ethylene (stream 1500)	307	176	132	96
	7344	50%	Ethylene (stream 1500)	243	139	105	76
	4406.4	30%	Ethylene (stream 1500)	205	118	88	64
	1034*	7%	Ethylene (stream 1500)	127	73	54	40

* Volume based on largest ½ LFL dispersion for 5D wind and 23mm release.

The size of the congested volume was compared with the size of the flammable cloud that could be expected. The largest cloud size from a 23mm release at 5D wind was taken as the credible worst-case scenario for this section, as shown in Figure 7-5. For conservatism, the ½ LFL cloud size was used.

From the explosion overpressure result, the manned buildings, storage tanks and hydrogen electrolyser building are outside of the 0.14 bar overpressure contour. Explosion from one module can however impact equipment and structure in other modules, causing escalation. The 0.07 bar and small section of the 0.14 bar explosion contour encroached offsite due to location of the module close to the plant boundary. Most of the other 23mm releases result in much smaller flammable cloud, hence the explosion contour is expected to be smaller however still possible to lead to escalation of adjacent modules.

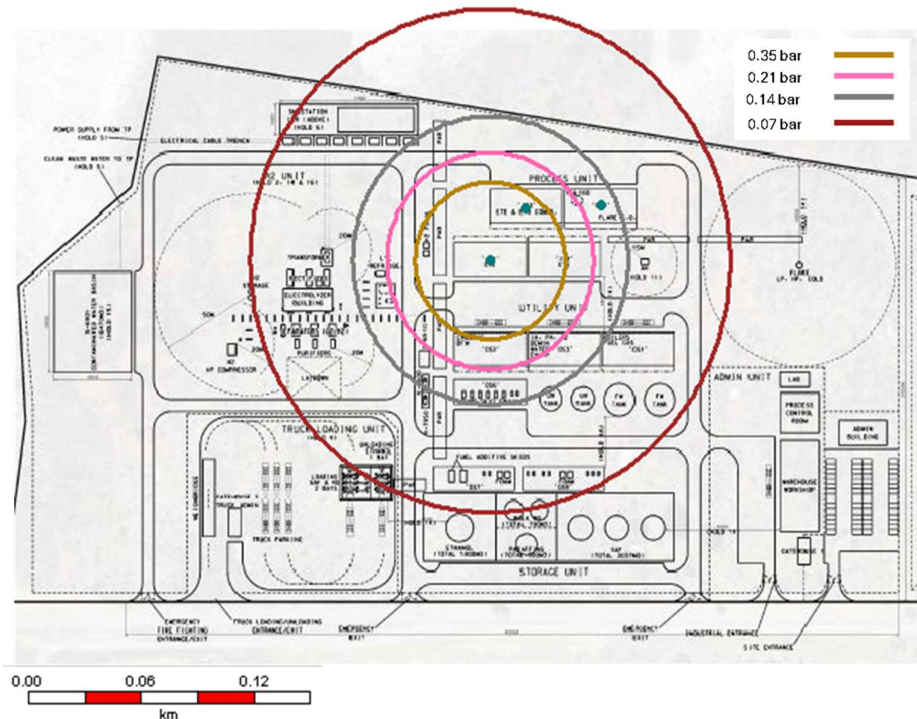


Figure 7-5: Explosion Overpressure from worst case 23mm release (IS1 Module), 5D wind

7.1.5 Toxic Dispersion

Acetaldehyde and Acetonitrile are the two toxic substances assessed; It should be noted that concentration of Acetonitrile is low (maximum of 0.04 mol%) hence Acetaldehyde presents the governing toxic risk.

Toxic dispersion from the ETE module from small releases ranges from 3m to 5m at 340ppm (AEGL-2 concentration) of Acetaldehyde. Medium, large and full-bore releases could have significant toxic downwind distance, however, the high initial release rate cannot be sustained for more than one minute. Exposure to acetaldehyde for such short duration at the AEGL-2 (exposure duration of >10 minutes) concentration is not expected to cause irreversible impact to people. The release after exhaustion of the inventory will be driven by the flow from upstream until isolation (10 minutes). This capped release rate is applied to large, full-bore rupture and some medium releases whereby the duration of release is short. Based on this, the Acetaldehyde toxic cloud is up to 120 m for medium release (23 mm) and 132 m for large/full-bore releases.

The worst-case dispersion tends to occur for the 2F weather condition, whereby the calm condition leads to less mixing of the plume with air and subsequently greater hazard distances. At 5D weather condition, the dispersion downwind distance is less, due to the increased mixing. Most of the releases at higher levels of the module does not reach the ground level, hence would not impact the people at ground level. As shown in Figure 7-6 the toxic cloud is contained within site and not found to impact the manned buildings.

At the Immediately dangerous to Life and Health (IDLH) concentration of 2000 ppm, the toxic cloud only extends 14m from the worst case 23mm leak. Personnel working on the modules in the immediate area would be alerted by gas detection upon loss of containment and can evacuate the area.

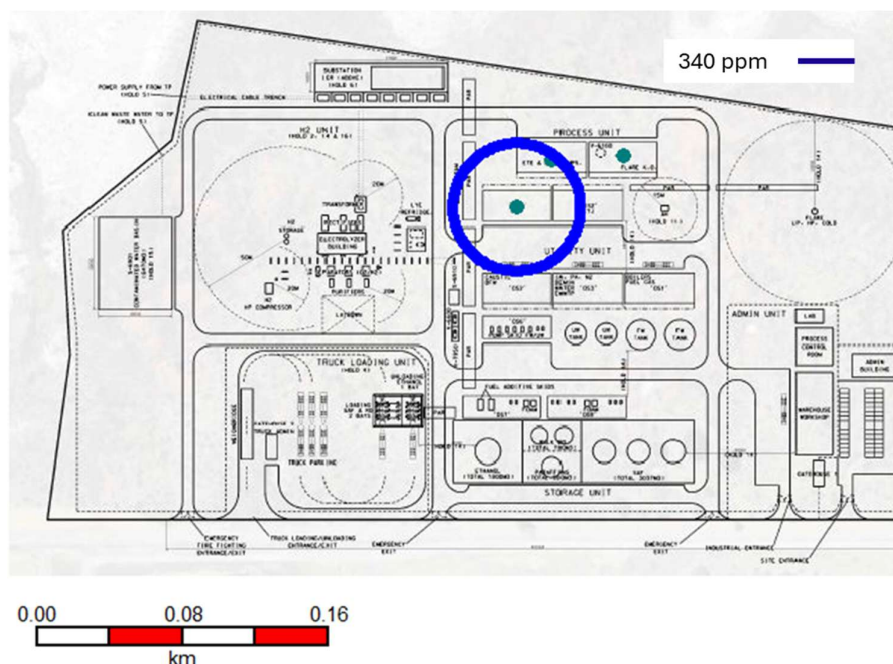


Figure 7-6: Toxic 340 ppm dispersion from FC28 5D wind, 23mm release

The consequence results for the below failure cases, which represents the worst-case toxic scenarios have been selected for illustration of the hazards present in the area:

- Pre-treatment Column Reflux Drum v-111 liquid release (FC08).
- Primary Separation Column Reflux Drum V-1361 liquid release (FC28).
- Ethylene Separation Column Reflux Drum V-1421 liquid release (FC36).
- Ethylene Refinement Column C-1550 liquid release (FC39)
- Dee and Ethanol Recovery KO Drum V-1631 liquid release (FC52).

Selected consequence results are presented in the following tables.

Table 7-5: Selected Toxic Dispersion Results - Module IS1

FAILURE CASE	Hole size	Release rate (kg/s)	Toxic dispersion downwind distance (340ppm) (m)	
			2F	5D
FC08-Liquid	6mm	0.2	NR*	NR*
	23mm	2.3	55	NR*
FC28-Liquid	6mm	0.5	NR*	NR*
	23mm	6.8 ^{Note 1}	120	38
FC36-Liquid	6mm	0.8	NR*	NR*
	23mm	1.4 ^{Note 1}	41	23 ^{Note 2}
FC39-Liquid	6mm	0.8	NR*	NR*
	23mm	5.7 ^{Note 1}	65 ^{Note 2}	48 ^{Note 2}
FC52-Liquid	6mm	0.8	5	5
	23mm	11.2	42	31

* No toxic concentration expected

Note 1: Capped release rate, Note 2: Toxic cloud > 2m above ground.

7.2 Module IS2 (ETJ)

The ETJ module spans over 5 levels, consisting of the Oligomerization of ethylene process. Main equipment located in this module is the OLIG 1 and 2 reactors, associated separators, stabiliser column, hydrogenation reactor, separator and the fractionator. The stabiliser column and fractionator are over 10m tall, and traverses across multiple levels of the module. Releases were modelled at the lowest points for each failure cases, as this would give the largest consequence contour at 1m height to evaluate offsite risks.

7.2.1 Jet Fire Thermal radiation

The operating pressure of equipment in this module range from very low (0.2 barg) for the vacuum pump to over 20 barg. The high pressure systems in this module consists of the OLIG reactors, hydrogenation reactors and the associated HP separators. The resulting jet fire from these systems will give rise to the larger jet fire thermal radiation result, particularly for liquid releases.

Small (6mm) liquid release could result in jet fire of approximately 10m in downwind distance, with release duration of over 30 minutes, due to inventory within the vessels. Thermal radiation downwind distance to 37.5kW/m^2 and 100kW/m^2 was found to be up to 20m and 14m respectively. Medium (23mm) releases could be over 66m and 54m in downwind distance to radiation levels of 37.5kW/m^2 and 100kW/m^2 respectively while large and full-bore releases could lead to jet fires of over 100m in downwind distance to radiation levels of 100kW/m^2 . Vapour releases results in jet fires that are approximately 50% smaller compared with liquid releases, due to the lower mass release rate.

As the basis for isolation is 10 minutes, most of the thermal radiation resulting from loss of containment event in this module could lead to impairment and subsequently escalation to neighbouring equipment and structures within the module and to adjacent modules (IS1 and IS3) due to the close proximity of equipment and module.

Within the ETJ module, there are a number of equipment with large liquid inventory that could sustain a release for more than 3 minutes after isolation (i.e. OLIG 1 HP and LP Separator, OLIG 2 Feed Surge Drum and Reactors, Stabiliser Column and Overhead Separator, Hydrogenation Reactor and HP/LP Separators and Fractionator). A small leak from the Stabiliser Column (C-2400) and Fractionator (C-2600) could sustain for over 30 minutes after isolation due to a substantial amount of inventory (i.e. Ethylene in C-2400 and paraffin in C-2600). For large and full-bore rupture, most of the releases cannot be sustained and would deplete within 1 minute after isolation.

Figure 7-7 and Figure 7-8 below shows the radiation contour at 1m height from the Hydrogenation reactor and Hydrogenation HP Separator, which represents the credible worst case jet fire from Module IS2. Due to the location of the reactor at ground level, jet fire from the reactor would have the highest impact to personnel and public at ground level. From the thermal radiation contour, the 4.7 kW/m^2 thermal radiation remains within the site boundary, and not expected to impact offsite. The 37.5 kW/m^2 and 100 kW/m^2 thermal radiation contour, particularly from the HP Separator is shown to engulf the utility unit and modules IS1, IS3 and OS5 and would have release duration >20 minute, enough to cause structural and equipment impairment. Critical utility systems such as the Flare Knock-out-drum in OS5 and the Nitrogen Unit (used for purging of reactor during emergency depressurisation) should be situated outside of the thermal radiation contours. However with shielding and impingement of equipment within the IS2 module, the jet fire is expected to be shorter. This should be confirmed in the next phase of the project once more information on equipment location and module arrangement is available.

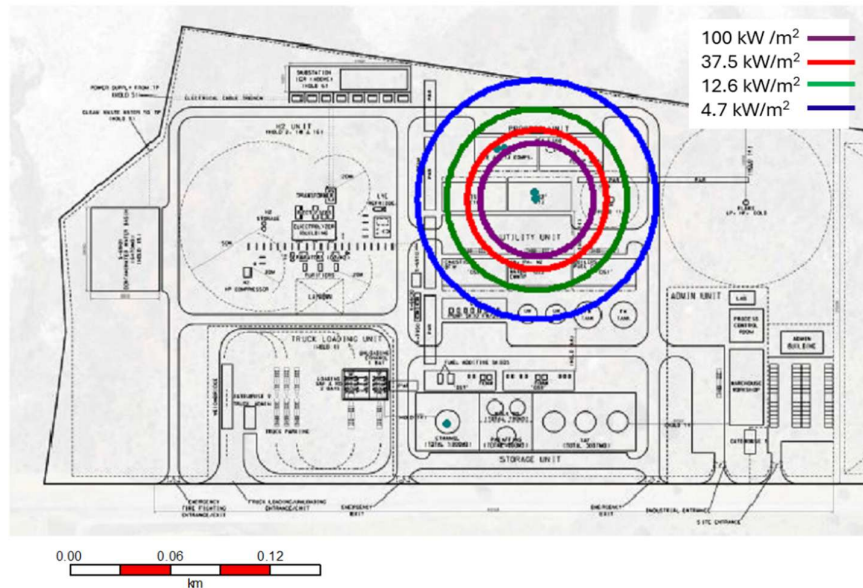


Figure 7-7: Jet fire Thermal Radiation from FC95, 5D wind, 23mm release

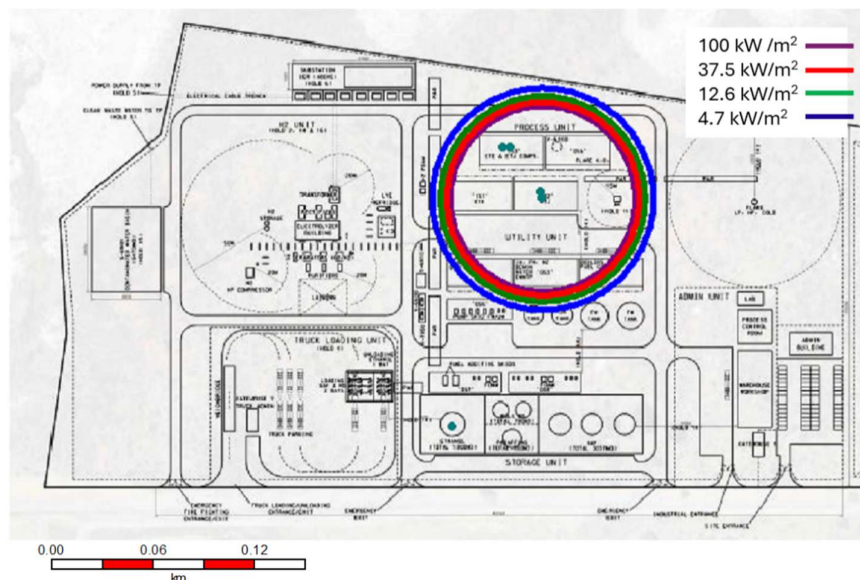


Figure 7-8: Jet fire Thermal Radiation from FC96, 5D wind, 23mm release

The consequence results for the below failure cases, which represents the worst case jet fire scenario have been selected for illustration of the hazards present in the area:

- OLIG 1 Reactors R-2130A/B (FC57).
- OLIG 1 high Pressure Separator liquid release (FC61).
- OLIG 2 Reactors R-2350A/B (FC74).
- Stabiliser Column C-2400 liquid release (FC82).
- Stabiliser Overhead Separator V-2420 liquid release (FC81).
- Hydrogenation Reactor R-2460 (FC95).

- Hydrogenation HP Separator V-2470 liquid release (FC96).

Selected consequence results are presented in the following tables.

Table 7-6: Selected Jet Fire Results - Module IS2

FAILURE CASE	Hole size	Release rate (kg/s)	Release duration (mins)	Jet Fire thermal radiation Downwind (m) 5D wind			
				4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
FC57-Vapour	6mm	0.12	>30.0	4.9	4.5	2.8	NR*
	23mm	1.7	12.1	20.2	18	15	11
FC61-Liquid	6mm	0.71	>30.0	20	16	13	11
	23mm	10.5	13.1	69	54	42	36
FC74-Liquid	6mm	0.79	>30.0	20	15	12	10
	23mm	11.6	29.4	59	45	35	28
FC81-Liquid	6mm	0.43	>30.0	17	13	10	9
	23mm	6.4	16.4	57	43	34	28
FC82-Liquid	6mm	0.43	>30.0	17	13	10	9
	23mm	6.4	11.9	57	43	34	28
FC95-Liquid	6mm	0.92	>30.0	22	17	13	11
	23mm	13.5	29.0	71	54	41	34
FC96-Liquid	6mm	0.93	>30.0	19	19	19	NR*
	23mm	13.7	23.3	65	60	56	54

* No thermal radiation at this value expected

7.2.2 Pool fire thermal radiation

Liquid release from vessels such as the OLIG 1 and Hydrogenation LP Separators, Hydrogenation Reactor, Fractionator and Fractionator Separator could form a pool upon release and lead to pool fires.

Small (6mm) release could lead to pool fires between 5m – 17m in diameter while medium release (23mm) could be up to 67m in diameter for release from the Hydrogenation Reactor, as shown in Figure 7-9. It is highlighted that PHAST assumes release on a perfectly flat concrete surface with no obstacles, which tend to overestimate the size of the pool. Provision of bunding/kerbing within the module and drainage would limit the size of the pool formed and the resulting pool fire size. Coupled with active fire production, the thermal radiation from a pool fire should be confined within the module, preventing escalation to adjacent modules.

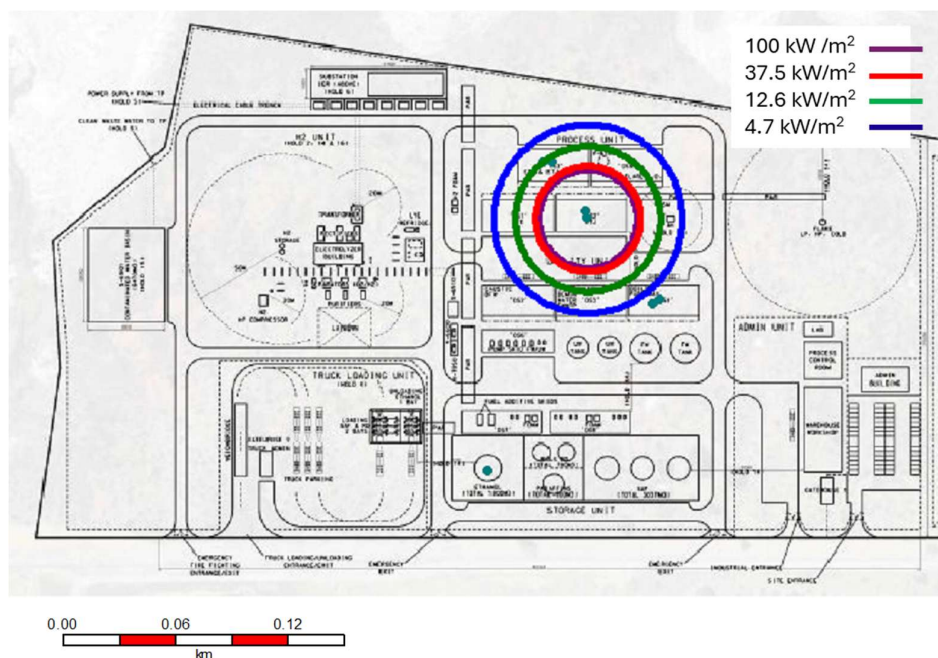


Figure 7-9: Pool fire Thermal Radiation from FC95, 5D wind, 23mm release

The consequence results for the below failure cases, which represents the worst case pool fire scenario have been selected for illustration of the hazards present in the area:

- OLIG 1 LP Separator V-2212 (FC64).
- Hydrogenation LP Separator V-2472 (liquid) (FC91)
- Hydrogenation Reactor R-2460 (FC95).
- Fractionator C-2600 liquid release (FC99).
- Fractionator Separator V-2671 liquid release (FC103).

Selected consequence results are presented in the following tables.

Table 7-7: Selected Pool Fire Results - Module IS2

FAILURE CASE	Hole size	Release rate (kg/s)	Pool diameter (m)	Pool Fire thermal radiation Downwind (m) 5D wind			
				4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
FC64-Liquid	6mm	0.28	3	19	15	10	7
	23mm	4.2	14	73	51	35	16
FC91-Liquid	6mm	0.92	NR*	NR*	NR*	NR*	NR*
	23mm	13.5	67	101	71	59	54
FC95-Liquid	6mm	0.35	2	14	11	9	6
	23mm	5.2	7	30	22	11	NR
FC99-Liquid	6mm	0.42	3	50	NR*	NR*	NR*
	23mm	602	12	68	62	56	56
FC103-Liquid	6mm	0.5	13	41	28	19	16
	23mm	7.4	45	66	45	36	31

* No pool fire/ thermal radiation expected

7.2.3 Flammable Dispersion

Flammable dispersion from the ETJ module from small releases (6mm) ranges from 2m to 33m for ½ LFL, to over 200m and 138m from a medium (23mm) release for ½ LFL and LFL respectively. The worst-case dispersion is for the 2F wind, whereby the calm condition leads to less mixing of the plume with air. At higher 5D wind, the dispersion downwind distance reduces by more than half, due to the increased mixing as shown in Figure 7-10. The larger dispersion distances tend to be from liquid releases, due to the larger mass being released which vaporises and forms a big cloud. Based on the worst-case dispersion from 23mm, the LFL cloud is contained within the site, with the ½ LFL only slightly offsite.

From Figure 7-10, it can be seen that the LFL cloud encroaches to the boiler module, which could present an ignition source for the gas cloud. The edge of ½ LFL cloud is seen to encroach to the Firewater Pump area, which could inhibit the firewater pump from starting.

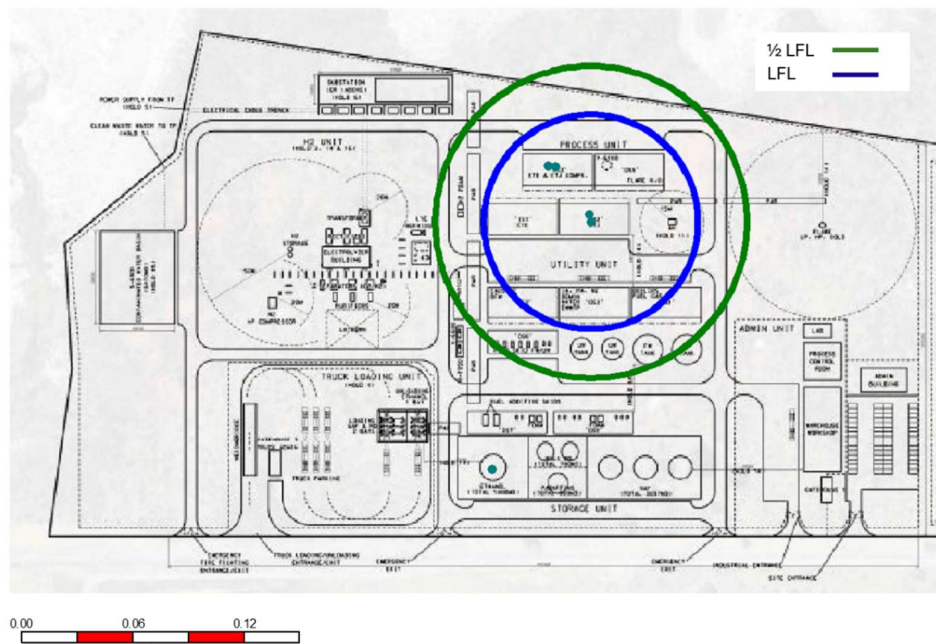


Figure 7-10: Flammable dispersion from FC96, 5D wind, 23mm release

Full-bore and large release could have downwind distance of over 1000m. Some liquid releases would form a pool upon release and vaporization from the pool leads to flammable gas dispersion. Although release duration from large to full-bore release cannot be sustained, ignition of a flammable gas cloud could lead to immediate fatality of personnel. However leak frequency for large and full-bore releases are generally much lower.

The consequence results for the below failure cases, which represents the worst-case flammable dispersion scenarios have been selected for illustration of the hazards present in the area:

- OLIG 2 Reactors R-2350A/B (FC74).
- Stabiliser Overhead Separator V-2420 liquid release (FC81).
- Stabiliser liquid volume (C-2400) liquid release (FC82).
- Hydrogenation Reactor R-2460 (FC95).
- Hydrogenation HP Separator V-2470 liquid release (FC96).

Selected consequence results are presented in the following tables.

Table 7-8: Selected Flammable Dispersion Results - Module IS2

FAILURE CASE	Hole size	Release rate (kg/s)	Flammable dispersion downwind distance (m)			
			2F		5D	
			1/2 LFL	LFL	1/2 LFL	LFL
FC74-Liquid	6mm	0.79	11	7	13	7
	23mm	12	183	121	75	51
FC81-Liquid	6mm	0.43	3	3	6	4
	23mm	6.4	119	81	37	15
FC82-Liquid	6mm	0.43	8	6	10	7
	23mm	6.4	119	81	37	15
FC95-Liquid	6mm	0.9	26	12	18	10
	23mm	14	131	74	78	48
FC96-Liquid	6mm	0.9	20	9	16	9
	23mm	14	208	138	84	58

7.2.4 Explosion

The most reactive material in the IS2 module are hydrogen (stream 2423) and ethylene (stream 2205 with highest % of ethylene) releases. Ethylene was chosen as the representative material given that the inventory and equipment containing hydrogen in the IS2 module is limited.

The size of the congested area is taken as the size of the module. IS2 is the largest module on the site, consisting of 5 levels (6m was assumed as height of each level). Different fill fraction was modelled for the module, representing different flammable cloud size within the congested area.

The scenarios modelled are as follows:

Table 7-9: Explosion Results - Module IS2

FAILURE CASE	Flammable Volume (m ³)	Fill Fraction	Material	Explosion Overpressure Radii (m)			
				0.07 bar	0.14 bar	0.21 bar	0.35 bar
IS2 Module Explosion	18360	100%	Ethylene (stream 2205)	330	189	142	103
	9180	50%	Ethylene (stream 2205)	262	150	113	82
	5508	30%	Ethylene (stream 2205)	221	127	95	69
	2490*	14%	Ethylene (stream 2205)	170	97	73	53

* Volume based on largest 1/2 LFL dispersion for 5D wind and 23mm release.

The size of the congested volume was compared with the size of the flammable cloud that could be expected. The largest cloud size from a 23mm release at 5D wind was taken as the credible worst-case scenario for this section, as shown in Figure 7-11. For conservatism, the 1/2 LFL cloud size was used.

From the explosion overpressure result, the manned buildings, storage tanks and hydrogen area are outside of the 0.14 bar overpressure contour. Explosion from one module can however impact equipment and structure in other modules, causing escalation. Critical utilities such as the Flare KOD, Firewater pumps and tanks are within the 0.21 bar explosion overpressure contour, which could lead to impairment of these critical emergency equipment.

These equipment should be protected based on the design accidental load or relocated further from the process module. The manned buildings (i.e. control room and admin building) is impacted by approximately 0.10 bar explosion overpressure, which could cause windows breakage and damage to the building but not to a level that leads to its failure, causing fatality of operators within. Design of the buildings will need to consider the credible explosion load (i.e windows facing away from process area/ no windows and strengthening of the structure may be required).

The 0.07 bar and small section of the 0.14 bar explosion contour encroached offsite due to location of the module close to the plant boundary. Most of the other 23mm releases result in much smaller flammable cloud, hence the explosion contour is expected to be smaller however still possible to lead to escalation of adjacent modules.

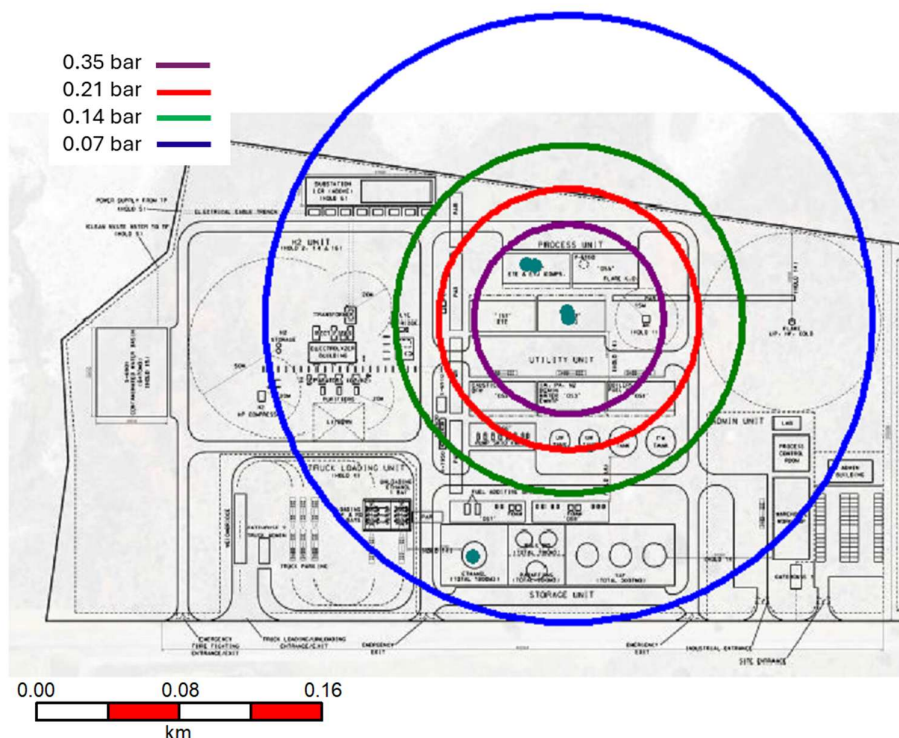


Figure 7-11: Explosion Overpressure from worst case 23mm release, 5D wind

7.3 Module IS3

This module consists of the compressors, guard bed packages, dryer package and also the refrigeration package. A variety of material is handled in the module, from ethanol, ethylene to propane. The operating pressures range from 3 bar to 26.4 bar.

7.3.1 Jet Fire Thermal radiation

A small (6mm) release in this module could result in jet fire ranging from 5m – 20m. Thermal radiation downwind distance to 37.5kW/m² and 100kW/m² was found to be up to 21m and 9m respectively. For majority of small releases, the maximum thermal radiation from the flame is less than 100 kW/m² (approximately 50 kW/m²) taking into consideration effects of the wind. However these releases could still cause impairment and escalation due to the long release duration. Larger jet fire is generally from liquid releases due to the higher mass release rate. Medium (23mm) releases could be over 66m and 33m in downwind distance to radiation levels

of 37.5kW/m^2 and 100kW/m^2 respectively as shown in Figure 7-12. Large and full-bore releases could lead to jet fire of over 240m in length.

As the basis for isolation is 10 minutes, most of the thermal radiation resulting from loss of containment event in this module could lead to impairment and subsequently escalation to neighbouring equipment and structures within the module and to adjacent modules (IS1, IS2 and OS5) due to the close proximity of equipment and module.

It should be noted that, the majority of the medium releases cannot be sustained more than 3 minutes after isolation, with the exception of some equipment with a large liquid inventory (i.e. Cation guard bed package and Ethylene Reflux Drum). For large and full-bore rupture, most of the releases cannot be sustained due to the limited inventory, particularly the compressors. The release will generally be driven by the upstream flowrate.

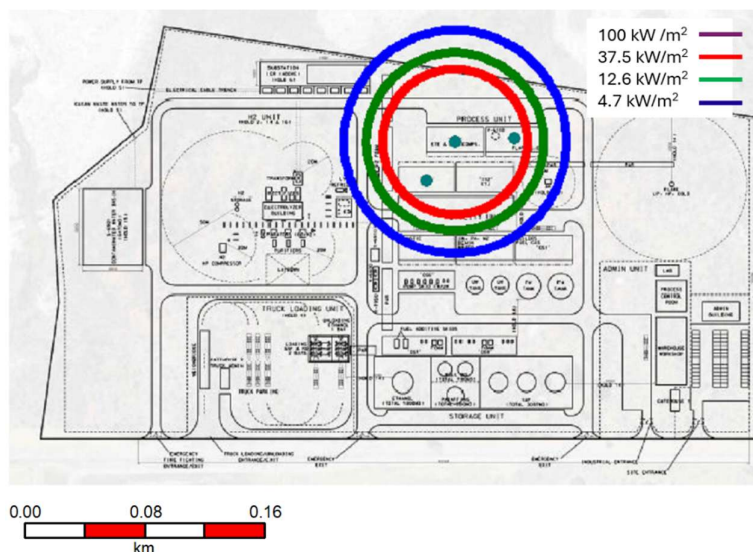


Figure 7-12: FC12 Jet fire Thermal Radiation 23mm release, 5D wind

The consequence results for the below failure cases, which represents the worst case jet fire scenario have been selected for illustration of the hazards present in the area:

- Ethanol FEED Guard Bed Package Z-1100 (FC01).
- Cation Guard Bed Package Z-1150 (FC12).
- Ethanol Product Guard Bed Package Z-1570 (FC43b).
- OLIG 1 HP Separator Gas Compressor Z-2280 (FC60).
- Anti Hydrate Ethanol Dryer Package Z-1450 (FC107).

Selected consequence results are presented in the following tables.

Table 7-10: Selected Jet Fire Results - Module IS3

FAILURE CASE	Hole size	Release rate (kg/s)	Release duration (mins)	Jet Fire thermal radiation Downwind (m) 5D wind			
				4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
FC01-Liquid	6mm	0.6	30.0	20	16	14	NR*
	23mm	8.8	11.5	50	40	34	NR*
FC12-Liquid	6mm	0.9	30.0	23	18	16	NR*
	23mm	13.0	30.0	74	59	48	NR*

FAILURE CASE	Hole size	Release rate (kg/s)	Release duration (mins)	Jet Fire thermal radiation Downwind (m) 5D wind			
				4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
FC43b-Vapour	6mm	0.2	30.0	8	7	6	5
	23mm	2.6	14.3	28	23	19	17
FC60- Vapour	6mm	0.14	24.3	5.4	4.9	3.1	NR*
	23mm	2	11.0	22.6	19.9	16.8	11.6
FC107-Liquid	6mm	1.2	20.5	25	20	17	NR*
	23mm	17.3	10.7	82	66	53	NR*

* No thermal radiation at this value expected

7.3.2 Pool Fire Thermal Radiation

Release from the Ethanol guard beds and dryer package could lead to formation of ethanol pool fire in the module.

Small (6mm) release could lead to pool fires approximately 6m in diameter while medium release (23mm) could be up to 28m in diameter for release from the Ethanol Dryer Package, as shown in Figure 7-13. It is highlighted that PHAST assumes release on a perfectly flat concrete surface with no obstacles, which tend to overestimate the size of the pool. Provision of bunding/kerbing within the module and drainage would limit the size of the pool formed and the resulting pool fire size. Coupled with active fire production, the thermal radiation from a pool fire should be confined within the module, preventing escalation to adjacent modules and offsite area.

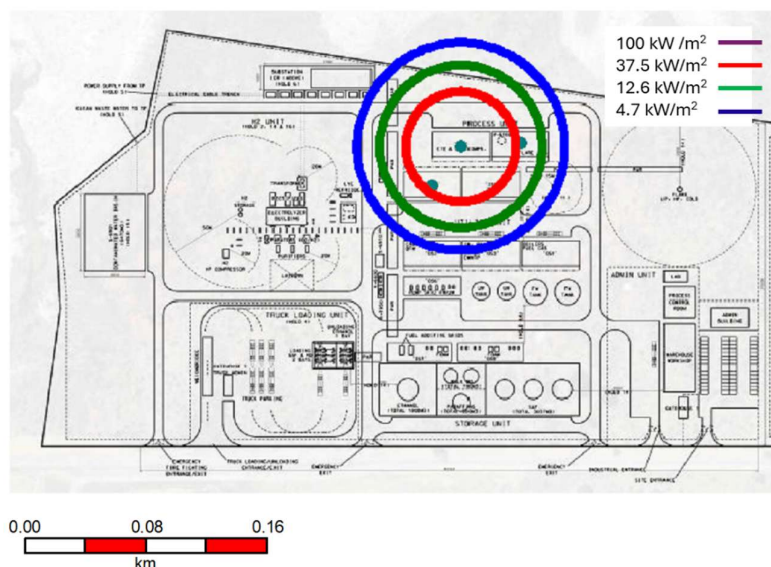


Figure 7-13: Pool fire Thermal Radiation from FC107, 5D wind, 23mm release

The consequence results for the below failure cases, which represents the worst-case pool fire scenario have been selected for illustration of the hazards present in the area:

- Ethanol FEED Guard Bed Package Z-1100 (FC01).
- Cation Guard Bed Package Z-1150 (FC12).
- Anti Hydrate Ethanol Dryer Package Z-1450 (FC107).

Selected consequence results are presented in the following tables.

Table 7-11: Selected Pool Fire Results - Module IS3

FAILURE CASE	Hole size	Release rate (kg/s)	Pool diameter (m)	Pool Fire thermal radiation Downwind (m) 5D wind			
				4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
FC01-Liquid	6mm	0.6	5	17	14	10	NR*
	23mm	8.8	21	47	35	21	NR*
FC12-Liquid	6mm	0.9	2	18	16	NR*	NR*
	23mm	13.0	24	59	45	30	NR*
FC107-Liquid	6mm	1.2	NR*	NR*	NR*	NR*	NR*
	23mm	17.3	27	69	54	36	NR*

* No pool fire/ thermal radiation expected

7.3.3 Flammable Dispersion

Flammable dispersion from the IS3 module from small releases (6mm) ranges from 3m to 11m for ½ LFL, to over 96m and 57m from a medium (23mm) release for ½ LFL and LFL respectively. The larger dispersion distances tend to be from liquid releases, as shown in Figure 7-14. The worst case dispersion was found to be from the refrigeration package, as the released propane vaporises upon release. The LFL and ½ cloud is mainly contained within the site.

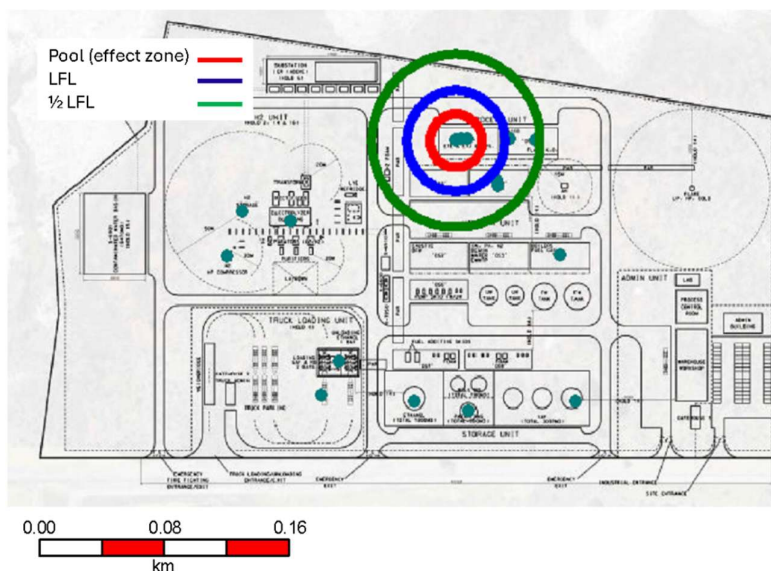


Figure 7-14: Flammable dispersion from FC145, 5D wind, 23mm release

Full-bore and large release could have downwind distance of over 900m. Some liquid releases would form a pool upon release and vaporization from the pool leads to flammable gas dispersion. Although release duration from large to full-bore release cannot be sustained, ignition of a flammable gas cloud could lead to immediate fatality of personnel. However leak frequency for large and full-bore releases are generally much lower.

The consequence results for the below failure cases, which represents the worst case flammable dispersion scenarios have been selected for illustration of the hazards present in the area:

- Ethylene Compressor Z-1400 package (FC30)

- Ethanol Product Guard Bed Package Z-1570 (FC43b).
- OLIG 1 HP Separator Gas Compressor Z-2280 (FC60).
- Anti Hydrate Ethanol Dryer Package Z-1450 (FC107).
- Refrigeration Package Z-3400 (FC145)

Selected consequence results are presented in the following tables.

Table 7-12: Selected Flammable Dispersion Results - Module IS3

FAILURE CASE	Hole size	Release rate (kg/s)	Flammable dispersion downwind distance (m)			
			2F		5D	
			1/2 LFL	LFL	1/2 LFL	LFL
FC30-Vapour	6mm	0.1	7	4	5	3
	23mm	2.2	57	24	43	16
FC43b-Vapour	6mm	0.2	10	5	6	4
	23mm	2.6	69	34	50	25
FC60- Vapour	6mm	0.14	7	4	5	3
	23mm	2	54	25	41	17
FC107-Liquid	6mm	1.2	10	7	11	7
	23mm	17.3	56	28	37	20
FC145-Liquid	6mm	0.3	6	5	7	5
	23mm	4.7	96	57	47	28

7.3.4 Explosion

The most reactive material in the IS3 module is ethylene (stream 1306 with highest % of ethylene) and was chosen to be the representative material for explosion modelling. The size of the congested area is taken as the size of the module with the height assumed to be 6m. Different fill fraction was modelled for the module, representing different flammable cloud size within the congested area.

The scenarios modelled are as follows:

Table 7-13: Explosion Results - Module IS3

FAILURE CASE	Flammable Volume (m³)	Fill Fraction	Material	Explosion Overpressure Radii (m)			
				0.07 bar	0.14 bar	0.21 bar	0.35 bar
IS3 Module Explosion	3672	100%	Ethylene (stream 1306)	193	111	83	60
	1836	50%	Ethylene (stream 1306)	153	88	66	48
	1101.6	30%	Ethylene (stream 1306)	129	74	56	40
	348*	9%	Ethylene (stream 1306)	88	50	38	27

* Volume based on largest ½ LFL dispersion for 5D wind and 23mm release.

The size of the congested volume was compared with the size of the flammable cloud that could be expected. The largest cloud size from a 23mm release at 5D wind was taken as the credible worst-case scenario for this section, as shown in Figure 7-15. For conservatism, the ½ LFL cloud size was used.

From the explosion overpressure result, the manned buildings, storage tanks and hydrogen area are outside of the 0.14 bar overpressure contour. Explosion from IS3 module can however impact equipment and structure in modules IS1 and IS2, causing escalation. The 0.07 bar contour encroached offsite due to location of the module close to the plant boundary.

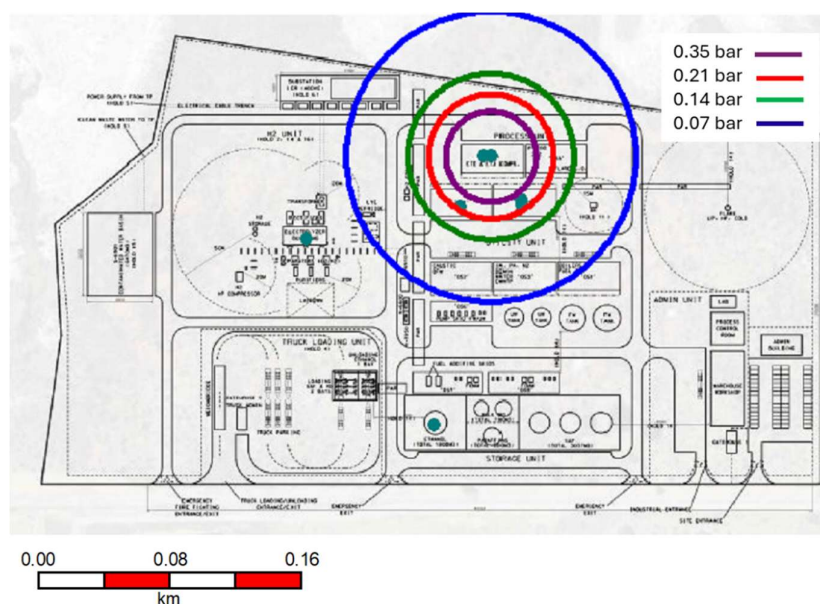


Figure 7-15: Explosion Overpressure from worst case 23mm release, 5D wind

7.3.5 Toxic

The only toxic expected from this module is from the Ethylene compressor package (FC30), due to carry over of Acetaldehyde from upstream. However the concentration in this stream is expected to be low (approximately 1 mol%). A medium release from this stream will result in 20m dispersion to AEGL-2 concentrations. Impact from thermal radiation is expected to dominate.

7.4 Module OS4

The main hazard from the hydrogen generation module is explosion overpressure, as hydrogen gas has the propensity for detonation. Scenarios considered in this module are:

- FC140 Electrolyser Package Z-4300 (including purification and separator).
- FC140A Hydrogen Compressor Z-4399.
- FC140B Hydrogen Storage V-47351/2.

Full consequence result is presented in Appendix D.

7.4.1 Thermal radiation

Jet fire from hydrogen release could occur within the electrolyser building, from the separation vessel located outside, the hydrogen storage tank and compressor. Worst case scenario is expected to be from the compressor and storage vessels due to the high operating pressure (120 barg). Due to the separation distance provided, the 100 kW/m² thermal radiation from the H₂ storage vessels was found to only encroach on the edge of the electrolyser building, as shown in Figure 7-16. Due to the inventory in the vessel, the jet fire would have sufficient

duration to impair the building. In addition the H₂ storage tanks, the O₂ and H₂ separators located outside the building could also impair the electrolyser building due to their close proximity. The jet fire length from the separators and purification unit is estimated to be approximately 14m at the estimated electrolyser operating pressure. Separation distance or fire protection could be provided to prevent escalation.

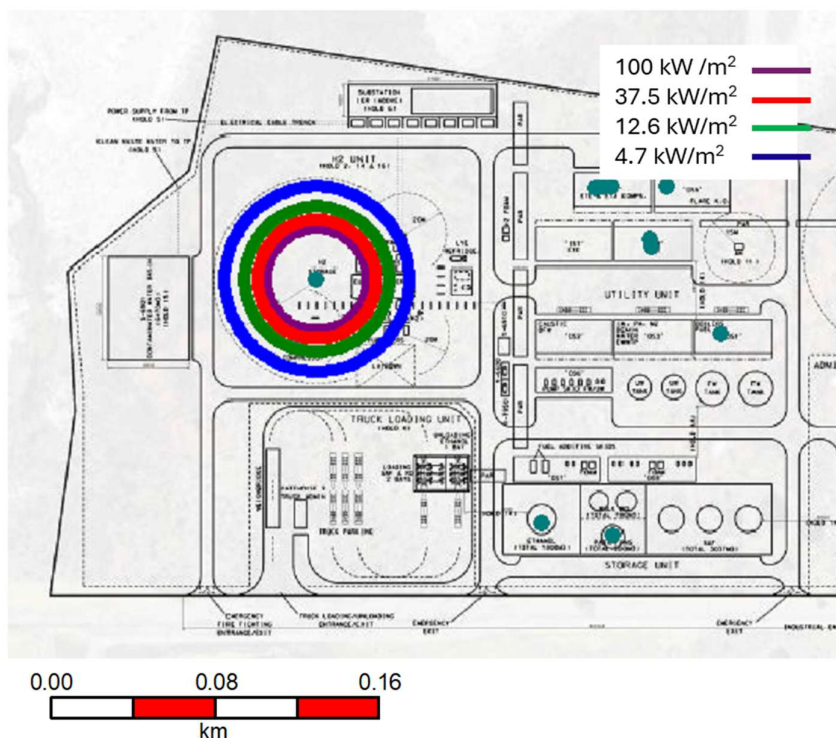


Figure 7-16: Jet Fire Thermal Radiation from F140B Hydrogen storage vessel 23mm release, 5D wind

The hydrogen compressor separation distance is sufficient such that 100 kW/m² thermal radiation from the jet fire would not impair critical equipment. In addition, inventory within the compressor is low, and the jet fire would subside once the compressor trips.

Table 7-14: Jet Fire Results - Module OS4

FAILURE CASE	Hole size	Release rate (kg/s)	Release duration (mins)	Jet Fire thermal radiation Downwind (m) 5D wind			
				4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
FC140-Vapour	6mm	0.05	19.9	7	5	5	4
	23mm	0.7	10.7	25	19	16	14
FC140A-Vapour	6mm	0.2	14.8	12	10	8	7
	23mm	2.5	10.3	43	34	28	24
FC140B-Vapour	6mm	0.2	>30.0	13	10	8	7
	23mm	2.7	>30.0	45	35	29	25

7.4.2 Explosion

Worst case explosion overpressure from the H₂ generation area is expected to be from the electrolyser building due to the congestion and confinement of the building. Although research

has shown that hydrogen gas does not necessarily need congestion to produce an explosion overpressure, the resulting maximum overpressure in the absence of congestion would be lower compared with explosion within a congested area. The H₂ compressors, typically housed in a shelter could also give rise to explosion overpressure, however the compressor shelter is much smaller compared with the electrolyser building.

Table 7-15: Explosion Results - Module OS4

FAILURE CASE	Flammable Volume (m ³)	Fill Fraction	Material	Explosion Overpressure Radii (m)			
				0.07 bar	0.14 bar	0.21 bar	0.35 bar
Electrolyser Building Module Explosion	1300	100%	Hydrogen	128	73	55	40
	650	50%	Hydrogen	102	58	44	32
	390	30%	Hydrogen	86	49	37	27

At 30% filled, the 0.21 bar explosion contour from the electrolyser building could impact the H₂ storage tanks, as shown in Figure 7-17 causing escalation. 30% fill was considered the credible explosion over pressure, as a 23mm leak could give rise of flammable cloud of nearly that volume. Sufficient ventilation within the electrolyser building is critical to prevent build-up of hydrogen gas and to dilute and hydrogen release swiftly to below the LFL, to minimise explosion.

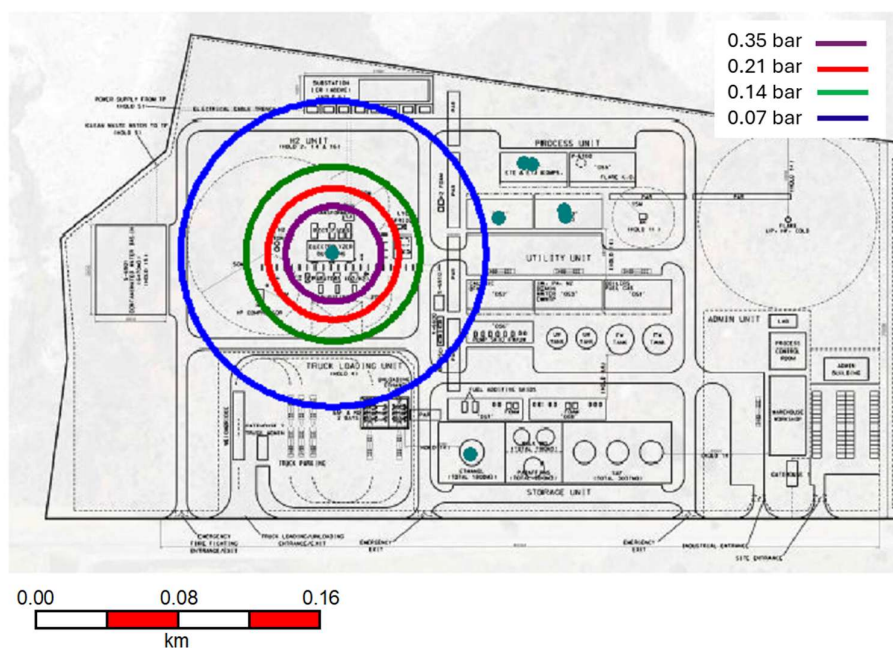


Figure 7-17: Explosion Overpressure from F140 Electrolyser building, 30% filled.

7.4.3 Flammable Dispersion

Flammable dispersion from the electrolyser stack would be contained within the building. Adequate ventilation is required to ensure releases are diluted to below the LFL. Flammable gas dispersion from the H₂ storage tank is contained within the module, and not found to impact the substation or tanker loading area, as shown in Figure 7-18.

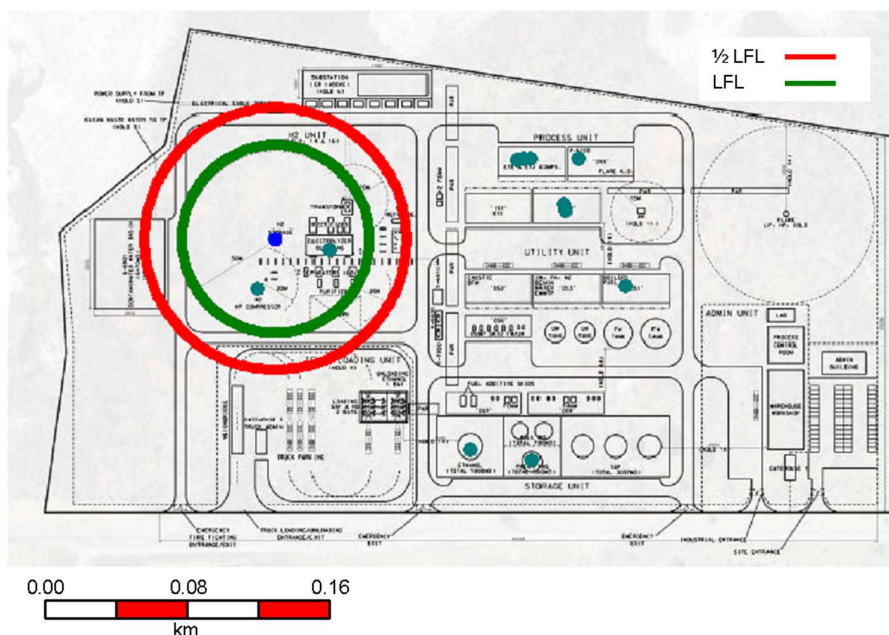


Figure 7-18: Hydrogen dispersion from F140B Hydrogen Storage Tank, 23mm release 5D wind.

Table 7-16: Flammable Dispersion Results - Module OS4

FAILURE CASE	Hole size	Release rate (kg/s)	Flammable dispersion downwind distance (m)			
			2F		5D	
			1/2 LFL	LFL	1/2 LFL	LFL
FC140-Vapour	6mm	0.05	11	6	8	5
	23mm	0.7	39	26	44	27
FC140A-Vapour	6mm	0.2	23	12	21	10
	23mm	2.5	60	44	71	51
FC140B-Vapour	6mm	0.2	24	13	23	10
	23mm	2.7	61	45	73	53

7.5 OSBL Module

7.5.1 Storage Tanks

Major hazard from the storage tank is pool fire in the event of leakage and ignition. Collapse of the roof and subsequent fire is also possible for internal floating roof tanks. However tank top fire is limited by the tank size and thermal radiation impact at ground level will be lower compared with fire in the bund. All of the tanks (i.e. Ethanol, SAF, Diesel, and Paraffin) are situated within bunds, sized sufficiently for the inventory (minimum 110%). For small and medium release, if the released material is ignited instantly, the pool fire formed is a balance between the mass release rate and the rate of vaporisation and burning. The resulting pool fire could be smaller than the bund size. For larger releases or when ignition is delayed, the pool formed generally fills the bund, limiting the pool size. Thermal radiation effects however could extend outside of the bund.

Figure 7-19 shows the thermal radiation from ethanol pool fire when the bund is full of liquid. The 4.7 kW/m² thermal radiation was found to encroached slightly offsite and towards the

tanker loading area. The offsite area impacted by the thermal radiation is the site access road (dead-end), hence public access is limited.

Provision of active fire protection can reduce the thermal radiation contour from bund fires and prevent escalation to neighbouring tanks.

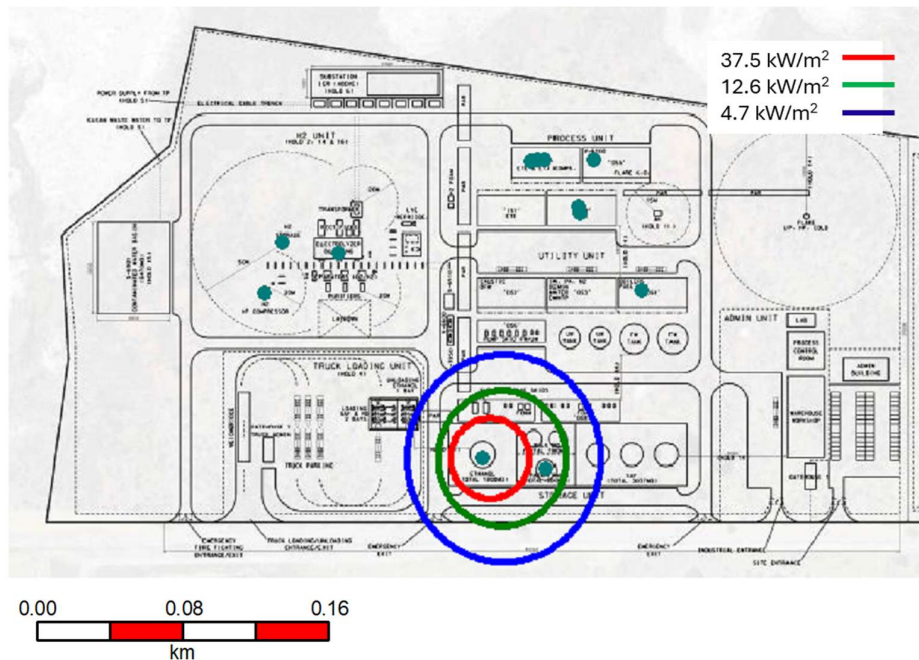


Figure 7-19: Ethanol Storage Tank bund fire, 5D wind.

Pool fire from the SAF tank is shown in Figure 7-20. Similarly to the Ethanol tank, due to the proximity to the site boundary, the 4.7 kW/m² thermal radiation was found to encroached slightly offsite. No thermal radiation impact to the manned buildings was found.

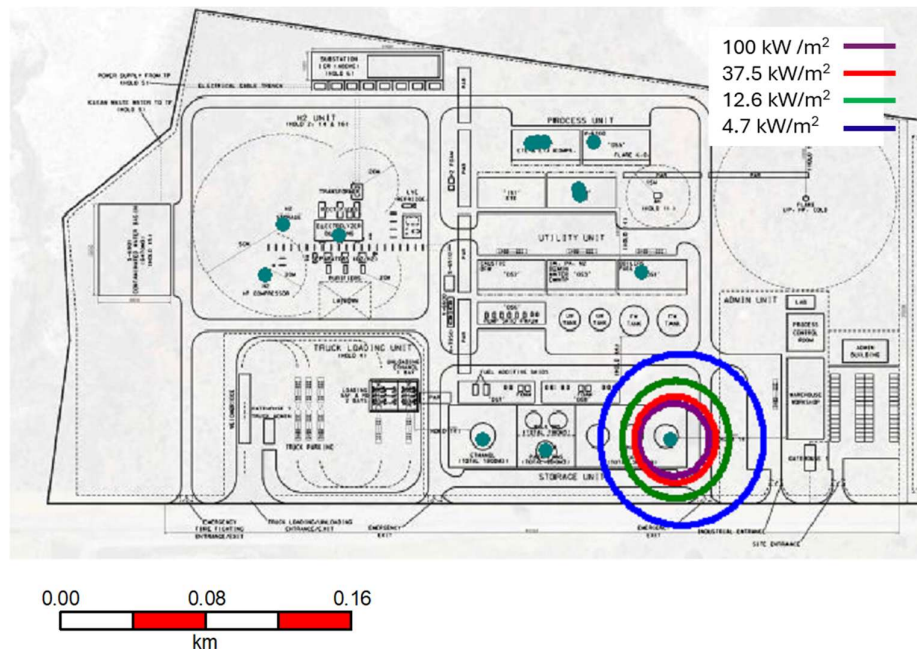


Figure 7-20: SAF Storage Tank bund fire, 5D wind

Tanks consequence results are presented in the following table.

Table 7-17: Selected Pool Fire Results - Tanks

FAILURE CASE	Hole size	Pool diameter (m)	Pool Fire thermal radiation Downwind (m) 5D wind			
			4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
FC132-Liquid	Bund fire	34	64	46	25	NR*
FC141-Liquid	Bund fire	36	51	33	24	21
FC143-Liquid	Bund fire	23	38	21	15	13
FC151-Liquid	Bund fire	23	39	23	16	13

* Thermal radiation < 100kW/m².

7.5.2 Tanker Loading

Tanker loading module consist of hazards arising from the tanker loading system, and the tankers, which can hold up to 74.5 m³ of inventory. Release of SAF was modelled as the representative material within this module.

Main hazard in this area is pool fire from ignition of leakages. For the tanker loading module, the inventory is limited, and the flow is driven by the pumping rate from the tank. The flow will quickly subside once the pump trips. The resulting pool fire impact is limited to within this module, as shown in Figure 7-21.

Release from the tanker (i.e. due to hose rupture, etc) would result in a larger pool fire, if the tanker is full of liquid. Provision of kerbing at the tanker loading area would limit the spread of the pool and the resulting fire size, preventing escalation to other tankers that could be in the area at the same time.

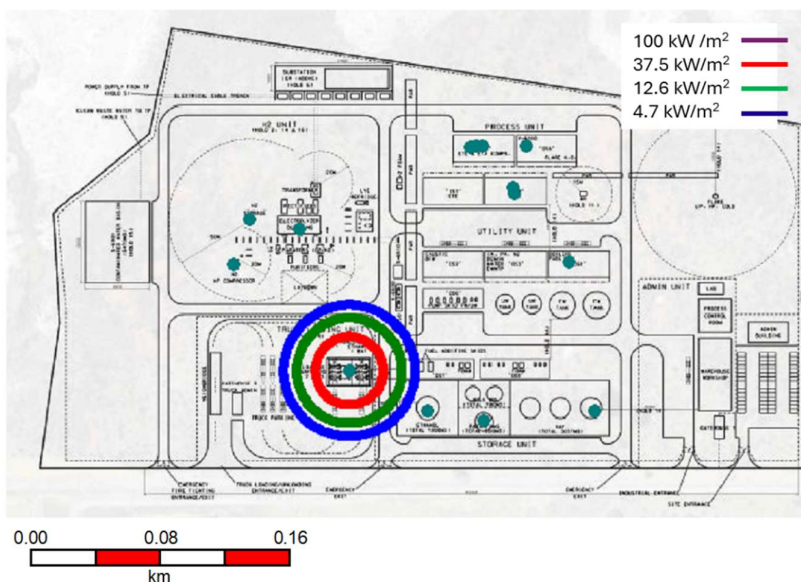


Figure 7-21: Tanker Loading module pool fire, 5D wind

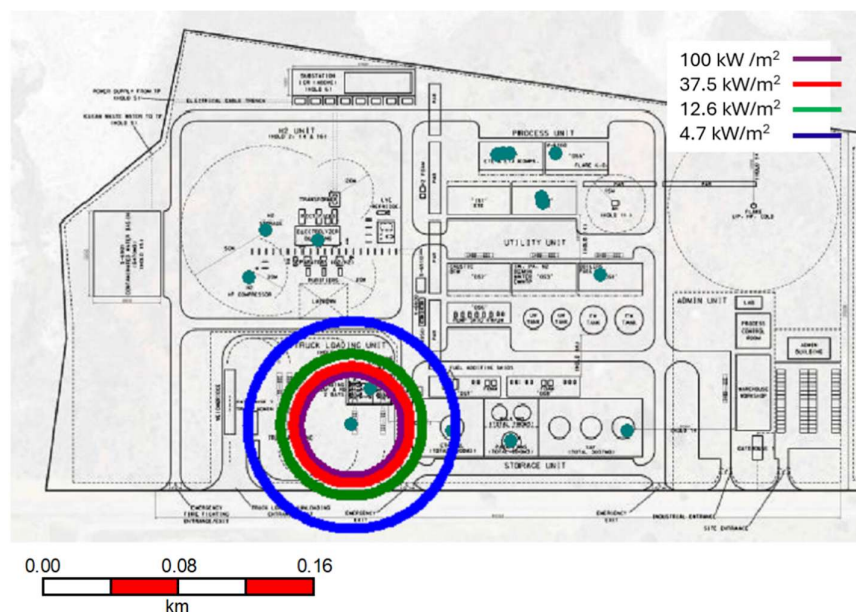


Figure 7-22: Tanker pool fire, 5D wind

7.5.3 OS5 Module

The OS5 module contains the following equipment:

- Liquid Hydrocarbon Storage Vessel V-4250.
- Olefins Processing Vessel V-6100.
- Flare gas recovery system Z-7450.
- LPG Storage Tank T-7500 (location subject to change based on layout study).

The Olefins Processing Vessel V-6100A/B (FC150) is located within the OSBL area and could hold a significant liquid inventory. A large leak from this vessel could result in a large pool fire if the vessel is full as shown in Figure 7-23, potentially causing escalation of other vessels in this module. However during normal operations, the vessel will be close to empty (off-spec vessels) and as such liquid inventory is small until abnormal operation.

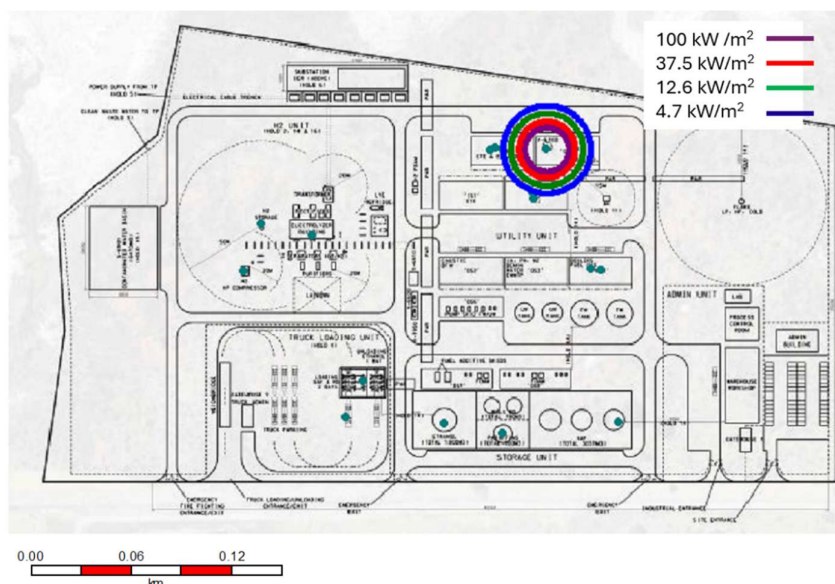


Figure 7-23: FC150 pool fire, 23mm release, 5D wind

The Liquid Hydrocarbon Storage Vessel could give rise to pool fire and also toxic dispersion due to presence of Acetaldehyde. Jet fire from this vessel is not expected to be sustained for long due to the low operating pressure. Similarly to the Olefins vessel, a leak from the Liquid Hydrocarbon Storage Vessel could result in a large pool fire. Vaporization from this pool could give rise to flammable and toxic cloud. For medium release (23mm), the toxic downwind distance to 340ppm of Acetaldehyde could reach 97m and 75m for 2F and 5D wind respectively and could impact offsite areas due to the proximity to the North Boundary. Bunding and drainage to reduce the size of pool formed would reduce the vaporisation rate and limit size of the toxic cloud.

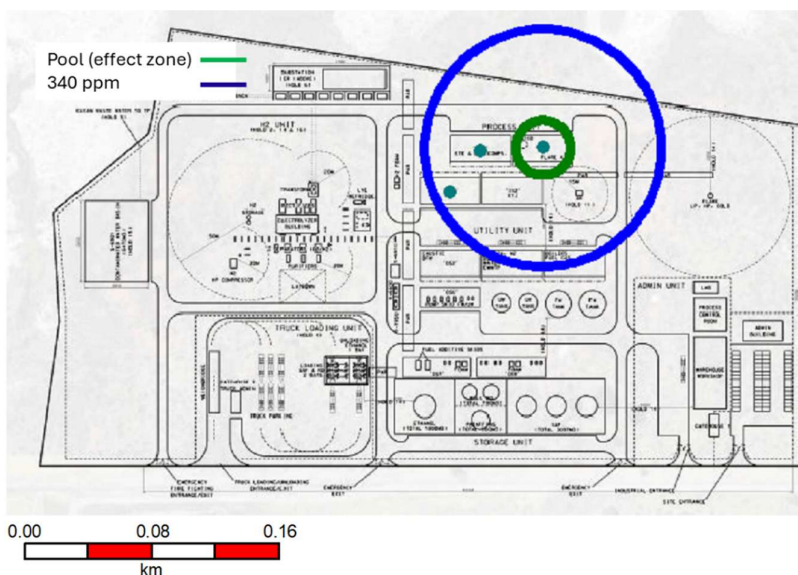


Figure 7-24: FC138 Toxic Dispersion, 23mm release, 5D wind

The consequence modelling associated with the Flare Gas Recovery System (FC160) was performed. For the purpose of this assessment it was assumed that the flare gas consists of ethylene. Medium release (23mm) from the flare gas recovery system could lead to jet fire of

over 10m. However inventory within the package is expected to be low, and the release in the event of loss of containment will be driven by the flow from upstream, which is expected to result in a lower release rate.

The LPG tank will also be located within this module. LPG tanks will be delivered by supply trucks, and generally contain standard safety devices based on regulatory requirement. Most likely failure scenario of the LPG tank is due to fire escalation, whereby the tank could BLEVE. This is assessed in Section 7.6.

Fuel gas will be used to pressurize the Flare KO drums to a low pressure (0.1-0.2 barg) with pressure control. Releases at such low pressure are not considered in the assessment as it is unlikely to result in hazardous effects. Release at upset conditions are usually not included in this type of assessment because it would only occur during site blowdown indicative of an event elsewhere. Thus such events are generally considered double jeopardy and excluded.

7.5.4 OS1 Module

Boiler explosion could occur either due to explosion of a fuel-gas mix (i.e. due to inadequate purging) or overpressure due to excessive steam generation (i.e. blockage of steam discharge or sudden introduction of water to the hot fired tubes). Boiler explosions could lead to overpressure which have the potential to damage structures in the immediate area including the adjacent firewater tanks and utility areas (i.e. the nitrogen unit, fuel gas KOD) [9].

Due to the relatively low operating pressure, release from the fuel gas KOD will lead to jet fire less than 10m in length.

However, boiler explosions generally have low probability if the boiler is built to code and maintained as required, hence potential for escalation event is deemed low.

7.6 Escalation events

As discussed previously, there are a number of fire events that could lead to sustained effects beyond the generally accepted survival times of equipment/ structural elements. This could lead to secondary event which may be more destructive compared with the primary event. Because of the difficulty to represent all possible escalation scenarios, some representative escalation events were identified to be studied further. The following escalation have been modelled:

- LPG tank BLEVE.
- Hydrogen tank catastrophic rupture.
- IS2 module escalation (Olig 1 HP Separator BLEVE).
- IS1 module escalation (Ethylene Refinement Column Reflux Drum BLEVE).
- IS3 module escalation (Refrigeration Package Z-3400).

As discussed in Section 7.5.3, The LPG tank if engulfed by fire arising from loss of containment of adjacent vessels could heat up, causing the liquid propane to vaporise, increasing the pressure within the tank rapidly causing failure. This phenomenon is called Boiling Liquid Expanding Vapour Explosion. The resulting explosion overpressure as presented in Figure 7-25, has a large impact and could cause damage to neighbouring modules. Based on previous assessment, the LPG storage tank at its current location could be impacted by fire scenarios arising from modules IS3 and IS2 due to the small separation distance. The risk of LPG tanks failure from fire scenarios will need to be evaluated and alternative location identified if required.

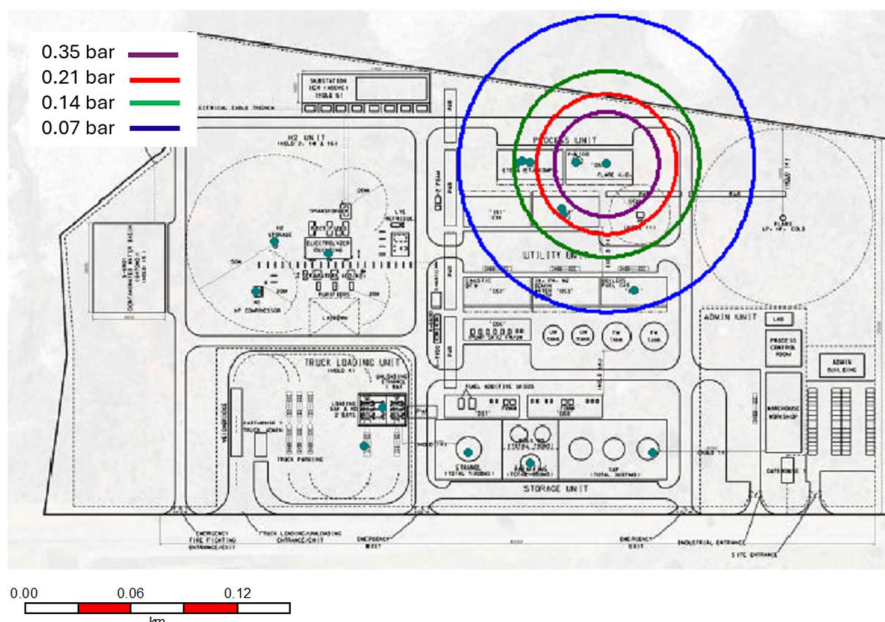


Figure 7-25: LPG Tank BLEVE

Similarly to the LPG tank, the Refrigeration Package with Propane inventory could also BLEVE if engulfed by fire. The resulting explosion overpressure is smaller compared with the LPG Tank due to the smaller inventory.

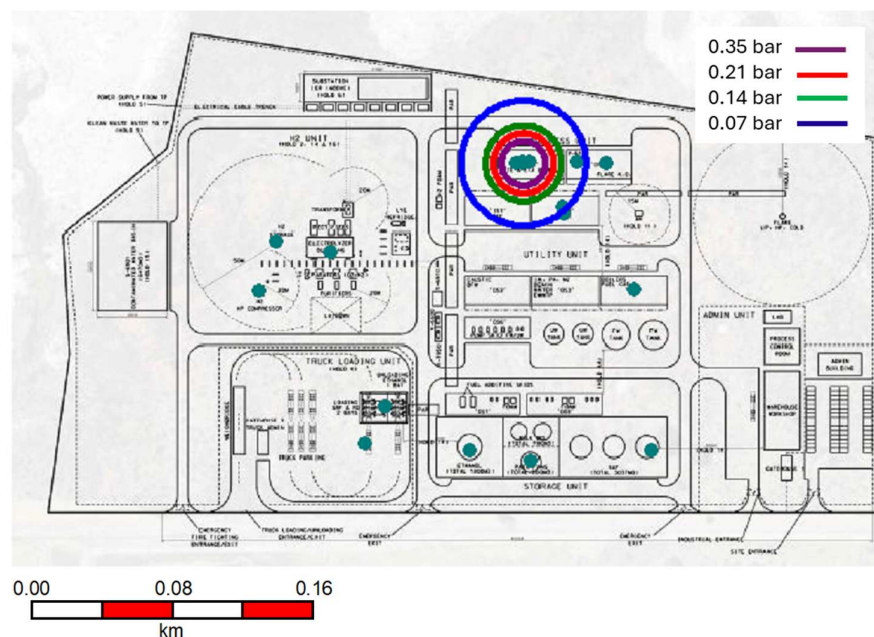


Figure 7-26: Refrigeration Package Z-3400 BLEVE

Damage to the hydrogen tank due to fire impingement, missiles from explosion or internal explosion could cause catastrophic failure of the tank. The resulting explosion and fireball could impact the equipment within the module. Due to the large separation distance, impact to other modules and the storage tank is not found.

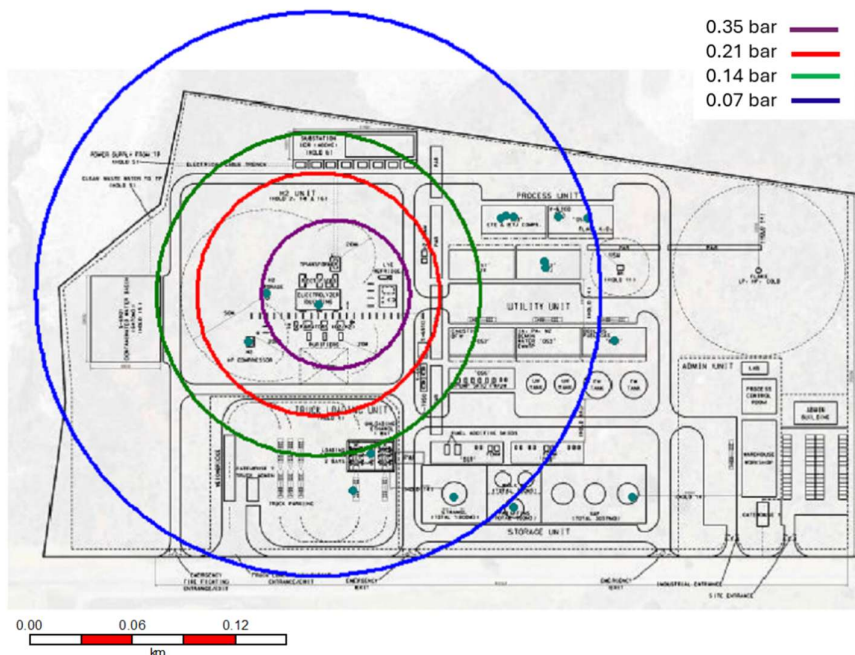


Figure 7-27: Hydrogen Storage Tank Catastrophic Rupture

A representative escalation scenario was modelled for module IS2 (ETJ). BLEVE of one of the vessels in this module (FC61) could lead to explosion overpressure over 30m away, causing further escalations within the module.

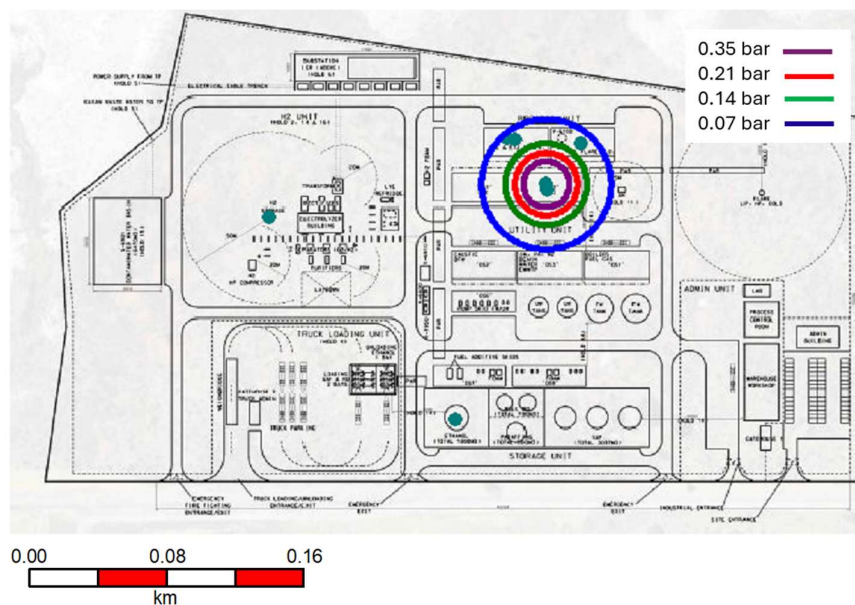


Figure 7-28: Olig 1 HP Separator BLEVE

Another representative escalation scenario was also modelled for module IS1 Module. A BLEVE of the Ethylene Refinement Column Reflux Drum (FC41) could lead to explosion overpressure over 50m away, leading to further escalations within the module and adjacent process modules.

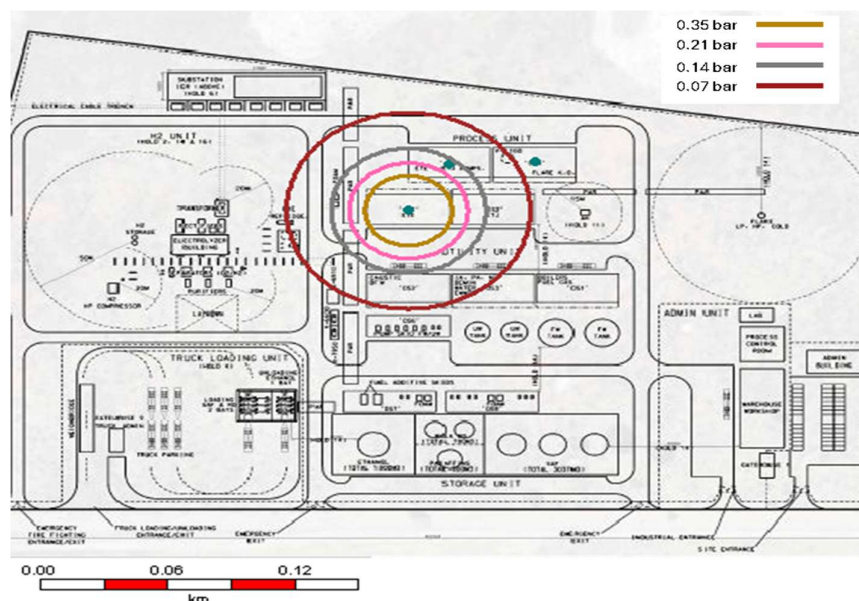


Figure 7-29: Ethylene Refinement Column Reflux Drum BLEVE

Escalation and BLEVEs can be prevented by separation distance between equipment or provision of passive fire protection if separation distance is not possible. Bunding and drainage provision for vessels containing large inventory of liquid could prevent accumulation of flammable pool under equipment. Active fire protection could also provide cooling, preventing vessel failure and BLEVEs.

The scenarios modelled are as follows:

Table 7-18: Escalation Results

FAILURE CASE	Event	Material	Explosion Overpressure Radii (m)			
			0.07 bar	0.14 bar	0.21 bar	0.35 bar
Domino_1	LPG Tank T-7500 BLEVE	Propane	83	52	39	29
Domino_2	Hydrogen Storage Tank V-4351/2 Catastrophic Rupture	Hydrogen	129	85	67	49
Domino_3	IS1 module escalation (Ethylene Refinement Column Reflux Drum) BLEVE	Stream 1503 (100% Ethylene)	56	36	27	20
Domino_4	IS2 module escalation (Olig 1 HP Separator) BLEVE	Stream 2203	38	24	18	13
Domino_5	IS3 module escalation (Refrigeration Package Z-3400) BLEVE	Propane	35	21	17	12

8.0 CONCLUSION AND RECOMMENDATIONS

8.1 Conclusions

Effects from loss of containment from the Ulysses ATJ facilities have been assessed for thermal radiation, flammable cloud dispersion, toxic dispersion and explosion. Potential escalatory hazards (domino effects) were also assessed. The 23mm release was used to represent the credible consequence case, as typically leak frequency for small to medium hole sizes has higher leak frequency. The main findings are as follows:

- Major hazards of this facility were found to be from the ETE (IS1) and ETJ (IS2) modules. These modules are 4-5 storeys high and contain large amount of process equipment within a small space and a high level of congestion. The separation distance between IS1 and IS2 is minimal, approximately 1m. The separation distance between IS1/2 and IS3 is approximately 10m. Consequence events have taken into account the location and elevation of the equipment, with jet fires based on horizontal non-impinged releases to account for greatest hazardous distance potential.
- Thermal radiation from 23mm release at 4 kW/m² from the ETE (IS1) and ETJ (IS2) modules was found to be contained within the site, with no encroachment to offsite areas and manned buildings at ground level.
- Fire and toxic events from small and medium process loss of containment events were not found to impact the manned buildings towards the east of the facility. The manned buildings (i.e. control room and admin building) can be impacted by approximately 0.10 bar explosion overpressure, which could cause windows breakage and damage to the building but not to a level that leads to its failure, causing fatality of operators within. Design of the buildings will need to consider the credible explosion load (i.e. windows facing away from process area/ no windows and strengthening of the structure may be required).
- Several escalation events were also considered in this assessment. Events such as BLEVE of the LPG tank and catastrophic rupture of the hydrogen storage tanks could lead to explosion overpressure that could have a larger impact compared to the primary event. Escalation events can be minimised with separation distance, provision of active fire protection and inventory reduction.
- The boiler on Ulysses facility is located away from manned buildings and critical process equipment, however boiler explosion could impair the firewater tanks and utilities located at adjacent modules. Boiler explosions generally have low probability if the boiler is built to code and maintained as required.
- The basis of this study is manual isolation (assumed to take 10 minutes), meaning that if ignited, all releases (from 6mm to FB ruptures) have the potential to cause escalation and secondary failures prior to isolation occurring, exceeding the duration for equipment and structural failures.
- The following consequence events exceed the offsite criteria:
 - Credible VCE from the ETE and ETJ modules were modelled based on the largest flammable dispersion cloud for a 23mm release. For both the modules, the credible VCE event is largely contained onsite. 0.07 bar overpressure contour from both modules and small section of 0.14 bar contour from ETJ module and was found to encroach to offsite areas. At these overpressure, fatality of personnel outdoors is expected to be minimum. In addition, the offsite area is expected to be very infrequently accessed.

- Loss of containment events from the IS3 module could lead to offsite thermal radiation from jet fire and pool fire events due to location of the module close to the site boundary. Although the IS3 module is much smaller compared to the ETE and ETJ module, the credible VCE event was found to lead to offsite impact from the 0.07 bar explosion contour.
- Release from the tanker loading system and leak from a tanker was considered for the Tanker Loading module. For the tanker loading module, the inventory is limited, and the flow will quickly subside once the pump trips. Release from the tanker (i.e. due to hose rupture, etc) would result in a larger pool fire with thermal radiation 12.6 kW/m² and below that could extend offsite. This can be minimised with provision of bunding and drainage.
- Main hazards arising from the storage tanks is leakage leading to pool fire in the bund. The resulting pool fire could be smaller than the bund size. For larger releases or when ignition is delayed, the pool formed generally fills the bund, limiting the pool size. Thermal radiation effects however could extend outside of the bund and was found to extend offsite for the 4.7 kW/m² thermal radiation contour due to the proximity of the tanks to the South boundary of the facility (i.e. plant access road). Provision of active fire protection can reduce the thermal radiation contour from bund fires, preventing impact to offsite public and escalation to neighbouring tanks.
- Release from vessels within the OS5 module would mainly lead to pool fire hazards. The Liquid Hydrocarbon Storage Vessel could give rise to pool fire and also toxic dispersion (97m for 23mm release) due to presence of Acetaldehyde which could impact offsite areas. Provision of bunding and drainage for vessel containing liquid inventory would limit the pool formed and reduce the vaporisation rate and size of the toxic cloud.
- The following consequence events have the potential for the domino effects to neighbouring modules:
 - Jet fire from a medium release from IS1, IS2 and IS3 modules could reach over 33m downwind distance while large and full-bore releases could lead to jet fires of over 100m in downwind distance to radiation levels of 100kW/m². As the basis for isolation is 10 minutes, most of the thermal radiation resulting from loss of containment event could lead to impairment and subsequently escalation to neighbouring equipment and structures within the module and to adjacent modules due to the close proximity of equipment in ISBL. Hence rapid detection and isolation is key to minimise escalation events, particularly for the modules whereby separation distance is difficult to achieve, as the release for medium, large and full-bore ruptures would typically deplete quickly after isolation.
 - The 0.35 bar and 0.21 bar explosion overpressure arising from explosion within IS1, IS2 and IS3 modules could impact neighbouring modules and extend to the utilities area. 0.21 bar explosion overpressure arising from the IS2 module could impact critical emergency equipment (i.e. flare KOD, firewater tanks and Firewater Pumps leading to escalation. However, the manned buildings, storage tanks and the hydrogen generation module are outside of the 0.14 bar overpressure contour.

- The following consequence events have the potential for domino effects within the same module:
 - Jet fire from a small release from modules could reach up to 10m downwind distance to 100 kW/m² thermal radiation, potentially causing escalation events to equipment and structure within the module. For majority of small releases, the maximum thermal radiation from the flame is less than 100 kW/m² (approximately 50 kW/m²) taking into consideration effects of the wind. However, these releases could still cause impairment and escalation due to the long release duration.
 - Liquid releases (i.e. from the IS1, IS2 and OS5) modules could form a pool upon release and subsequently lead to pool fires when ignited. The pool formation has assumed no bunding provision within the module. Provision of bunding/kerbing within the module and drainage would limit the size of the pool formed and the resulting pool fire size. Coupled with active fire production, the thermal radiation from a pool fire should be confined within the module, preventing escalation to adjacent modules. However critical equipment and structures above the pool fire source will likely require PFP to prevent escalation.
 - The major hazard arising from the hydrogen module is explosion overpressure as hydrogen has the propensity for detonation. Worst case explosion overpressure from the H₂ generation area is expected to be from the electrolyser building due to the congestion and confinement of the building. The 0.21 bar explosion contour from the electrolyser building could impact the H₂ storage tanks and the H₂ separation and purification skids located within the module. Due to the large separation distance provided in the OS4 module, thermal radiation from jet fire and flammable dispersion was found to be confined within the module.

Sensitive areas of interest include:

- Manned Buildings (CCR, workshop).
- Muster Areas (within CCR, Admin Building).
- Substation.
- Flare KOD.
- North Plant Boundary.
- South Plant Boundary.
- Storage Tanks.
- H₂ Storage.
- Firewater System.
- Nitrogen Unit (used for purging of reactor during emergency depressurisation).

The table below presents the failure cases that were assessed to cause impairment/escalation to the sensitive areas. The recommended separation distances (based on credible scenario from 23mm release, 5D wind) between the sensitive area and the failure case location are based on the greatest hazardous extent of the failure cases listed in the below table. It should be noted that large and full-bore ruptures will also

exceed offsite and lead to escalation since isolation is considered to take 10 minutes, however these events tend to have lower frequencies.

Table 8-1: Recommended Separation Distances

SENSITIVE AREAS	Failure Cases causing Impairment	Recommended Separation Distance (m)
Manned Buildings(CCR, Workshop)	Explosion overpressure < 0.14 bar	-
Muster Areas	Explosion overpressure < 0.14 bar	-
Flare KOD	FC57 Jet Fire (IS2) FC61 Jet Fire (IS2) FC71 Jet Fire (IS2) FC74 Jet Fire (IS2) FC89 Jet Fire (IS2) FC95 Jet Fire (IS2) FC96 Jet Fire (IS2) FC102 Jet Fire (IS2) IS2 Module Explosion IS3 Module Explosion	38m and 73m based on 0.21 bar explosion from IS3 and IS2 respectively.
North Boundary	FC33 Jet Fire (IS1) FC52 Jet Fire (IS1) IS1 Module Explosion	75m and 130m (IS1 Module Explosion) based on 0.14bar and 0.07bar respectively*
	FC54 Jet Fire (IS2) FC61 Jet Fire (IS2) FC89 Jet Fire (IS2) FC95 Jet Fire (IS2) FC96 Jet Fire (IS2) FC102 Jet Fire (IS2) IS2 Module Explosion	100m and 170m (IS2 Module Explosion) based on 0.14bar and 0.07bar respectively*
	FC01 Jet Fire, Pool Fire (IS3) FC12 Jet Fire, Pool Fire (IS3) FC107 Jet Fire, Pool Fire (IS3) IS3 Module Explosion	82m (FC107 Jet Fire) based 4.7kW/m2 respectively** 90m (IS3 Module Explosion) based 0.07bar respectively*
	FC138 Pool Fire, Toxic Release (OS5) FC150 Jet Fire (OS5)	75m (FC138 Toxic Release)
South Boundary	Ethanol Storage Tank (Pool Fire)	65m and 46m (based on 4.7kW/m2 and 12.7kW/m2 respectively*)
	SAF Storage Tank (Pool Fire)	51m and 33m (based on 4.7kW/m2 and 12.7kW/m2 respectively*)
	Tanker (Pool Fire)	61m and 42m (Based on 4.7kW/m2 and 12.7kW/m2 respectively**)
	Paraffins Storage Tank (Pool Fire)	30m (Based on 4.7kW/m2**)

SENSITIVE AREAS	Failure Cases causing Impairment	Recommended Separation Distance (m)
Storage Tanks	Ethanol Storage Bund (Pool Fire)	25m between neighbouring tanks
	SAF Storage Bund (Pool Fire)	25m between neighbouring tanks
	Diesel Storage Bund (Pool Fire)	15m between neighbouring tanks
	Paraffins Storage Bund (Pool Fire)	16m between neighbouring tanks
H2 Storage	F140 Electrolyser Building (Explosion)	40m based on 0.21 bar overpressure from Electrolyser Building
Firewater System (tank and pumps)	IS2 Module Explosion OS1 Boiler Explosion	75m based on 0.21 bar overpressure from IS2 Module Explosion
Nitrogen Unit	FC61 Jet Fire (IS2) FC74 Jet Fire (IS2) FC95 Jet Fire (IS2) IS1 Module Explosion IS2 Module Explosion	54m and 73m based on 0.21 bar explosion from IS1 and IS2 respectively.

*Queensland thermal radiation criteria of 4.7kW/m² outside facility boundary, except for industrial land use 12.7kW/m² limit.

** Queensland overpressure criteria of 0.07bar outside facility boundary, except for industrial land use 0.14bar limit.

8.2 Recommendations

The following recommendations are raised to reduce the escalation risk within the facility and to the public:

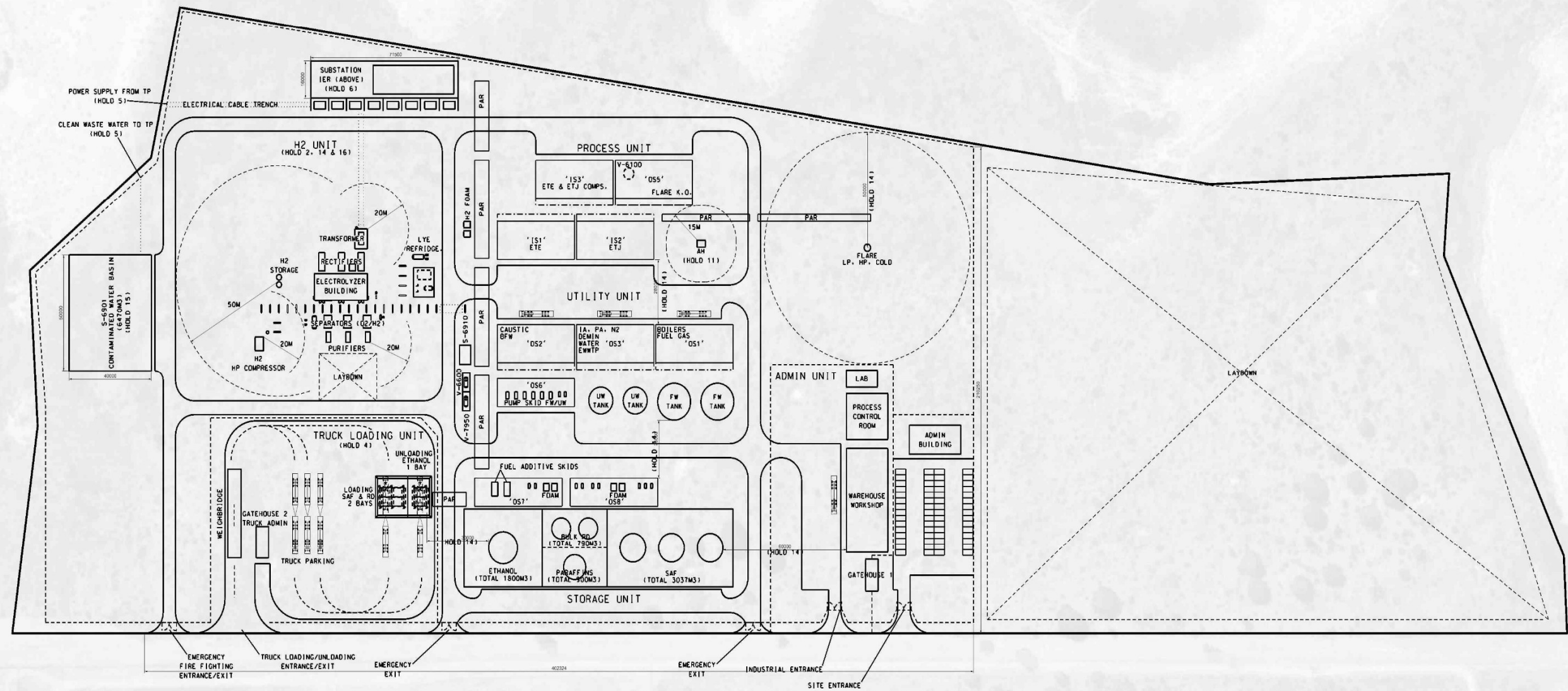
- The basis of this study is manual isolation (assumed to take 10 minutes), meaning that if ignited, most releases could have the potential to cause escalation due to the modular design of the plant. Modularisation of plants tend to have a greater safety cost due to greater congestion which increases the risk of escalation and explosions. Rapid detection and isolation (i.e. with automatic isolation and blowdown upon confirmed detection) would reduce the duration of release, such that escalation is less likely to happen. Provision of automatic shutdown would be most beneficial for the IS1, IS2 and IS3 modules whereby there are large number of process equipment with limited separation distances.
- It should be noted that even small releases can impair adjacent modules due to limited separation between modules. Acceptability of escalations due to jet/pool fires and explosions between modules should be considered and recommended for separation distances to be reviewed based on COMPANY escalation acceptance criteria.
- Most large and full-bore releases are anticipated to exceed offsite and lead to escalation, it is recommended to evaluate frequencies of these releases in future QRA studies to ensure the risk to offsite is acceptable.
- Explosion with the IS1, IS2 and IS3 modules could give rise to large explosion overpressure. Equipment containing significant ethylene and hydrogen inventory that can give rise to large explosive cloud (e.g. Hydrogenation HP Separator, hydrogenation reactor, ethylene separation and refinement columns) should be located whereby the ventilation is maximised to disperse any released flammable vapour (i.e. edge of module, at the top elevation) or be sited outside of the module in a more open location to reduce the resulting explosion overpressure.

- Computational Fluid Dynamics (CFD) explosion analysis is recommended during FEED design phase for more accurate explosion overpressure prediction due to the high confinement and congestion within the IS1, IS2, IS3 modules and electrolyser building.
- Suitable containment and drainage should be provided for process vessels containing large amounts of liquid inventory and at the tanker loading area to limit the spread of any liquid release and the resulting pool fire.
- Required fire and explosion design accidental loads should be evaluated during FEED design phase to evaluate passive fire/blast protection for critical process/ emergency equipment and structure to avoid catastrophic escalation events.
- Provision of active fire protection for the storage tanks and other critical process vessel containing significant quantities of flammable liquid inventory could provide cooling, reducing likelihood of escalation.
- Critical utilities required during emergency such as the firewater system, flare KOD, nitrogen unit should be located in a safe area, preferably upwind from process releases and protected from fire and explosion hazards. In addition, critical process equipment that could lead to catastrophic escalation events (i.e. Hydrogen Storage Tank, LPG tank) should be located away/ protected from process hazards.
- Although the manned buildings were found to be outside the 0.14 bar explosion overpressure threshold, the buildings could still be subjected to explosion overpressure of around 0.1 bar. Design of the buildings will need to consider the credible explosion load (i.e windows facing away from process area/ no windows and strengthening of the structure may be required). Risk to operators working within the facility and offsite personnel should be evaluated to ensure the risk is acceptable.
- The following conservative assumptions have been considered in this study and are recommended to accounted for in future updates to this study and QRA development in order to reduce the level of conservatism:
 - It was assumed that no bunding is provided to contain pool fires in the process modules.
 - The module size and height has been estimated for explosion modelling.
 - The location of the equipment in the module has not been rationalised and assumed in the centre of the module.
 - Equipment and piping volume is an estimate based on the preliminary equipment list sizing. Where equipment sizing is not available, assumption is made based on previous project experience.
 - Isolatable sections are based on equipment as the provision of ESDV is not finalised at the time of the modelling.

9.0 REFERENCES

- [1] “217530C-000-RT-0009 FEA Study Basis”.
- [2] 2811007-PI-PLA-00001 *Conceptual Plot Plan*.
- [3] “28011007-PR-SCH-00001 HEAT AND MATERIAL BALANCE ETHANOL TO ETHYLENE (ETE) START OF LIFE (SOL)”.
- [4] “28011007-PR-SCH-00004 HEAT AND MASS BALANCE ETJ MAXIMUM MAXIMUM JET MODE - START OF RUN (SOR)”.
- [5] Workplace Health and Safety Queensland, “Planning guideline State Code 21: Hazardous chemical facilities”.
- [6] “202947C-000-RT-1990-00004 Dragon Integrated FEED Assumption Register”.
- [7] “<https://www.epa.gov/aegl/acetdehyde-results-aegl-program>,” [Online].
- [8] “<https://www.epa.gov/aegl/acetonitrile-results-aegl-program>,” [Online].
- [9] S. C. & M. L. S. E. A. C. B. B. P. B. T. 4. Gaynor Woodford-Phillips, “Is there a bomb in your basement? Boiler explosion hazards that are often forgotten in risk assessments,” *ICHEME HAZARDS 27, SYMPOSIUM SERIES NO 162*.
- [10] IOGP, “434-01 Process Release Frequencies,” 2019.
- [11] IOGP, 434-14 Vulnerability of Humans, 2010.
- [12] “217233C-000-CN-0007-00001 PDP Ulysses ISBL Basis of Design”.
- [13] “API RP 521 Pressure-relieving and Depressuring Systems”.
- [14] “2811007-HSE-REP-00006 Fire and Explosion Analysis”.
- [15] Centre for Marine and Petroleum Technology, “A Guide to Quantitative Risk Assessment for Offshore Installations”, John Spouge of DNV Technica, 1999..
- [16] “2811007-HSE-REP-00005 Flare Radiation and Dispersion Report”.
- [17] “202947C-000-RT-1900-00003 Dragon Integrated FEED HAZID Report”.

APPENDIX A: OVERALL PLOT PLAN



APPENDIX B: FAILURE CASES SUMMARY

Table B-0-1: Failure Case Summary

FAILURE CASE NO.	Description	Process	Module	HMB Stream	Temp (°C)	Pressure (barg)	Volume (m ³) ^{Note 1}
FC01	Ethanol feed from OSBL to Z-1100 Ethanol FEED Guard Bed Package	ETE	IS3.1	1100	10	6.5	1.0 ^{Note 2}
FC02	Ethanol FEED Pre Heater HE-1101 (tube side) and HE-1102 (tube side)	ETE	IS1.2-4	1106	80	3.3	0.4 ^{Note 2}
FC03	Ethanol Pre Treatment Column Reboiler C-1100 (vapour) and Pre Treatment Column Condenser HE-1110	ETE	IS1.2	1108	74	0.5	162.4
FC04	Ethanol Pre Treatment Column Reboiler C-1100 bottom and Side Draw Condenser HE-1103 including Pre Treatment Column Base Bleed Pump P-1120A/B	ETE	IS1.2	1134	100	2.0	3.7
FC07	Pre Treatment Column Reflux Drum V-1111 (vapour)	ETE	IS1.2	1114	44	0.3	2.6
FC08	Pre Treatment Column Reflux Drum V-1111 (liquid) and Pre Treatment Column Reflux Pump P-1112A/B	ETE	IS1.2	1110	44	0.3	2.1
FC11	Pre Treatment Side Draw Condenser and Drum, HE-1130 and V-1131	ETE	IS1.2-3	1118	95	0.8	2.2
FC12	Pre Treatment Column Base Pump P-1132A/B and Cation Guard Bed Package Z-1150	ETE	IS3.1	1124	72	15.0	19.5
FC14	Vaporiser Feed Drum V-1250 (Vapour) and Feed Vaporiser HE-1251 (shell side) to HE-1330	ETE	IS1.3	1202	153	12.3	22.9
FC108	Vaporiser Feed Drum V-1250 (liquid side)	ETE	IS1.3	1201	114	3.7	4.2
FC15	Reactor 1 R-1260	ETE	IS1.1	1204	216	11.9	51.5
FC16	Reactor R-1270/80/90/1300/1310/1320	ETE	IS1.1	1205	241	11.5	16.0
FC23	Reactor Product Separator V-1332 (vapour)	ETE	IS1.2	1302	135	8.3	8.1
FC26	Primary Separation Column C-1350 (vapour)	ETE	IS1.3	1304	59	6.9	38.9
FC27	Primary Separation Column C-1350 (liquid)	ETE	IS1.3	1312	106	7.4	1.4
FC28	Primary Separation Column Reflux Drum V-1361 (liquid) and reflux pump P-1362A/B	ETE	IS1.2	1309	33	6.9	0.9
FC31	Primary Separation Column Reflux Drum V-1361 (vapour)	ETE	IS1.2	1305	44	6.4	6.3

FAILURE CASE NO.	Description	Process	Module	HMB Stream	Temp (°C)	Pressure (barg)	Volume (m ³) ^{Note 1}
FC30	Ethylene Compressor Z-1400 package	ETE	IS3.1	1306	110	26.4	5.0
FC32	Ethylene Separation Column C-1410 vapour	ETE	IS1.3	1402	24	26.0	15.0
FC33	Ethylene Separation Column C-1410 liquid	ETE	IS1.3	1401	44	27.7	0.7
FC36	Ethylene Separation Column Reflux Drum V-1421 (liquid)	ETE	IS1.2	1405	-2	25.6	0.9
FC38	Ethylene Separation Column Reflux Drum V-1421 (vapour)	ETE	IS1.2	1500	-3	25.6	2.7
FC39	Ethylene Refinement Column C-1550 (liquid)	ETE	IS1.3	1512	40	25.7	0.5
FC40	Ethylene Refinement Column C-1550 (Vapour) and Column Condenser HE-1560 (tube side)	ETE	IS1.3	1501	-19	25.0	26.5
FC41	Ethylene Refinement Column Reflux Drum V-1561 (liquid) and Ethylene Refinement Column Reflux Pump P-1562A/B	ETE	IS1.2	1503	-20	24.8	1.5
FC43a	Ethylene Refinement Column Reflux Drum V-1561 (vapour) to HE-2100 from Z-1570 ^{Note 3}	ETE	IS1.2	1504	-20	24.8	3.6
FC43b		ETE	IS3.1	1504	-20	24.8	3.6
FC43c		ETE	IS2.2-3	1504	-20	24.8	3.6
FC46	Dee and Ethanol Recovery Flash Vessel V-1600 (vapour)	ETE	IS1.4	1601	82	3.2	4.7
FC47	Dee and Ethanol Recovery Condenser HE-1630	ETE	IS1.4	1602	45	1.7	0.4 ^{Note 2}
FC49	Water Separation Column Condenser HE-1620, Reflux Drum V-1621	ETE	IS1.2-4	1606	45	1.5	1.9
FC51	Water Separation Column C-1610 (vapour)	ETE	IS1.3	1604	89	1.5	40.2
FC52	Dee and Ethanol Recovery KO Drum V-1631, P-1632A/B outlet line to HE-1331 inlet line	ETE	IS1.1-2	1610	51	12.5	2.5
FC54	OLIG 1 Effluent Exchanger HE-2100 (shell)	ETJ	IS2.2	2105	88	19.2	1.7 ^{Note 2}
FC57	OLIG 1 Reactors R-2130A/B to HE-2100, HE-2200 to V-2210 inlet	ETJ	IS2.1-5	2104	145	19.7	66.4 ^{Note 2}
FC59	OLIG 1 High Pressure Separator V-2210 (vapour)	ETJ	IS2.4	2205	48	18.9	12.3
FC60	OLIG 1 HP Separator Gas Compressor Z-2280	ETJ	IS3.1	2209	56	21.3	1.0 ^{Note 2}
FC61	OLIG 1 High Pressure Separator V-2210 (bottom)	ETJ	IS2.4	2203	48	18.9	4.3
FC63	OLIG 1 LP Separator V-2212 (vapour)	ETJ	IS2.2	2208	6	1.4	8.8

FAILURE CASE NO.	Description	Process	Module	HMB Stream	Temp (°C)	Pressure (barg)	Volume (m ³) ^{Note 1}
FC64	OLIG 1 LP Separator V-2212 (bottom), P2211A/B to V2301 inlet	ETJ	IS2.1-2	2300	6	2.0	3.1
FC66	OLIG 1 LP Separator Gas Compressor Z-2250	ETJ	IS3.1	2210	114	21.3	1.0 ^{Note 2}
FC69	OLIG 2 Feed Surge Drum V-2301 (vapour)	ETJ	IS2.3	2302	20	1.9	5.3
FC70	OLIG 2 Feed Surge Drum V-2301 (liquid)	ETJ	IS2.3	2303	20	1.9	2.3
FC71	OLIG 2 Reactor Charge Pump P-2302A/B and Recycle Exchangers HE-2321A/B (shell side)	ETJ	IS2.1-2	2304	21	19.4	1.0 ^{Note 2}
FC74	OLIG 2 Reactors R-2350A/B	ETJ	IS2.1	2310	205	16.2	24.5 ^{Note 2}
FC77	Stabiliser Column C-2400 (vap) and Overhead Cooler HE-2411 (shell side)	ETJ	IS2.2-5	2400	250	2.2	36.0
FC79	Stabiliser Overhead Condenser HE-2412 (fin fan) and Stabiliser Overhead Separator V-2420 (vapour)	ETJ	IS2.2-5	2404	48	1.3	6.1
FC81	Stabiliser Overhead Separator V-2420 (bottom), P-2421A/B to V2301	ETJ	IS2.2	2406	48	4.5	3.6
FC82	Stabiliser liquid volume (C-2400) liq, bottoms Pump P-2402A/B, HE-2401	ETJ	IS2.2	2406	48	4.5	1.7
FC85	Hydrogenation Charge Pump P-2453A/B to Intermediate Product Cooler HE-2403	ETJ	IS2.1-5	2415	240	22.2	1.0 ^{Note 2}
FC88	Stabiliser Bottoms Cooler HE-2420A/B outlet (tube side), HE-2322 (shell) to R-2350 inlet	ETJ	IS2.2-3	2307	166	18.0	2.1 ^{Note 2}
FC89	Stabiliser Bottoms Cooler HE-2420A/B shell side, Hydrogenation Recycle Cooler HE-2480	ETJ	IS2.2-5	2417	119	21.5	2.0 ^{Note 2}
FC95	Hydrogenation Reactor R-2460	ETJ	IS2.1	2420	149	19.9	22.0
FC96	Hydrogenation HP Separator V-2470 (liquid) and R-2460 outlet line	ETJ	IS2.3	2421	149	19.8	14.9
FC97	Hydrogenation HP Separator V-2470 (vapour)	ETJ	IS2.3-4	2423	149	19.8	13.8
FC91	Hydrogenation LP Separator V-2472 (liquid)	ETJ	IS2.1-2	2432	147	3.1	1.7
FC99	Fractionator C-2600, Bottoms Pump P-2602A/B, HE-2701 to diesel storage	ETJ	IS2.2-5	2610	262	4.3	1.8

FAILURE CASE NO.	Description	Process	Module	HMB Stream	Temp (°C)	Pressure (barg)	Volume (m ³) ^{Note 1}
FC102	Fractionator C-2600, Side Draw pump P-2711A/B, Cooler HE-2710 to Jet storage	ETJ	IS2.2-4	2616	99	5.3	46.4
FC103	Fractionator Separator V2671 (Liquid) and Reflux Pump P-1672A/B to C-2600	ETJ	IS2.1-3	2605	55	5.3	2.8
FC104	Vacuum pump Z-2680 discharge	ETJ	IS2.4	2625	48	0.2	0.100 ^{Note 2}
FC107	Anti Hydrate Ethanol Booster Pump P-1452A/B and Dryer Package Z-1450	ETE	IS3.1	1136	73	27.0	1.0 ^{Note 2}
FC132	Ethanol Storage Tank T-6000	OSBL	OSBL	Ethanol	Amb	Atm	1800
FC138	V-4250 Liq Hydrocarbon Storage Vessel	OSBL	OS5	1116	44	2.8	46.0
FC140	Z-4300 Electrolyser	OSBL	OS4	H ₂	65	32.0	3.0 ^{Note 2}
FC140A	Z-4399 Hydrogen Compressor	OSBL	OS4	H ₂	65	121.0	1.0 ^{Note 2}
FC140B	V-4351/2 Hydrogen Storage	OSBL	OS4	H ₂	Amb	121.0	72.5
FC141	T-6400A/B/C Jet Storage Tanks	OSBL	OSBL	2620	Amb	4.0	1100
FC143	T-6431A/B/C Diesel Storage Tanks	OSBL	OSBL	2621	Amb	4.2	395
FC145	Refrigeration Package Z-3400 (within enclosure)	ISBL	IS3.1	Propane	-23	3.0	6500 kg
FC146	Ethylene Separation Column Condenser HE-1420 (shell side, propane)	ETE	IS1.4	Propane	-6	3.0	1.0 ^{Note 2}
FC147	Ethylene Refinement Column Condenser HE-1560 (shell side, propane)	ETE	IS1.3	Propane	-23	1.2	1.0 ^{Note 2}
FC150	V-6100 Olefins Processing Vessels (NNF)	OSBL	OS5	2300	6	2.0	909
FC151	T-6160 Paraffins Reprocessing Tank (NNF)	OSBL	OSBL	2621	Amb	Atm	900
FC160	Z-7450 Flare gas recovery system	OSBL	OS5	Ethylene	Atm	10	1.0 ^{Note 2}
FC163	Z-7710 Product Tanker Loading	OSBL	OSBL	2620	38	4.0	1.0 ^{Note 2}
FC164	V-4010 Fuel Gas KOD	OSBL	OS1.1	Nat Gas	35	4.0	5.0
FC166	T-7500 LPG Storage Tank	OSBL	OS5	Propane	30	10.0	19.2
FC165	HP Boiler	OSBL	OS1.1	Nat Gas	-	-	-
FC167	Road Tanker leak (pool fire)	OSBL	OSBL	2620	Atm	Atm	74.5
Note 1: Liquid inventory in vessels is based on the NLL.							
Note 2: Inventory assumed based on previous experience.							
Note 3: Same failure case, located in different module.							

APPENDIX C: MARKED-UP PFDS AND UFDS

APPENDIX D: CONSEQUENCE RESULTS

D.1 Jet Fire results

Table D-0-1: Jet fire Thermal Radiation result (at release height)

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind									5D Wind									
			Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	
IS3.1-FC01-Liquid-S	0.6	>30.0	16	22	18	18	8	NR	NR	NR	NR	13	20	19	16	11	14	5	NR	NR	
IS3.1-FC01-Liquid-M	8.8	11.5	35	50	46	41	22	37	7	NR	NR	32	50	54	40	31	34	10	NR	NR	
IS3.1-FC01-Liquid-L	127	10.1	67	97	95	78	49	69	13	NR	NR	57	94	105	75	63	61	23	NR	NR	
IS3.1-FC01-Liquid-FB	173	10.1	71	104	102	84	54	74	15	NR	NR	61	101	113	80	69	65	25	NR	NR	
IS1.2-4-FC02-Liquid-S	0.4	22.4	15	21	16	18	7	NR	NR	NR	NR	11	18	16	15	9	12	5	NR	NR	
IS1.2-4-FC02-Liquid-M	6.1	10.9	45	68	60	57	32	46	12	NR	NR	35	59	59	49	36	40	14	NR	NR	
IS1.2-4-FC02-Liquid-	8.1 ^{Note 1}	10.1	50	76	68	64	36	52	13	NR	NR	40	67	67	55	42	45	16	NR	NR	
IS1.2-4-FC02-Liquid-FB	8.1 ^{Note 1}	10.1	50	76	68	64	36	52	13	NR	NR	40	67	67	55	42	45	16	NR	NR	
IS1.2-FC03-Vapour-S	0.01	>30.0	1	1	0	NR	NR	NR	NR	NR	NR	1	1	0	NR	NR	NR	NR	NR	NR	
IS1.2-FC03-Vapour-M	0.1	>30.0	5	5	1	2	1	NR	NR	NR	NR	5	6	1	3	1	NR	NR	NR	NR	
IS1.2-FC03-Vapour-L	1.4	12.2	15	19	15	15	6	7	3	NR	NR	17	20	14	18	6	13	2	NR	NR	
IS1.2-FC03-Vapour-FB	30	10.1	49	73	87	55	48	39	17	21	7	54	75	88	63	49	53	20	34	7	
IS1.2-FC04-Liquid-S	0.3	>30.0	12	17	15	14	7	13	4	NR	NR	9	15	14	12	8	10	4	NR	NR	
IS1.2-FC04-Liquid-M	4.7	17.5	36	56	53	48	30	40	11	NR	NR	28	49	51	41	33	34	14	NR	NR	
IS1.2-FC04-Liquid-L	8.1 ^{Note 1}	10.5	46	70	67	57	38	48	13	NR	NR	82	62	67	49	40	39	17	NR	NR	
IS1.2-FC04-Liquid-FB	8.1 ^{Note 1}	10.0	46	70	67	57	38	48	13	NR	NR	82	62	67	49	40	39	17	NR	NR	
IS1.2-FC07-Vapour-S	0.005	15.2	1	NR	NR	NR	NR	NR	NR	NR	NR	1	NR	NR	NR	NR	NR	NR	NR	NR	
IS1.2-FC07-Vapour-M	0.1	10.4	5	2	1	NR	NR	NR	NR	NR	NR	5	5	0	NR	NR	NR	NR	NR	NR	
IS1.2-FC07-Vapour-L	1.0	10.0	14	14	7	7	2	NR	NR	NR	NR	16	17	6	16	3	NR	NR	NR	NR	

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind									5D Wind									
			Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	
IS1.2-FC07-Vapour-FB	1.4	10.0	15	16	9	9	2	NR	NR	NR	NR	18	19	8	18	3	NR	NR	NR	NR	
IS1.2-FC08-Liquid-S	0.2	>30.0	11	14	7	NR	NR	NR	NR	NR	NR	9	12	8	10	4	NR	NR	NR	NR	
IS1.2-FC08-Liquid-M	2.3	23.2	35	46	30	38	12	NR	NR	NR	NR	27	39	32	33	16	NR	NR	NR	NR	
IS1.2-FC08-Liquid-L	34	10.9	104	138	111	117	47	NR	NR	NR	NR	81	121	116	101	64	86	21	NR	NR	
IS1.2-FC08-Liquid-FB	46	10.7	118	157	129	133	56	NR	NR	NR	NR	92	138	135	115	74	98	25	NR	NR	
IS1.2-3-FC11-Vapour-S	0.01	19.2	2	3	2	2	1	NR	NR	NR	NR	2	2	2	2	1	2	1	NR	NR	
IS1.2-3-FC11-Vapour-M	0.1	10.6	7	9	8	8	4	7	2	NR	NR	5	8	8	7	5	6	2	NR	NR	
IS1.2-3-FC11-Vapour-L	2.0	10.1	21	31	29	27	16	24	5	NR	NR	17	27	29	23	18	20	7	NR	NR	
IS1.2-3-FC11-Vapour-FB	2.7	10.0	24	36	34	31	18	27	6	NR	NR	19	31	33	26	20	22	8	NR	NR	
IS3.1-FC12-Liquid-S	0.9	>30.0	19	26	23	22	11	20	5	NR	NR	14	23	23	18	13	16	5	NR	NR	
IS3.1-FC12-Liquid-M	13	>30.0	58	85	83	70	45	60	13	NR	NR	45	74	82	59	50	48	18	NR	NR	
IS3.1-FC12-Liquid-L	186	11.6	142	218	231	178	133	148	44	NR	NR	116	203	237	161	150	127	62	119	14	
IS3.1-FC12-Liquid-FB	254	11.2	159	245	261	200	152	165	51	NR	NR	129	227	268	180	169	142	72	133	16	
IS1.3-FC14-Vapour-S	0.1	>30.0	4	4	1	4	0	NR	NR	NR	NR	4	4	1	4	0	NR	NR	NR	NR	
IS1.3-FC14-Vapour-M	1.2	>30.0	13	16	14	14	7	12	2	NR	NR	13	16	13	14	6	13	2	NR	NR	
IS1.3-FC14-Vapour-L	17	11.5	41	61	70	50	41	40	17	24	5	43	62	70	52	40	44	17	28	5	
IS1.3-FC14-Vapour-FB	148	10.2	92	159	199	121	119	95	57	66	24	97	161	200	128	121	101	60	76	25	
IS1.3-FC108-Liquid-S	0.4	>30.0	12	17	16	15	8	13	4	NR	NR	9	15	15	13	9	11	4	NR	NR	
IS1.3-FC108-Liquid-M	6.2	17.6	38	58	57	49	33	43	12	NR	NR	29	51	55	42	35	35	16	NR	NR	
IS1.3-FC108-Liquid-L	88	10.5	117	189	199	159	122	137	51	118	21	91	168	194	137	125	114	64	98	24	
IS1.3-FC108-Liquid-FB	1473	10.0	383	642	744	529	467	444	213	400	73	298	575	734	459	471	371	253	323	99	
IS1.1-FC15-Vapour-S	0.1	>30.0	4	4	1	4	0	NR	NR	NR	NR	4	4	1	3	0	NR	NR	NR	NR	

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind									5D Wind									
			Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	
IS1.1-FC15-Vapour-M	1.1	>30.0	12	15	12	13	6	11	2	NR	NR	12	15	11	13	5	12	2	NR	NR	
IS1.1-FC15-Vapour-L	15	13.0	38	57	64	47	37	38	16	24	4	40	57	64	49	37	40	16	28	5	
IS1.1-FC15-Vapour-FB	188	10.2	102	177	219	136	132	106	65	77	28	107	179	221	142	134	112	67	87	29	
IS1.1-FC16-Vapour-S	0.1	>30.0	3	4	1	3	1	NR	NR	NR	NR	3	3	1	3	1	NR	NR	NR	NR	
IS1.1-FC16-Vapour-M	0.9	21.5	11	13	11	10	5	10	1	NR	NR	11	13	10	12	5	11	1	NR	NR	
IS1.1-FC16-Vapour-L	13	10.8	35	52	59	43	34	36	15	19	5	37	53	58	45	34	37	15	27	5	
IS1.1-FC16-Vapour-FB	164	10.1	98	168	203	130	123	103	61	76	26	103	169	204	135	124	108	62	84	26	
IS1.2-FC23-Vapour-S	0.05	>30.0	3	3	1	3	0	NR	NR	NR	NR	3	3	1	3	0	NR	NR	NR	NR	
IS1.2-FC23-Vapour-M	0.7	15.1	10	12	9	11	4	9	1	NR	NR	10	12	8	6	3	6	2	NR	NR	
IS1.2-FC23-Vapour-L	10	10.4	31	47	53	39	31	32	13	21	4	33	47	52	40	30	34	13	24	4	
IS1.2-FC23-Vapour-FB	85	10.0	77	128	156	101	94	80	45	57	18	81	129	157	105	94	84	46	65	18	
IS1.3-FC26-Vapour-S	0.05	>30.0	3	3	1	3	0	NR	NR	NR	NR	3	3	1	3	0	NR	NR	NR	NR	
IS1.3-FC26-Vapour-M	0.7	>30.0	10	13	12	12	6	10	2	5	2	11	13	11	12	5	11	2	NR	NR	
IS1.3-FC26-Vapour-L	10	12.0	33	52	64	42	38	34	17	22	5	36	53	63	44	37	36	16	28	5	
IS1.3-FC26-Vapour-FB	89	10.2	76	139	185	107	112	81	56	59	23	81	139	186	111	113	86	58	71	24	
IS1.3-FC27-Liquid-S	0.6	>30.0	14	19	15	17	7	NR	NR	NR	NR	11	17	16	14	8	12	4	NR	NR	
IS1.3-FC27-Liquid-M	8.6	11.6	45	65	57	56	29	49	10	NR	NR	35	56	56	47	34	40	13	NR	NR	
IS1.3-FC27-Liquid-L	123	10.1	141	210	202	180	114	156	42	NR	NR	109	184	197	153	123	130	54	111	22	
IS1.3-FC27-Liquid-FB	376	10.0	226	341	342	289	197	251	73	NR	NR	176	300	335	247	211	207	34	182	34	
IS1.2-FC28-Liquid-S	0.5	26.2	11	20	22	16	14	13	6	12	4	8	18	21	14	14	11	8	9	4	
IS1.2-FC28-Liquid-M	7.9	11.1	33	66	78	53	50	44	28	37	11	26	59	79	46	49	37	30	31	14	
IS1.2-FC28-Liquid-FB	87	10.1	91	189	249	149	158	120	90	103	38	70	173	252	132	155	103	94	86	49	

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind									5D Wind									
			Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	
IS1.2-FC31-Vapour-S	0.04	>30.0	3	3	1	3	0	NR	NR	NR	NR	3	3	1	3	0	NR	NR	NR	NR	
IS1.2-FC31-Vapour-M	0.7	14.2	10	13	11	11	6	10	2	5	2	10	13	11	11	5	10	1	NR	NR	
IS1.2-FC31-Vapour-L	9.5	10.3	32	50	62	41	36	33	16	22	5	34	51	61	43	36	35	16	28	5	
IS1.2-FC31-Vapour-FB	52	10.1	62	111	146	86	88	66	44	49	17	66	111	146	89	88	71	44	59	17	
IS3.1-FC30-Vapour-S	0.1	>30.0	5	6	3	5	1	3	1	NR	NR	5	3	2	3	1	3	1	NR	NR	
IS3.1-FC30-Vapour-M	2.2	14.6	16	23	24	19	14	16	6	11	2	17	23	24	20	13	17	5	12	1	
IS3.1-FC30-Vapour-L	7.3 ^{Note 1}	10.3	27	26	52	15	31	10	14	7	5	29	26	51	15	30	11	14	9	5	
IS3.1-FC30-Vapour-FB	7.3 ^{Note 1}	10.1	27	26	52	15	31	10	14	7	5	29	26	51	15	30	11	14	9	5	
IS1.3-FC32-Vapour-S	0.2	>30.0	5	6	4	6	2	4	0	NR	NR	5	6	3	6	1	4	1	NR	NR	
IS1.3-FC32-Vapour-M	2.5	26.2	18	26	29	22	17	18	7	11	2	19	26	28	22	16	19	6	13	2	
IS1.3-FC32-Vapour-L	36	11.1	55	96	126	76	76	58	38	45	14	58	96	126	78	76	64	38	53	15	
IS1.3-FC32-Vapour-FB	195	10.2	103	207	282	156	173	117	92	91	42	109	206	284	160	175	123	95	103	45	
IS1.3-FC33-Liquid-S	0.8	11.4	12	22	25	18	16	15	8	13	4	9	20	25	15	16	13	9	11	4	
IS1.3-FC33-Liquid-M	12	10.1	37	73	91	59	58	49	32	43	13	29	67	92	52	56	42	34	36	17	
IS1.3-FC33-Liquid-FB	131	10.0	103	213	288	171	181	140	106	122	49	80	195	283	151	173	120	106	101	23	
IS1.2-FC36-Liquid-S	0.8	16.8	13	21	24	18	15	15	6	14	4	10	19	23	15	15	13	8	11	4	
IS1.2-FC36-Liquid-M	12	10.5	40	72	85	59	54	50	27	44	10	31	65	84	52	53	42	31	37	13	
IS1.2-FC36-Liquid-L	177	10.0	126	234	301	190	192	159	103	139	41	98	213	301	167	188	135	111	115	53	
IS1.2-FC36-Liquid-FB	242	10.0	144	268	348	218	222	181	119	159	30	112	245	349	192	217	154	129	132	62	
IS1.2-FC38-Vapour-S	0.2	>30.0	6	9	10	8	6	7	2	NR	NR	5	8	9	7	6	6	3	5	2	
IS1.2-FC38-Vapour-M	2.6	13.0	19	32	35	27	21	23	9	20	5	15	28	34	23	22	19	11	17	5	
IS1.2-FC38-Vapour-L	37	10.2	63	106	124	89	77	77	36	68	14	49	94	122	77	78	64	43	56	18	

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind									5D Wind								
			Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²	
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)
IS1.2-FC38-Vapour-FB	113	10.1	103	175	210	146	132	125	65	111	24	80	156	208	126	132	105	74	92	32
IS1.3-FC39-Liquid-S	0.3	23.1	7	8	6	7	2	3	1	NR	NR	8	9	5	8	2	4	1	NR	NR
IS1.3-FC39-Liquid-M	3.7	10.9	22	33	38	27	21	22	8	10	3	25	34	37	29	21	25	8	14	3
IS1.3-FC39-Liquid-L	53	10.1	61	111	151	84	90	63	43	41	17	65	110	152	88	92	71	46	58	18
IS1.3-FC39-Liquid-FB	162	10.0	97	185	256	64	119	50	50	50	29	102	180	260	143	159	112	84	92	38
IS1.3-FC40-Vapour-S	0.2	>30.0	6	9	10	8	6	7	2	NR	NR	5	8	10	7	6	6	3	5	2
IS1.3-FC40-Vapour-M	2.6	>30.0	20	32	36	27	21	23	9	21	5	15	28	35	23	22	20	11	17	5
IS1.3-FC40-Vapour-L	37	12.2	64	108	125	90	78	78	37	69	14	50	96	123	78	79	65	43	57	18
IS1.3-FC40-Vapour-FB	114	10.7	133	232	278	194	177	166	89	148	35	104	207	276	167	175	139	101	122	46
IS1.2-FC41-Liquid-S	0.8	19.3	13	21	22	17	13	15	5	NR	NR	10	18	22	15	14	13	7	11	4
IS1.2-FC41-Liquid-M	12	10.6	42	70	79	59	49	51	22	45	8	32	62	78	51	50	42	27	37	11
IS1.2-FC41-Liquid-FB	136	10.1	118	204	246	169	156	143	77	127	28	92	183	244	146	155	121	88	105	38
IS1.2-FC43a-Vapour-S	0.2	>30.0	6	9	10	8	6	7	2	NR	NR	5	8	10	7	6	6	3	5	2
IS1.2-FC43a-Vapour-M	2.6	14.3	20	32	36	27	21	23	9	21	5	15	28	35	23	22	19	11	17	5
IS1.2-FC43a-Vapour-L	37	10.3	64	107	125	90	78	77	37	69	14	49	95	123	78	78	65	43	57	18
IS1.2-FC43a-Vapour-FB	113	10.1	104	177	212	147	134	126	65	112	24	81	158	210	127	134	106	75	93	32
IS3.1-FC43b-Vapour-S	0.2	>30.0	6	9	10	8	6	7	2	NR	NR	5	8	10	7	6	6	3	5	2
IS3.1-FC43b-Vapour-M	2.6	14.3	20	31	36	26	21	23	8	21	4	15	28	35	23	22	19	11	17	4
IS3.1-FC43b-Vapour-L	37	10.3	64	105	126	87	78	73	34	66	11	49	93	124	75	79	61	42	53	15
IS3.1-FC43b-Vapour-FB	113	10.1	104	174	213	144	133	120	61	107	20	81	155	211	124	134	101	73	86	28
IS2.2-3-FC43c-Vapour-S	0.2	>30.0	6	9	10	8	6	7	2	NR	NR	5	8	10	7	6	6	3	5	2
IS2.2-3-FC43c-Vapour-M	2.6	14.3	20	32	36	27	21	23	9	21	5	15	28	35	23	22	19	11	17	5

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind									5D Wind								
			Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²	
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)
IS2.2-3-FC43c-Vapour-L	37	10.3	64	107	125	90	78	77	37	69	14	49	95	123	78	78	65	43	57	18
IS2.2-3-FC43c-Vapour-FB	113	10.1	104	177	212	147	134	126	65	112	24	81	158	210	127	134	106	75	93	32
IS1.4-FC46-Vapour-S	0.03	>30.0	9	3	3	2	1	1	NR	NR	NR	3	3	0	1	0	NR	NR	NR	NR
IS1.4-FC46-Vapour-M	0.4	13.3	30	9	11	16	9	7	5	2	NR	9	11	14	10	6	6	2	NR	NR
IS1.4-FC46-Vapour-L	6.4	10.2	92	28	41	94	33	54	26	20	13	30	42	92	36	52	30	20	18	8
IS1.4-FC46-Vapour-FB	20	10.1	148	42	68	170	53	100	41	42	24	46	69	170	57	100	46	44	33	14
IS1.4-FC47-Liquid-S	0.3	26.2	10	16	32	13	18	11	8	NR	NR	8	14	30	11	20	9	8	NR	NR
IS1.4-FC47-Liquid-M	4.1	11.1	31	54	112	44	72	36	30	NR	NR	24	47	112	38	72	31	38	26	16
IS1.4-FC47-Liquid-L	2.6 ^{Note 1}	10.1	25	44	45	36	29	30	12	NR	NR	20	39	45	31	29	25	15	21	7
IS1.4-FC47-Liquid-FB	2.6 ^{Note 1}	10.0	25	44	45	36	29	30	12	NR	NR	20	39	45	31	29	25	15	21	7
IS1.2-4-FC49-Liquid-S	0.3	>30.0	12	17	15	14	7	NR	NR	NR	NR	9	15	15	12	9	10	4	NR	NR
IS1.2-4-FC49-Liquid-M	4.0	18.1	35	56	53	47	31	38	11	NR	NR	27	49	52	40	33	33	15	NR	NR
IS1.2-4-FC49-Liquid-L	57	10.6	103	169	183	137	111	115	43	NR	NR	83	155	187	124	120	101	59	87	22
IS1.2-4-FC49-Liquid-FB	175	10.2	149	249	278	200	170	165	68	NR	NR	124	237	299	188	191	151	98	132	36
IS1.3-FC51-Vapour-S	0.02	>30.0	2	2	0	NR	NR	NR	NR	NR	NR	2	1	0	NR	NR	NR	NR	NR	NR
IS1.3-FC51-Vapour-M	0.2	27.3	7	8	4	7	1	3	1	NR	NR	7	8	4	7	1	3	1	NR	NR
IS1.3-FC51-Vapour-L	3.3	11.2	21	29	31	24	16	19	5	9	3	23	31	30	27	16	23	5	11	3
IS1.3-FC51-Vapour-FB	28	10.1	47	77	97	59	56	45	24	26	8	51	78	97	64	57	52	25	36	9
IS1.1-2-FC52-Liquid-S	0.8	>30.0	15	24	24	20	14	17	5	NR	NR	12	21	23	17	15	14	6	NR	NR
IS1.1-2-FC52-Liquid-M	11.2	13.4	47	77	87	63	53	51	20	NR	NR	36	69	85	54	54	43	26	38	8
IS1.1-2-FC52-Liquid-L	160	10.2	143	253	303	202	193	162	87	147	25	111	228	303	177	192	138	104	116	37
IS1.1-2-FC52-Liquid-FB	218	10.2	163	290	350	232	223	186	103	167	31	127	261	350	203	222	158	122	132	44

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind									5D Wind								
			Flame Length (m)	4.7 kW/m ²		12.6 kW/m ²		37.5 kW/m ²		100 kW/m ²		Flame Length (m)	4.7 kW/m ²		12.6 kW/m ²		37.5 kW/m ²		100 kW/m ²	
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)
IS2.2-FC54-Vapour-S	1.2	20.5	20	29	26	24	13	21	5	NR	NR	16	25	26	20	15	17	5	NR	NR
IS2.2-FC54-Vapour-M	17	10.7	63	94	94	77	51	66	16	NR	NR	49	82	92	66	57	53	21	NR	NR
IS2.2-FC54-Vapour-FB	85	10.2	5	7	5	6	2	NR	NR	NR	NR	4	6	5	5	3	4	2	NR	NR
IS2.1-5-FC57-Vapour-S	0.3	>30.0	9	16	18	13	11	11	4	NR	NR	7	14	17	11	11	9	6	8	3
IS2.1-5-FC57-Vapour-M	5	11.9	30	54	63	44	40	37	20	32	7	23	49	62	39	39	32	23	27	10
IS2.1-5-FC57-Vapour-L	67	10.1	92	178	222	145	142	121	79	105	33	72	163	223	128	138	103	84	88	42
IS2.1-5-FC57-Vapour-FB	205	10.1	148	293	378	237	241	197	137	172	60	115	269	380	210	234	168	143	143	76
IS2.4-FC59-Vapour-S	0.2	>30.0	9	14	15	12	9	10	4	NR	NR	7	13	14	10	9	8	5	NR	NR
IS2.4-FC59-Vapour-M	3	13.2	27	48	53	40	34	33	16	28	7	21	43	52	34	34	28	19	24	7
IS2.4-FC59-Vapour-L	44	10.2	83	158	189	128	122	107	65	92	26	64	144	189	113	118	91	71	77	34
IS2.4-FC59-Vapour-FB	134	10.1	132	258	322	207	207	171	114	148	46	103	235	324	183	201	146	122	123	59
IS3.1-FC60-Vapour-S	0.1	24.3	5	6	3	5	1	3	1	NR	NR	5	5	3	5	1	3	1	NR	NR
IS3.1-FC60-Vapour-M	2	11.0	16	23	24	19	14	16	5	10	2	17	23	24	20	12	17	5	12	1
IS3.1-FC60-Vapour-L	5.9 Note 1	10.1	26	26	48	32	28	40	13	20	4	27	29	48	34	28	29	12	24	4
IS3.1-FC60-Vapour-FB	5.9 Note 1	10.0	26	26	48	32	28	40	13	20	4	27	29	48	34	28	29	12	24	4
IS2.4-FC61-Liquid-S	0.71	>30.0	12	22	27	18	17	15	9	13	4	9	20	27	16	16	13	10	11	4
IS2.4-FC61-Liquid-M	11	13.1	36	75	100	60	62	49	37	43	16	28	69	100	54	60	42	37	36	20
IS2.4-FC61-Liquid-L	150	10.2	112	249	351	197	217	160	131	138	66	87	216	312	167	190	132	120	111	66
IS2.4-FC61-Liquid-FB	818	10.0	228	493	693	389	435	316	260	272	124	177	423	610	327	377	259	231	219	124
IS2.2-FC63-Vapour-S	0.01	>30.0	2	2	0.5	1	0.3	NR	NR	NR	NR	2	1	0.3	1	0.3	NR	NR	NR	NR
IS2.2-FC63-Vapour-M	0.22	13.4	7	8	6	7	2	NR	0.5	NR	NR	7	8	5	8	2	5	0.5	NR	NR
IS2.2-FC63-Vapour-L	3.1	10.2	21	32	38	26	22	23	8	11	2	23	33	38	28	21	21	8	16	2

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind									5D Wind									
			Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	
IS2.2-FC63-Vapour-FB	27	10.0	47	86	118	66	71	21	36	11	13	51	85	118	69	71	56	36	47	13	
IS2.1-2-FC64-Liquid-S	0.28	>30.0	9	17	20	14	11	12	4	NR	NR	7	15	20	12	11	10	6	8	3	
IS2.1-2-FC64-Liquid-M	4.2	17.8	29	55	66	43	42	34	20	30	6	22	49	66	38	42	30	24	25	10	
IS2.1-2-FC64-Liquid-L	60	10.6	87	179	243	139	149	109	80	91	40	68	162	243	123	149	95	80	76	28	
IS2.1-2-FC64-Liquid-FB	81	10.4	99	206	282	159	175	124	104	104	34	77	186	282	141	175	108	104	87	50	
IS3.1-FC66-Vapour-S	0.13	24.1	5	5	2	5	1	3	1	NR	NR	5	5	3	5	1	3	1	NR	NR	
IS3.1-FC66-Vapour-M	1.9 ^{Note 1}	11.0	15	22	24	19	14	16	5	10	12	16	22	23	19	14	16	5	11	2	
IS3.1-FC66-Vapour-L	1.9 ^{Note 1}	10.1	15	22	24	19	14	16	5	10	12	16	22	23	19	14	16	5	11	2	
IS3.1-FC66-Vapour-FB	1.9	10.0	15	22	24	19	14	16	5	10	12	16	22	23	19	14	16	5	11	2	
IS2.3-FC69-Vapour-S	0.02	>30.0	2	2	0.4	1	0.4	NR	NR	NR	NR	2	1	0.4	1	0.4	NR	NR	NR	NR	
IS2.3-FC69-Vapour-M	0.27	12.3	7	9	6	8	3	5	1	NR		8	9	6	8	2	6	1	NR		
IS2.3-FC69-Vapour-L	3.8	10.2	23	35	42	28	23	23	10	13	2	25	35	42	30	23	25	10	18	2	
IS2.3-FC69-Vapour-FB	5.2	10.1	26	40	50	33	29	25	12	15	3	28	41	50	35	29	29	12	22	3	
IS2.3-FC70-Liquid-S	0.28	>30.0	9	17	18	14	11	11	5	NR	NR	7	15	18	12	11	10	6	8	3	
IS2.3-FC70-Liquid-M	4.1	16.0	29	56	65	45	42	37	22	31	9	22	50	66	39	42	31	24	27	11	
IS2.3-FC70-Liquid-L	58	10.4	86	183	234	145	148	117	90	100	36	67	165	238	128	146	101	90	85	48	
IS2.3-FC70-Liquid-FB	80	10.3	98	210	270	165	172	134	100	113	42	76	190	276	146	170	115	104	97	56	
IS2.1-2-FC71-Liquid-S	0.84	22.9	13	24	30	20	20	16	10	14	4	10	22	30	17	20	14	10	12	4	
IS2.1-2-FC71-Liquid-M	7.2 ^{Note 1}	10.9	32	64	84	50	52	40	30	34	10	26	58	84	45	52	35	30	29	14	
IS2.1-2-FC71-Liquid-L	7.2 ^{Note 1}	10.1	32	64	84	50	52	40	30	34	10	26	58	84	45	52	35	30	29	14	
IS2.1-2-FC71-Liquid-FB	7.2 ^{Note 1}	10.0	32	64	84	50	52	40	30	34	10	26	58	84	45	52	35	30	29	14	
IS2.1-FC74-Liquid-S	0.79	>30.0	10	21	30	16	18	13	10	11	4	7	20	30	15	18	12	10	10	6	

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind									5D Wind									
			Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	
IS2.1-FC74-Liquid-M	12	29.4	30	69	104	54	64	42	40	35	20	23	59	90	45	54	35	33	28	20	
IS2.1-FC74-Liquid-FB	127	11.8	65	157	272	119	168	92	100	74	45	65	157	238	119	146	92	88	74	45	
IS2.2-5-FC77-Vapour-S	0.23	>30.0	2	2	0.6	2	0.1	NR	NR	NR	NR	2	2	0.4	1	0.1	NR	NR	NR	NR	
IS2.2-5-FC77-Vapour-M	0.33	>30.0	8	10	8	8	4	6	1	NR	NR	8	10	7	9	3	8	1	NR	NR	
IS2.2-5-FC77-Vapour-L	4.8	11.5	24	38	48	31	28	25	12	14	3	27	39	48	33	28	28	12	21	3	
IS2.2-5-FC77-Vapour-FB	41	10.2	54	103	145	78	88	58	44	41	16	59	101	145	81	88	66	44	55	16	
IS2.2-5-FC79-Vapour-S	0.01	>30.0	2	2	0.3	1	0.3	NR	NR	NR	NR	2	2	0.1	1	0.3	NR	NR	NR	NR	
IS2.2-5-FC79-Vapour-M	0.18	12.0	6	7	5	6	2	3	0.4	NR	NR	6	7	4	7	2	4	0.4	NR	NR	
IS2.2-5-FC79-Vapour-L	2.6	10.2	20	29	34	24	20	19	7	10	3	21	30	34	26	20	22	7	14	3	
IS2.2-5-FC79-Vapour-FB	8.1	10.1	30	50	64	40	38	31	16	19	5	33	50	64	42	38	35	16	29	5	
IS2.2-FC81-Liquid-S	0.43	>30.0	9	18	22	15	14	12	8	10	4	7	17	22	13	14	10	8	9	4	
IS2.2-FC81-Liquid-M	6.4	16.4	28	62	83	49	50	39	30	34	14	22	57	83	43	50	34	30	28	17	
IS2.2-FC81-Liquid-L	91	10.5	86	202	294	156	181	123	110	104	56	66	170	254	129	156	101	94	84	52	
IS2.2-FC81-Liquid-FB	280	10.2	136	320	470	247	290	193	174	161	82	106	264	396	201	244	155	147	129	72	
IS2.2-FC82-Liquid-S	0.43	>30.0	9	18	22	15	14	12	8	10	4	7	17	22	13	14	10	8	9	4	
IS2.2-FC82-Liquid-M	6.4	11.9	28	62	83	49	50	39	30	34	14	22	57	82	43	50	34	30	28	17	
IS2.2-FC82-Liquid-L	91	10.1	85	202	294	156	181	123	110	104	56	66	170	254	129	155	101	95	84	56	
IS2.2-FC82-Liquid-FB	280	10.1	136	320	470	247	291	193	176	161	88	106	264	400	201	244	155	148	129	80	
IS2.1-5-FC85-Liquid-S	0.9	19.6	13	17	30	14	10	12	3	4	2	16	17	10	17	4	17	3	NR	NR	
IS2.1-5-FC85-Liquid-M	4.6 ^{Note 1}	10.7	25	37	49	30	28	24	12	13	4	31	37	40	35	21	35	8	31	4	
IS2.1-5-FC85-Liquid-L	4.6 ^{Note 1}	10.1	25	37	49	30	28	24	12	13	4	31	37	40	35	21	35	8	31	4	
IS2.1-5-FC85-Liquid-FB	4.6	10.0	25	37	49	30	28	24	12	13	4	31	37	40	35	21	35	8	31	4	

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind									5D Wind								
			Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²	
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)
IS2.2-3-FC88-2 Phase-S	0.13	27.3	5	6	3	5	2	3	1	NR	NR	5	5	2	5	2	3	1	NR	NR
IS2.2-3-FC88-2 Phase-M	1.9	11.2	16	23	25	19	14	16	5	9	2	17	23	25	20	14	17	5	11	2
IS2.2-3-FC88-2 Phase-L	7.2 ^{Note 1}	10.1	28	45	56	37	13	29	15	20	5	29	45	56	38	13	32	15	27	5
IS2.2-3-FC88-2 Phase-FB	7.2 ^{Note 1}	10.1	28	45	56	37	13	29	15	20	5	29	45	56	38	13	32	15	27	5
IS2.2-5-FC89-Liquid-S	0.9	>30.0	13	16	16	5	6	5	2	5	2	17	19	10	18	4	18	3	NR	NR
IS2.2-5-FC89-Liquid-M	13	11.5	39	57	86	48	50	40	22	29	10	51	63	84	58	46	55	20	53	8
IS2.2-5-FC89-Liquid-FB	33 ^{Note 1}	10.1	56	91	146	75	86	62	42	51	18	76	96	146	88	84	82	40	81	18
IS2.1-FC95-Liquid-S	0.9	>30.0	12	24	31	19	20	15	11	13	5	9	22	31	17	20	13	11	11	4
IS2.1-FC95-Liquid-M	14	29.0	36	79	114	62	70	49	40	41	20	28	71	110	54	65	41	40	34	20
IS2.1-FC95-Liquid-L	193	11.3	112	244	359	190	222	151	130	125	57	87	209	314	159	193	123	116	99	57
IS2.1-FC95-Liquid-FB	1053	10.3	228	485	696	380	438	302	255	251	108	178	414	614	317	376	246	228	199	108
IS2.3-FC96-Liquid-S	0.93	>30.0	13	17	16	15	8	12	2	5	2	18	19	10	19	4	19	2	NR	NR
IS2.3-FC96-Liquid-M	14	23.3	41	59	90	50	51	41	24	31	10	52	65	90	60	51	56	20	54	10
IS2.3-FC96-Liquid-L	195	10.9	121	209	354	167	206	137	110	115	50	149	216	354	187	206	169	110	156	50
IS2.3-FC96-Liquid-FB	1066	10.2	240	457	782	359	476	287	260	239	128	290	465	782	390	476	339	260	304	128
IS2.3-4-FC97-Vapour-S	0.03	>30.0	3	5	5	4	3	3	2	3	1	3	5	5	4	4	3	2	3	1
IS2.3-4-FC97-Vapour-M	0.4	12.4	11	17	19	14	11	11	4	10	3	11	17	19	14	11	11	4	10	3
IS2.3-4-FC97-Vapour-FB	1.9	10.5	23	36	42	29	25	24	13	21	6	23	36	42	29	25	24	13	21	6
IS2.1-2-FC91-Liquid-S	0.35	>30.0	9	17	20	14	13	11	7	10	4	7	16	20	12	13	10	6	8	4
IS2.1-2-FC91-Liquid-M	5.2	14.5	29	58	75	45	46	36	24	31	8	22	52	75	40	46	31	28	25	12
IS2.1-2-FC91-Liquid-L	74	10.3	87	189	264	146	164	114	96	93	20	68	170	264	128	164	98	96	78	70

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind										5D Wind									
			Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²			
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		
IS2.1-2-FC91-Liquid-FB	101	10.2	99	217	306	168	192	131	111	106	54	77	192	300	145	180	111	111	89	54		
IS2.2-5-FC99-Liquid-S	0.42	>30.0	8	17	20	14	13	11	7	9	4	7	16	22	12	13	10	8	8	4		
IS2.2-5-FC99-Liquid-M	602	12.2	15	33	42	26	26	21	14	18	6	19	48	70	37	42	29	26	24	14		
IS2.2-5-FC99-Liquid-L	89	10.2	36	81	110	63	68	51	40	43	20	27	71	106	54	64	42	40	35	22		
IS2.2-5-FC99-Liquid-FB	759	10.0	202	461	672	357	418	280	250	233	122	147	358	538	273	332	211	200	174	104		
IS2.2-4-FC102-Liquid-S	0.5	>30.0	10	11	11	NR	NR	NR	NR	NR	NR	8	10	11	NR	NR	NR	NR	NR	NR		
IS2.2-4-FC102-Liquid-M	8	>30.0	31	68	90	54	53	44	24	NR	NR	24	63	90	48	53	38	24	NR	NR		
IS2.2-4-FC102-Liquid-L	114	>30.0	96	225	322	175	200	140	116	119	54	74	191	280	146	174	115	102	96	54		
IS2.2-4-FC102-Liquid-FB	350	17.4	137	319	460	248	289	198	170	167	78	116	289	426	221	264	173	170	145	78		
IS2.1-3-FC103-Liquid-S	0.5	>30.0	11	20	24	16	15	13	7	12	4	8	18	24	14	15	11	8	9	4		
IS2.1-3-FC103-Liquid-M	7.4	15.2	26	53	68	41	43	33	23	28	8	23	55	80	42	48	32	29	26	13		
IS2.1-3-FC103-Liquid-L	105	10.4	59	125	173	97	108	76	61	63	21	49	123	188	93	115	71	70	57	35		
IS2.1-3-FC103-Liquid-FB	144	10.3	65	139	193	107	120	84	69	70	27	54	136	208	102	128	78	77	62	40		
IS3.1-FC107-Liquid-S	1.2	20.5	20	29	26	24	13	21	5	NR	NR	16	25	26	20	15	17	5	NR	NR		
IS3.1-FC107-Liquid-M	17	10.7	63	94	94	77	51	66	16	NR	NR	49	82	92	66	57	53	21	NR	NR		
IS3.1-FC107-Liquid-FB	85	10.2	114	174	182	143	104	119	35	NR	NR	96	167	194	133	122	104	50	99	12		
OS4-FC140-Vapour-S	0.05	19.9	4	7	8	5	5	5	4	4	3	4	7	8	5	5	5	4	4	3		
OS4-FC140-Vapour-M	0.7	10.7	15	25	31	19	21	16	14	14	13	15	25	31	19	21	16	14	14	13		
OS4-FC140-Vapour-FB	3.3	10.1	30	52	68	40	44	33	30	28	25	30	52	68	40	44	33	30	28	25		
OS4-FC140A-Vapour-S	0.2	14.8	8	12	13	10	8	8	4	7	2	8	12	13	10	8	8	4	7	2		
OS4-FC140A-Vapour-M	2.5	10.3	26	43	51	34	31	28	16	24	8	26	43	51	34	31	28	16	24	8		
OS4-FC140A-Vapour-FB	12	10.1	53	90	110	70	66	56	36	48	17	53	90	110	70	66	56	36	48	17		

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind									5D Wind								
			Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²		Flame Length (m)	4.7 kW/m²		12.6 kW/m²		37.5 kW/m²		100 kW/m²	
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)
OS4-FC140B-Vapour-S	0.2	>30.0	8	13	25	10	20	8	16	7	15	8	13	25	10	20	8	16	7	15
OS4-FC140B-Vapour-M	2.7	>30.0	27	45	90	35	70	29	57	25	50	27	45	90	35	70	29	57	25	50
OS4-FC140B-Vapour-FB	13	15.2	56	93	186	72	144	58	116	50	100	56	93	186	72	144	58	116	50	100
IS3.1-FC145-Liquid-S	0.3	>30.0	10	17	18	14	11	12	4	NR	4	8	15	18	12	11	10	5	9	3
IS3.1-FC145-Liquid-M	4.7	12.7	32	56	65	45	41	37	18	33	6	25	51	65	39	41	31	22	27	8
IS3.1-FC145-Liquid-L	67	10.2	98	184	234	146	148	117	76	102	25	76	167	234	129	146	100	84	82	34
IS3.1-FC145-Liquid-FB	573	10.0	240	476	620	376	406	300	224	250	84	186	436	642	333	400	257	240	207	112
IS1.4-FC146-Liquid-S	0.3	>30.0	9	16	18	13	11	11	4	NR	NR	7	14	17	11	11	9	6	8	3
IS1.4-FC146-Liquid-M	4.7	11.9	30	54	63	44	40	37	20	32	7	23	49	62	39	39	32	23	27	10
IS1.4-FC146-Liquid-L	67	10.1	92	178	222	145	142	121	79	105	33	72	163	223	128	138	103	84	88	42
IS1.4-FC146-Liquid-FB	205	10.1	148	293	378	237	241	197	137	172	60	115	269	380	210	234	168	143	143	76
IS1.3-FC147-Liquid-S	0.2	30.0	9	14	15	12	9	10	4	NR	NR	7	13	14	10	9	8	5	NR	NR
IS1.3-FC147-Liquid-M	3.1	13.2	27	48	53	40	34	33	16	28	7	21	43	52	34	34	28	19	24	7
IS1.3-FC147-Liquid-L	44	10.2	83	158	189	128	122	107	65	92	26	64	144	189	113	118	91	71	77	34
IS1.3-FC147-Liquid-FB	134	10.1	132	258	322	207	207	171	114	148	46	103	235	324	183	201	146	122	123	59
OS5-FC150-Liquid-S	0.32	>30.0	10	17	19	14	12	11	5	NR	NR	8	16	19	12	12	10	7	8	3
OS5-FC150-Liquid-M	4.7	>30.0	30	57	71	45	45	36	22	31	7	23	52	72	40	44	31	26	26	11
OS5-FC150-Liquid-L	67	>30.0	91	188	254	146	160	114	88	96	33	70	171	260	129	160	99	95	80	46
OS5-FC150-Liquid-FB	207	>30.0	144	310	432	240	272	187	155	152	62	112	275	420	208	258	160	156	128	77
OS5-FC160-Vapour-S	0.06	19.8	3	4	2	3	1	NR	NR	NR	NR	3	2	1	2	1	NR	NR	NR	NR
OS5-FC160-Vapour-M	0.9	10.7	11	15	14	13	8	11	2	6	2	12	15	14	13	7	12	2	6	2

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	2F Wind									5D Wind								
			Flame Length (m)	4.7 kW/m ²		12.6 kW/m ²		37.5 kW/m ²		100 kW/m ²		Flame Length (m)	4.7 kW/m ²		12.6 kW/m ²		37.5 kW/m ²		100 kW/m ²	
				L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)		L (m)	W (m)	L (m)	W (m)	L (m)	W (m)	L (m)	W (m)
OS5-FC160-Vapour-L	13	10.1	36	60	76	48	46	38	22	31	8	38	60	76	50	46	42	22	35	8
OS5-FC160-Vapour-FB	40	10.0	57	101	134	80	82	62	42	49	16	61	101	134	82	82	67	42	57	16
OSBL-FC163-Liquid-S	0.5	>30.0	7	14	16	11	10	9	8	8	3	7	15	20	12	12	9	6	8	3
OSBL-FC163-Liquid-M	4.4 ^{Note 1}	12.0	15	30	40	24	24	19	13	17	3	13	32	44	24	28	19	16	16	7
OSBL-FC163-Liquid-L	4.4 ^{Note 1}	10.1	15	30	40	24	24	19	13	17	3	13	32	44	24	28	19	16	16	7
OSBL-FC163-Liquid-FB	4.4 ^{Note 1}	10.1	15	30	40	24	24	19	13	17	3	13	32	44	24	28	19	16	16	7
OS1.1-FC164-Vapour-S	0.02	>30.0	2	2	1	2	1	NR	NR	NR	NR	2	2	1	2	1	NR	NR	NR	NR
OS1.1-FC164-Vapour-M	0.3	11.7	7	8	6	7	2	7	1	NR	NR	7	8	6	7	2	7	1	NR	NR
OS1.1-FC164-Vapour-L	4	10.1	22	33	40	28	22	23	10	20	2	23	33	40	28	22	24	10	21	3
OS1.1-FC164-Vapour-FB	23	10.0	46	78	101	64	61	51	31	42	12	48	78	101	64	61	54	31	46	12

L = Length, W = Width

NR: Maximum thermal radiation below this value.

Note 1: Release rate capped to 150% of upstream flowrate.

Note 2: No large releases were considered if the maximum piping size in the section is <87mm

D.2 Pool Fire results

Table D-0-2: Pool fire Thermal Radiation result

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Thermal radiation diameter (m) at 2F Wind					Thermal radiation diameter (m) at 5D Wind				
			Flame Diameter (m)	4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²	Flame Diameter (m)	4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
IS3.1-FC01-Liquid-S	0.6	>30.0	5	16	12	8	NR	5	17	14	10	NR

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Thermal radiation diameter (m) at 2F Wind					Thermal radiation diameter (m) at 5D Wind				
			Flame Diameter (m)	4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²	Flame Diameter (m)	4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
IS3.1-FC01-Liquid-M	8.8	11.5	22	46	33	20	NR	21	47	35	21	NR
IS3.1-FC01-Liquid-L	127	10.1	82	143	100	61	NR	82	146	105	68	NR
IS3.1-FC01-Liquid-FB	173	10.1	96	164	115	70	NR	96	167	120	79	NR
IS1.2-4-FC02-Liquid-S	0.4	22.4	4	17	14	12	NR	3	31	29	27	NR
IS1.2-4-FC02-Liquid-M	6.1	10.9	16	39	30	19	NR	15	45	36	25	NR
IS1.2-4-FC02-Liquid-L	8.1 ^{Note 1}	10.1	18	44	33	21	NR	17	48	39	27	NR
IS1.2-4-FC02-Liquid-FB	8.1 ^{Note 1}	10.1	18	44	33	21	NR	17	48	39	27	NR
IS1.2-FC04-Liquid-S	0.3	>30.0	2	19	17	NR	NR	NR	NR	NR	NR	NR
IS1.2-FC04-Liquid-M	4.7	17.5	12	40	32	23	NR	9	48	42	34	NR
IS1.2-FC04-Liquid-L	8.1 ^{Note 1}	10.5	13	60	51	42	NR	10	69	62	54	NR
IS1.2-FC04-Liquid-FB	8.1 ^{Note 1}	10.0	13	60	51	42	NR	10	69	62	54	NR
IS1.2-FC08-Liquid-S	0.2	>30.0	3	8	7	NR	NR	3	12	11	NR	NR
IS1.2-FC08-Liquid-M	2.3	23.2	10	20	15	NR	NR	10	23	19	NR	NR
IS1.2-FC08-Liquid-L	34	10.9	40	63	44	25	NR	38	63	47	26	NR
IS1.2-FC08-Liquid-FB	46	10.7	47	72	51	29	NR	45	72	54	30	NR
IS3.1-FC12-Liquid-S	0.9	>30.0	6	19	15	11	NR	2	18	16	NR	NR
IS3.1-FC12-Liquid-M	13	>30.0	24	56	41	26	NR	24	59	45	30	NR
IS3.1-FC12-Liquid-L	186	11.6	95	171	122	78	NR	94	174	128	88	NR
IS3.1-FC12-Liquid-FB	254	11.2	111	195	139	89	NR	110	199	146	101	NR
IS1.3-FC108-Liquid-S	0.4	>30.0	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS1.3-FC108-Liquid-M	6.2	17.6	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS1.3-FC108-Liquid-L	88	10.5	38	116	93	71	NR	12	86	78	68	NR
IS1.3-FC108-Liquid-FB	1473	10.0	213	406	299	210	169	207	407	308	231	172
IS1.3-FC27-Liquid-S	0.6	>30.0	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Thermal radiation diameter (m) at 2F Wind					Thermal radiation diameter (m) at 5D Wind				
			Flame Diameter (m)	4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²	Flame Diameter (m)	4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
IS1.3-FC27-Liquid-M	8.6	11.6	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS1.3-FC27-Liquid-L	123	10.1	26	98	84	70	NR	NR	NR	NR	NR	NR
IS1.3-FC27-Liquid-FB	376	10.0	87	196	155	116	NR	49	155	132	106	NR
IS1.2-FC28-Liquid-S	0.5	26.2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS1.2-FC28-Liquid-M	7.9	11.1	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS1.2-FC28-Liquid-FB	87	10.1	25	104	74	47	29	15	74	56	41	24
IS1.2-4-FC49-Liquid-S	0.3	>30.0	2	12	11	8	NR	2	22	20	19	NR
IS1.2-4-FC49-Liquid-M	4.0	18.1	9	31	23	14	NR	9	34	28	19	NR
IS1.2-4-FC49-Liquid-L	57	10.6	40	99	69	41	28	38	97	70	47	NR
IS1.2-4-FC49-Liquid-FB	175	10.2	73	164	113	69	44	70	162	114	78	43
IS1.1-2-FC52-Liquid-S	0.8	>30.0	3	15	12	8	NR	3	16	13	9	NR
IS1.1-2-FC52-Liquid-M	11.2	13.4	14	47	34	20	NR	14	47	35	22	NR
IS1.1-2-FC52-Liquid-L	160	10.2	60	155	107	66	40	59	157	111	76	40
IS1.1-2-FC52-Liquid-FB	218	10.2	70	179	123	76	46	69	181	127	88	46
IS2.4-FC61-Liquid-S	0.71	>30.0	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS2.4-FC61-Liquid-M	11	13.1	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS2.4-FC61-Liquid-L	150	10.2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS2.4-FC61-Liquid-FB	818	10.0	32	181	134	102	81	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS2.1-2-FC64-Liquid-S	0.28	>30.0	4	25	17	10	6	3	19	15	10	7
IS2.1-2-FC64-Liquid-M	4.2	17.8	18	86	58	35	17	14	73	51	35	16
IS2.1-2-FC64-Liquid-L	60	10.6	65	274	182	111	58	57	247	169	113	60
IS2.1-2-FC64-Liquid-FB	81	10.4	76	315	209	129	68	66	285	195	130	71
IS2.3-FC70-Liquid-S	0.28	>30.0	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS2.3-FC70-Liquid-M	4.1	16.0	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Thermal radiation diameter (m) at 2F Wind					Thermal radiation diameter (m) at 5D Wind				
			Flame Diameter (m)	4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²	Flame Diameter (m)	4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
IS2.3-FC70-Liquid-L	58	10.4	16	88	62	45	33	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS2.3-FC70-Liquid-FB	80	10.3	21	108	75	53	37	7	47	37	34	31
IS2.1-2-FC71-Liquid-S	0.84	22.9	5	32	23	14	9	3	25	19	14	10
IS2.1-2-FC71-Liquid-M	7.2 ^{Note 1}	10.9	8	32	27	21	18	5	31	27	23	20
IS2.1-2-FC71-Liquid-L	7.2 ^{Note 1}	10.1	8	32	27	21	18	5	31	27	23	20
IS2.1-2-FC71-Liquid-FB	7.2 ^{Note 1}	10.0	8	32	27	21	18	5	31	27	23	20
IS2.2-FC81-Liquid-S	0.43	>30.0	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS2.2-FC81-Liquid-M	6.4	16.4	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS2.2-FC81-Liquid-L	91	10.5	19	108	75	52	33	10	66	51	41	30
IS2.2-FC81-Liquid-FB	280	10.2	38	195	133	87	52	33	175	125	88	55
IS2.2-FC82-Liquid-S	0.43	>30.0	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS2.2-FC82-Liquid-M	6.4	11.9	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS2.2-FC82-Liquid-L	91	10.1	19	108	75	52	33	10	66	51	41	30
IS2.2-FC82-Liquid-FB	280	10.1	38	195	133	87	52	33	175	125	88	55
IS2.1-FC95-Liquid-S	0.9	>30.0	17	44	30	22	20	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS2.1-FC95-Liquid-M	14	29.0	67	94	67	54	49	67	101	71	59	54
IS2.1-FC95-Liquid-L	193	11.3	173	196	138	115	107	170	208	141	118	109
IS2.1-FC95-Liquid-FB	1053	10.3	406	386	276	239	227	401	410	282	242	227
IS2.1-2-FC91-Liquid-S	0.35	>30.0	2	13	10	7	5	2	14	11	9	6
IS2.1-2-FC91-Liquid-M	5.2	14.5	8	28	20	11	NR	7	30	22	11	NR
IS2.1-2-FC91-Liquid-L	74	10.3	32	51	34	26	22	31	51	33	26	22
IS2.1-2-FC91-Liquid-FB	101	10.2	38	56	38	29	25	37	56	37	29	25
IS2.2-5-FC99-Liquid-S	0.42	>30.0	3	31	29	NR	NR	3	50	NR	NR	NR
IS2.2-5-FC99-Liquid-M	602	12.2	13	63	55	47	47	12	68	62	56	56

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Thermal radiation diameter (m) at 2F Wind					Thermal radiation diameter (m) at 5D Wind				
			Flame Diameter (m)	4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²	Flame Diameter (m)	4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
IS2.2-5-FC99-Liquid-L	89	10.2	33	58	36	35	35	39	71	46	46	46
IS2.2-5-FC99-Liquid-FB	759	10.0	102	123	84	68	68	98	126	75	70	70
IS2.2-4-FC102-Liquid-S	0.5	>30.0	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
IS2.2-4-FC102-Liquid-M	8	>30.0	8	43	36	34	NR	NR	NR	NR	NR	NR
IS2.2-4-FC102-Liquid-L	114	>30.0	42	74	47	47	47	40	82	61	61	61
IS2.2-4-FC102-Liquid-FB	350	17.4	76	110	65	63	63	74	113	71	70	70
IS2.1-3-FC103-Liquid-S	0.5	>30.0	16	38	24	16	14	13	41	28	19	16
IS2.1-3-FC103-Liquid-M	7.4	15.2	46	66	45	35	30	45	66	45	36	31
IS2.1-3-FC103-Liquid-L	105	10.4	149	176	117	95	84	149	176	117	95	84
IS2.1-3-FC103-Liquid-FB	144	10.3	151	168	115	93	84	174	200	132	108	97
IS3.1-FC107-Liquid-S	1.2	20.5	6	22	18	13	NR	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS3.1-FC107-Liquid-M	17	10.7	28	65	49	32	NR	27	69	54	36	NR
IS3.1-FC107-Liquid-FB	85	10.2	63	125	91	59	NR	62	129	97	67	NR
OS5-FC138-Liquid-S	0.2	>30.0	4	12	10	NR	NR	4	13	11	NR	NR
OS5-FC138-Liquid-M	3	13.2	16	34	26	18	NR	15	34	27	18	NR
OS5-FC138-Liquid-L	44	10.2	62	101	74	47	NR	61	102	78	48	NR
OS5-FC138-Liquid-FB	134	10.1	73	116	85	54	NR	72	117	89	55	NR
OSBL-FC141-Liquid-S	0.2	>30.0	2	12	9	6	4	2	12	10	7	5
OSBL-FC141-Liquid-M	2.9	>30.0	7	26	18	9	7	7	28	20	10	7
OSBL-FC141-Liquid-L	41	>30.0	28	45	29	21	18	28	46	28	22	18
OSBL-FC141-Liquid-FB	1409	29.2	36	50	32	24	20	36	51	33	24	21
OSBL-FC143-Liquid-S	0.04	>30.0	1	6	4	3	2	1	6	5	4	3
OSBL-FC143-Liquid-M	0.6	>30.0	4	15	11	6	4	4	16	12	8	4
OSBL-FC143-Liquid-L	8	>30.0	15	30	19	11	9	15	32	21	11	10

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Thermal radiation diameter (m) at 2F Wind					Thermal radiation diameter (m) at 5D Wind				
			Flame Diameter (m)	4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²	Flame Diameter (m)	4.7 kW/m ²	12.6 kW/m ²	37.5 kW/m ²	100 kW/m ²
OSBL-FC143-Liquid-FB	68	19.6	23	36	21	15	13	23	38	21	15	13
IS3.1-FC145-Liquid-S	0.3	>30.0	1	7	7	6	NR	1	7	NR	NR	NR
IS3.1-FC145-Liquid-M	4.7	12.7	5	34	25	15	10	4	32	24	16	11
IS3.1-FC145-Liquid-L	67	10.2	23	108	73	42	23	22	109	78	51	23
IS3.1-FC145-Liquid-FB	573	10.0	70	253	168	93	50	69	261	181	114	52
IS1.3-FC147-Liquid-S	0.2	>30.0	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS1.3-FC147-Liquid-M	3.1	13.2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS1.3-FC147-Liquid-L	44	10.2	7	60	47	34	26	_ Note 2	_ Note 2	_ Note 2	_ Note 2	_ Note 2
IS1.3-FC147-Liquid-FB	134	10.1	25	128	92	58	38	12	88	69	52	35
OS5-FC150-Liquid-S	0.32	>30.0	0.4	8	8	7	NR	0.4	8	8	7	NR
OS5-FC150-Liquid-M	4.7	>30.0	4	30	23	16	12	3	26	22	17	13
OS5-FC150-Liquid-L	67	>30.0	21	111	79	52	31	19	108	79	58	33
OS5-FC150-Liquid-FB	207	>30.0	40	192	133	86	50	38	190	136	96	55
OSBL-FC151-Liquid-S	0.18	>30.0	2	12	8	6	4	2	12	9	7	4
OSBL-FC151-Liquid-M	2.7	>30.0	8	25	17	9	8	8	27	20	9	8
OSBL-FC151-Liquid-L	38	>30.0	23	37	22	15	13	23	39	23	16	13
OSBL-FC151-Liquid-FB	327	>30.0	23	37	22	15	13	23	39	23	16	13
OSBL-FC163-Liquid-S	0.5	>30.0	3	20	16	12	10	3	22	19	16	13
OSBL-FC163-Liquid-M	4.4 ^{Note 1}	12.0	9	38	28	19	9	9	40	32	21	9
OSBL-FC163-Liquid-L	4.4 ^{Note 1}	10.1	9	38	28	19	9	9	40	32	21	9
OSBL-FC163-Liquid-FB	4.4 ^{Note 1}	10.1	9	38	28	19	9	9	40	32	21	9
TRUCK_Leak-Liquid-FB	72	12.5	37	60	42	34	30	37	61	42	34	30
NR: Maximum thermal radiation below this value.												
Note 1: Release rate capped to 150% of upstream flowrate.												

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Thermal radiation diameter (m) at 2F Wind					Thermal radiation diameter (m) at 5D Wind				
			Flame Diameter (m)	4.7 kW/m²	12.6 kW/m²	37.5 kW/m²	100 kW/m²	Flame Diameter (m)	4.7 kW/m²	12.6 kW/m²	37.5 kW/m²	100 kW/m²
Note 2: No pool fire formed.												

D.3 Explosion Results

Table D-0-3: Explosion Results

FAILURE CASE	Flammable volume (m ³)	Fill Fraction	Material	Explosion Overpressure Radii (m)			
				0.07 bar	0.14 bar	0.21 bar	0.35 bar
IS1 Module Explosion	14688	100%	Ethylene (stream 1500)	307	176	132	96
	7344	50%	Ethylene (stream 1500)	243	139	105	76
	4406.4	30%	Ethylene (stream 1500)	205	118	88	64
	1034*	7%	Ethylene (stream 1500)	127	73	54	40
IS2 Module Explosion	18360	100%	Ethylene (stream 2205)	330	189	142	103
	9180	50%	Ethylene (stream 2205)	262	150	113	82
	5508	30%	Ethylene (stream 2205)	221	127	95	69
	2490*	14%	Ethylene (stream 2205)	170	97	73	53
IS3 Module Explosion	3672	100%	Ethylene (stream 1306)	193	111	83	60
	1836	50%	Ethylene (stream 1306)	153	88	66	48
	1101.6	30%	Ethylene (stream 1306)	129	74	56	40
	348*	9%	Ethylene (stream 1306)	88	50	38	27
Electrolyser Building Module Explosion	1300	100%	Hydrogen	128	73	55	40
	650	50%	Hydrogen	102	58	44	32
	390	30%	Hydrogen	86	49	37	27
Note 1: Volume based on largest ½ LFL dispersion for 5D wind.							

D.4 Flammable Dispersion Results

Table D-0-4: Flammable Dispersion result

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Dispersion Downwind Distance (m) at 2F Wind		Dispersion Downwind Distance (m) at 5D Wind	
			½ LFL	LFL	½ LFL	LFL
IS3.1-FC01-Liquid-S	0.6	>30.0	3	2	5	4
IS3.1-FC01-Liquid-M	8.8	11.5	4	3	6	6
IS3.1-FC01-Liquid-L	127	10.1	10	8	12	8
IS3.1-FC01-Liquid-FB	173	10.1	10	8	18	8
IS1.2-4-FC02-Liquid-S	0.4	22.4	2	2	5	3
IS1.2-4-FC02-Liquid-M	6.1	10.9	3	3	5	4
IS1.2-4-FC02-Liquid-L	8.1 ^{Note 1}	10.1	3	3	5	4
IS1.2-4-FC02-Liquid-FB	8.1 ^{Note 1}	10.1	3	3	5	4
IS1.2-FC03-Vapour-S	0.01	>30.0	1	1	1	1
IS1.2-FC03-Vapour-M	0.1	>30.0	4	2	4	2
IS1.2-FC03-Vapour-L	1.4	12.2	14	8	13	8
IS1.2-FC03-Vapour-FB	30	10.1	58	34	45	30
IS1.2-FC04-Liquid-S	0.3	>30.0	6	5	7	5
IS1.2-FC04-Liquid-M	4.7	17.5	10	8	15	11
IS1.2-FC04-Liquid-L	8.1 ^{Note 1}	10.5	36	15	23	17
IS1.2-FC04-Liquid-FB	8.1 ^{Note 1}	10.0	36	15	23	17
IS1.2-FC07-Vapour-S	0.005	15.2	1	0.3	1	0.3
IS1.2-FC07-Vapour-M	0.1	10.4	2	1	2	1
IS1.2-FC07-Vapour-L	1.0	10.0	7	4	6	3
IS1.2-FC07-Vapour-FB	1.4	10.0	8	4	7	4
IS1.2-FC08-Liquid-S	0.2	>30.0	0.5	0.4	2	1
IS1.2-FC08-Liquid-M	2.3	23.2	1	1	3	2

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Dispersion Downwind Distance (m) at 2F Wind		Dispersion Downwind Distance (m) at 5D Wind	
			½ LFL	LFL	½ LFL	LFL
IS1.2-FC08-Liquid-L	34	10.9	2	2	7	6
IS1.2-FC08-Liquid-FB	46	10.7	2	2	8	6
IS1.2-3-FC11-Vapour-S	0.01	19.2	2	1	2	1
IS1.2-3-FC11-Vapour-M	0.1	10.6	6	4	5	3
IS1.2-3-FC11-Vapour-L	2.0	10.1	19	12	16	10
IS1.2-3-FC11-Vapour-FB	2.7	10.0	22	14	18	12
IS3.1-FC12-Liquid-S	0.9	>30.0	7	6	9	6
IS3.1-FC12-Liquid-M	13	>30.0	47	23	29	14
IS3.1-FC12-Liquid-L	186	11.6	174	109	110	73
IS3.1-FC12-Liquid-FB	254	11.2	201	127	124	83
IS1.3-FC14-Vapour-S	0.1	>30.0	5	3	4	3
IS1.3-FC14-Vapour-M	1.2	>30.0	15	9	14	9
IS1.3-FC14-Vapour-L	17	11.5	51	31	42	28
IS1.3-FC14-Vapour-FB	148	10.2	156	87	114	69
IS1.3-FC108-Liquid-S	0.4	>30.0	9	7	10	7
IS1.3-FC108-Liquid-M	6.2	17.6	19	15	22	16
IS1.3-FC108-Liquid-L	88	10.5	34	29	40	33
IS1.3-FC108-Liquid-FB	1473	10.0	58	49	61	52
IS1.1-FC15-Vapour-S	0.1	>30.0	3	2	3	2
IS1.1-FC15-Vapour-M	1.1	>30.0	15	7	10	6
IS1.1-FC15-Vapour-L	15	13.0	57	36	68	38
IS1.1-FC15-Vapour-FB	188	10.2	148	113	176	133
IS1.1-FC16-Vapour-S	0.1	>30.0	3	2	2	2
IS1.1-FC16-Vapour-M	0.9	21.5	12	6	9	5
IS1.1-FC16-Vapour-L	13	10.8	44	28	50	30

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Dispersion Downwind Distance (m) at 2F Wind		Dispersion Downwind Distance (m) at 5D Wind	
			½ LFL	LFL	½ LFL	LFL
IS1.1-FC16-Vapour-FB	164	10.1	102	80	120	93
IS1.2-FC23-Vapour-S	0.05	>30.0	4	2	3	2
IS1.2-FC23-Vapour-M	0.7	15.1	12	7	11	7
IS1.2-FC23-Vapour-L	10	10.4	44	25	32	21
IS1.2-FC23-Vapour-FB	85	10.0	200	83	141	56
IS1.3-FC26-Vapour-S	0.05	>30.0	5	3	5	3
IS1.3-FC26-Vapour-M	0.7	>30.0	17	10	16	10
IS1.3-FC26-Vapour-L	10	12.0	48	32	45	31
IS1.3-FC26-Vapour-FB	89	10.2	101	73	98	70
IS1.3-FC27-Liquid-S	0.6	>30.0	10	7	10	7
IS1.3-FC27-Liquid-M	8.6	11.6	22	17	24	18
IS1.3-FC27-Liquid-L	123	10.1	43	36	47	39
IS1.3-FC27-Liquid-FB	376	10.0	55	46	59	50
IS1.2-FC28-Liquid-S	0.5	26.2	3	3	6	4
IS1.2-FC28-Liquid-M	7.9	11.1	5	5	6	5
IS1.2-FC28-Liquid-FB	87	10.1	8	8	8	7
IS1.2-FC31-Vapour-S	0.04	>30.0	5	3	4	3
IS1.2-FC31-Vapour-M	0.7	14.2	15	9	13	8
IS1.2-FC31-Vapour-L	9.5	10.3	47	30	36	26
IS1.2-FC31-Vapour-FB	52	10.1	130	69	113	56
IS3.1-FC30-Vapour-S	0.1	>30.0	7	4	5	3
IS3.1-FC30-Vapour-M	2.2	14.6	57	24	43	16
IS3.1-FC30-Vapour-L	7.3 ^{Note 1}	10.3	121	58	96	50
IS3.1-FC30-Vapour-FB	7.3 ^{Note 1}	10.1	121	58	96	50
IS1.3-FC32-Vapour-S	0.2	>30.0	10	6	10	6

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Dispersion Downwind Distance (m) at 2F Wind		Dispersion Downwind Distance (m) at 5D Wind	
			½ LFL	LFL	½ LFL	LFL
IS1.3-FC32-Vapour-M	2.5	26.2	30	20	29	19
IS1.3-FC32-Vapour-L	36	11.1	80	58	77	55
IS1.3-FC32-Vapour-FB	195	10.2	146	109	152	105
IS1.3-FC33-Liquid-S	0.8	11.4	8	7	11	8
IS1.3-FC33-Liquid-M	12	10.1	13	11	17	13
IS1.3-FC33-Liquid-FB	131	10.0	21	18	20	18
IS1.2-FC36-Liquid-S	0.8	16.8	14	10	14	10
IS1.2-FC36-Liquid-M	12	10.5	28	23	32	25
IS1.2-FC36-Liquid-L	177	10.0	56	44	71	47
IS1.2-FC36-Liquid-FB	242	10.0	223	48	89	51
IS1.2-FC38-Vapour-S	0.2	>30.0	9	6	8	5
IS1.2-FC38-Vapour-M	2.6	13.0	29	19	24	17
IS1.2-FC38-Vapour-L	37	10.2	109	64	99	52
IS1.2-FC38-Vapour-FB	113	10.1	305	130	228	111
IS1.3-FC39-Liquid-S	0.3	23.1	10	7	10	6
IS1.3-FC39-Liquid-M	3.7	10.9	27	19	27	19
IS1.3-FC39-Liquid-L	53	10.1	63	50	67	50
IS1.3-FC39-Liquid-FB	162	10.0	90	71	97	73
IS1.3-FC40-Vapour-S	0.2	>30.0	11	7	11	7
IS1.3-FC40-Vapour-M	2.6	>30.0	31	21	30	20
IS1.3-FC40-Vapour-L	37	12.2	79	59	78	57
IS1.3-FC40-Vapour-FB	114	10.7	139	107	147	106
IS1.2-FC41-Liquid-S	0.8	19.3	16	12	15	11
IS1.2-FC41-Liquid-M	12	10.6	39	31	41	30
IS1.2-FC41-Liquid-FB	136	10.1	270	85	202	81

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Dispersion Downwind Distance (m) at 2F Wind		Dispersion Downwind Distance (m) at 5D Wind	
			½ LFL	LFL	½ LFL	LFL
IS1.2-FC43a-Vapour-S	0.2	>30.0	9	6	8	5
IS1.2-FC43a-Vapour-M	2.6	14.3	28	19	24	17
IS1.2-FC43a-Vapour-L	37	10.3	103	62	95	52
IS1.2-FC43a-Vapour-FB	113	10.1	300	126	221	108
IS3.1-FC43b-Vapour-S	0.2	>30.0	10	5	6	4
IS3.1-FC43b-Vapour-M	2.6	14.3	69	34	50	25
IS3.1-FC43b-Vapour-L	37	10.3	362	205	207	140
IS3.1-FC43b-Vapour-FB	113	10.1	611	367	355	249
IS2.2-3-FC43c-Vapour-S	0.2	>30.0	9	6	8	5
IS2.2-3-FC43c-Vapour-M	2.6	14.3	28	19	24	17
IS2.2-3-FC43c-Vapour-L	37	10.3	103	62	95	52
IS2.2-3-FC43c-Vapour-FB	113	10.1	300	126	221	108
IS1.4-FC46-Vapour-S	0.03	>30.0	9	7	11	8
IS1.4-FC46-Vapour-M	0.4	13.3	16	13	20	15
IS1.4-FC46-Vapour-L	6.4	10.2	23	21	27	23
IS1.4-FC46-Vapour-FB	20	10.1	27	24	29	25
IS1.4-FC47-Liquid-S	0.3	26.2	9	7	11	8
IS1.4-FC47-Liquid-M	4.1	11.1	16	13	20	15
IS1.4-FC47-Liquid-L	2.6 ^{Note 1}	10.1	2	2	3	3
IS1.4-FC47-Liquid-FB	2.6 ^{Note 1}	10.0	2	2	3	3
IS1.2-4-FC49-Liquid-S	0.3	>30.0	1	1	2	2
IS1.2-4-FC49-Liquid-M	4.0	18.1	2	2	3	2
IS1.2-4-FC49-Liquid-L	57	10.6	NR	NR	11	9
IS1.2-4-FC49-Liquid-FB	175	10.2	4	4	13	12
IS1.3-FC51-Vapour-S	0.02	>30.0	3	2	3	1

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Dispersion Downwind Distance (m) at 2F Wind		Dispersion Downwind Distance (m) at 5D Wind	
			½ LFL	LFL	½ LFL	LFL
IS1.3-FC51-Vapour-M	0.2	27.3	8	5	8	5
IS1.3-FC51-Vapour-L	3.3	11.2	25	16	23	15
IS1.3-FC51-Vapour-FB	28	10.1	59	40	53	36
IS1.1-2-FC52-Liquid-S	0.8	>30.0	6	5	7	5
IS1.1-2-FC52-Liquid-M	11.2	13.4	73	38	47	27
IS1.1-2-FC52-Liquid-L	160	10.2	273	193	173	117
IS1.1-2-FC52-Liquid-FB	218	10.2	319	228	204	139
IS2.2-FC54-Vapour-S	1.2	20.5	10	7	11	7
IS2.2-FC54-Vapour-M	17	10.7	56	28	37	20
IS2.2-FC54-Vapour-FB	85	10.2	3	2	3	2
IS2.1-5-FC57-Vapour-S	0.3	>30.0	9	7	11	8
IS2.1-5-FC57-Vapour-M	5	11.9	16	13	20	15
IS2.1-5-FC57-Vapour-L	67	10.1	23	21	27	23
IS2.1-5-FC57-Vapour-FB	205	10.1	27	24	29	25
IS2.4-FC59-Vapour-S	0.2	>30.0	5	4	7	5
IS2.4-FC59-Vapour-M	3	13.2	7	6	10	8
IS2.4-FC59-Vapour-L	44	10.2	9	8	10	9
IS2.4-FC59-Vapour-FB	134	10.1	11	10	11	10
IS3.1-FC60-Vapour-S	0.1	24.3	7	4	5	3
IS3.1-FC60-Vapour-M	2	11.0	54	25	41	17
IS3.1-FC60-Vapour-L	5.9 ^{Note 1}	10.1	670	400	409	286
IS3.1-FC60-Vapour-FB	5.9 ^{Note 1}	10.0	670	400	409	286
IS2.4-FC61-Liquid-S	0.71	>30.0	8	7	11	8
IS2.4-FC61-Liquid-M	11	13.1	56	24	37	27
IS2.4-FC61-Liquid-L	150	10.2	678	492	295	200

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Dispersion Downwind Distance (m) at 2F Wind		Dispersion Downwind Distance (m) at 5D Wind	
			½ LFL	LFL	½ LFL	LFL
IS2.4-FC61-Liquid-FB	818	10.0	1425	1209	1164	742
IS2.2-FC63-Vapour-S	0.01	>30.0	3	2	3	2
IS2.2-FC63-Vapour-M	0.22	13.4	10	7	9	6
IS2.2-FC63-Vapour-L	3.1	10.2	29	20	25	18
IS2.2-FC63-Vapour-FB	27	10.0	70	48	72	41
IS2.1-2-FC64-Liquid-S	0.28	>30.0	2	2	4	3
IS2.1-2-FC64-Liquid-M	4.2	17.8	66	NR	41	20
IS2.1-2-FC64-Liquid-L	60	10.6	397	273	150	102
IS2.1-2-FC64-Liquid-FB	81	10.4	416	228	174	119
IS3.1-FC66-Vapour-S	0.13	24.1	7	4	5	3
IS3.1-FC66-Vapour-M	1.9	11.0	52	23	39	15
IS3.1-FC66-Vapour-L	1.9 ^{Note 1}	10.1	52	23	39	15
IS3.1-FC66-Vapour-FB	1.9 ^{Note 1}	10.0	52	23	39	15
IS2.3-FC69-Vapour-S	0.02	>30.0	4	2	4	2
IS2.3-FC69-Vapour-M	0.27	12.3	12	8	11	7
IS2.3-FC69-Vapour-L	3.8	10.2	33	23	31	23
IS2.3-FC69-Vapour-FB	5.2	10.1	37	26	34	24
IS2.3-FC70-Liquid-S	0.28	>30.0	8	5	9	7
IS2.3-FC70-Liquid-M	4.1	16.0	50	11	20	14
IS2.3-FC70-Liquid-L	58	10.4	387	284	162	108
IS2.3-FC70-Liquid-FB	80	10.3	436	325	190	132
IS2.1-2-FC71-Liquid-S	0.84	22.9	15	8	13	8
IS2.1-2-FC71-Liquid-M	7.2 ^{Note 1}	10.9	138	95	64	44
IS2.1-2-FC71-Liquid-L	7.2 ^{Note 1}	10.1	138	95	64	44
IS2.1-2-FC71-Liquid-FB	7.2 ^{Note 1}	10.0	138	95	64	44

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Dispersion Downwind Distance (m) at 2F Wind		Dispersion Downwind Distance (m) at 5D Wind	
			½ LFL	LFL	½ LFL	LFL
IS2.1-FC74-Liquid-S	0.79	>30.0	11	7	13	7
IS2.1-FC74-Liquid-M	12	29.4	183	121	75	51
IS2.1-FC74-Liquid-FB	127	11.8	728	517	238	175
IS2.2-5-FC77-Vapour-S	0.23	>30.0	4	2	4	2
IS2.2-5-FC77-Vapour-M	0.33	>30.0	11	7	10	7
IS2.2-5-FC77-Vapour-L	4.8	11.5	31	21	29	20
IS2.2-5-FC77-Vapour-FB	41	10.2	67	50	64	46
IS2.2-5-FC79-Vapour-S	0.01	>30.0	3	2	3	2
IS2.2-5-FC79-Vapour-M	0.18	12.0	10	6	8	6
IS2.2-5-FC79-Vapour-L	2.6	10.2	30	20	24	17
IS2.2-5-FC79-Vapour-FB	8.1	10.1	49	32	36	26
IS2.2-FC81-Liquid-S	0.43	>30.0	3	3	6	4
IS2.2-FC81-Liquid-M	6.4	16.4	119	81	37	15
IS2.2-FC81-Liquid-L	91	10.5	496	384	195	141
IS2.2-FC81-Liquid-FB	280	10.2	675	570	360	263
IS2.2-FC82-Liquid-S	0.43	>30.0	8	6	10	7
IS2.2-FC82-Liquid-M	6.4	11.9	119	81	37	15
IS2.2-FC82-Liquid-L	91	10.1	490	381	195	141
IS2.2-FC82-Liquid-FB	280	10.1	672	566	360	263
IS2.1-5-FC85-Liquid-S	0.9	19.6	33	18	18	8
IS2.1-5-FC85-Liquid-M	4.6 ^{Note 1}	10.7	95	60	62	40
IS2.1-5-FC85-Liquid-L	4.6 ^{Note 1}	10.1	95	60	62	40
IS2.1-5-FC85-Liquid-FB	4.6 ^{Note 1}	10.0	95	60	62	40
IS2.2-3-FC88-2 Phase-S	0.13	27.3	7	5	7	4
IS2.2-3-FC88-2 Phase-M	1.9	11.2	24	15	20	13

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Dispersion Downwind Distance (m) at 2F Wind		Dispersion Downwind Distance (m) at 5D Wind	
			½ LFL	LFL	½ LFL	LFL
IS2.2-3-FC88-2 Phase-L	7.2 ^{Note 1}	10.1	47	28	33	23
IS2.2-3-FC88-2 Phase-FB	7.2 ^{Note 1}	10.1	47	28	33	23
IS2.2-5-FC89-Liquid-S	0.9	>30.0	6	6	9	7
IS2.2-5-FC89-Liquid-M	13	11.5	190	136	78	47
IS2.2-5-FC89-Liquid-FB	33 ^{Note 1}	10.1	331	246	133	97
IS2.1-FC95-Liquid-S	0.9	>30.0	26	12	18	10
IS2.1-FC95-Liquid-M	14	29.0	131	74	78	48
IS2.1-FC95-Liquid-L	193	11.3	406	266	230	156
IS2.1-FC95-Liquid-FB	1053	10.3	1131	722	447	307
IS2.3-FC96-Liquid-S	0.93	>30.0	20	9	16	9
IS2.3-FC96-Liquid-M	14	23.3	208	138	84	58
IS2.3-FC96-Liquid-L	195	10.9	928	667	601	386
IS2.3-FC96-Liquid-FB	1066	10.2	1983	1464	1435	931
IS2.3-4-FC97-Vapour-S	0.03	>30.0	10	7	10	7
IS2.3-4-FC97-Vapour-M	0.4	12.4	24	18	26	18
IS2.3-4-FC97-Vapour-FB	1.9	10.5	38	29	44	31
IS2.1-2-FC91-Liquid-S	0.35	>30.0	8	3	5	4
IS2.1-2-FC91-Liquid-M	5.2	14.5	45	28	38	23
IS2.1-2-FC91-Liquid-L	74	10.3	236	156	122	80
IS2.1-2-FC91-Liquid-FB	101	10.2	275	183	138	91
IS2.2-5-FC99-Liquid-S	0.42	>30.0	13	9	12	8
IS2.2-5-FC99-Liquid-M	602	12.2	28	14	26	18
IS2.2-5-FC99-Liquid-L	89	10.2	61	49	45	34
IS2.2-5-FC99-Liquid-FB	759	10.0	214	168	259	211
IS2.2-4-FC102-Liquid-S	0.5	>30.0	12	10	13	10

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Dispersion Downwind Distance (m) at 2F Wind		Dispersion Downwind Distance (m) at 5D Wind	
			½ LFL	LFL	½ LFL	LFL
IS2.2-4-FC102-Liquid-M	8	>30.0	36	27	36	27
IS2.2-4-FC102-Liquid-L	114	>30.0	180	93	149	90
IS2.2-4-FC102-Liquid-FB	350	17.4	365	146	287	124
IS2.1-3-FC103-Liquid-S	0.5	>30.0	4	3	7	5
IS2.1-3-FC103-Liquid-M	7.4	15.2	23	5	17	7
IS2.1-3-FC103-Liquid-L	105	10.4	64	39	53	25
IS2.1-3-FC103-Liquid-FB	144	10.3	70	44	60	30
IS2.4-FC104-Liquid-S	0.002 Note 1	20.1	2	1	2	1
IS2.4-FC104-Liquid-M	0.002 Note 1	10.7	2	1	2	1
IS2.4-FC104-Liquid-FB	0.002 Note 1	10.1	2	1	2	1
IS3.1-FC107-Liquid-S	1.2	20.5	10	7	11	7
IS3.1-FC107-Liquid-M	17	10.7	56	28	37	20
IS3.1-FC107-Liquid-FB	85	10.2	128	76	85	51
OS5-FC138-Liquid-S	0.2	>30.0	5	4	7	5
OS5-FC138-Liquid-M	3	13.2	7	6	10	8
OS5-FC138-Liquid-L	44	10.2	9	8	10	9
OS5-FC138-Liquid-FB	134	10.1	11	10	11	10
OS4-FC140-Vapour-S	0.05	19.9	11	6	8	5
OS4-FC140-Vapour-M	0.7	10.7	39	26	44	27
OS4-FC140-Vapour-FB	3.3	10.1	63	47	75	55
OS4-FC140A-Vapour-S	0.2	14.8	23	12	21	10
OS4-FC140A-Vapour-M	2.5	10.3	60	44	71	51
OS4-FC140A-Vapour-FB	12	10.1	90	71	111	86
OS4-FC140B-Vapour-S	0.2	>30.0	24	13	23	10
OS4-FC140B-Vapour-M	2.7	>30.0	61	45	73	53

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Dispersion Downwind Distance (m) at 2F Wind		Dispersion Downwind Distance (m) at 5D Wind	
			½ LFL	LFL	½ LFL	LFL
OS4-FC140B-Vapour-FB	13	15.2	92	73	113	88
IS3.1-FC145-Liquid-S	0.3	>30.0	6	5	7	5
IS3.1-FC145-Liquid-M	4.7	12.7	96	57	47	28
IS3.1-FC145-Liquid-L	67	10.2	397	262	165	113
IS3.1-FC145-Liquid-FB	573	10.0	902	631	480	339
IS1.4-FC146-Liquid-S	0.3	>30.0	9	7	11	8
IS1.4-FC146-Liquid-M	4.7	11.9	16	13	20	15
IS1.4-FC146-Liquid-L	67	10.1	23	21	27	23
IS1.4-FC146-Liquid-FB	205	10.1	27	24	29	25
IS1.3-FC147-Liquid-S	0.2	>30.0	5	4	7	5
IS1.3-FC147-Liquid-M	3.1	13.2	7	6	10	8
IS1.3-FC147-Liquid-L	44	10.2	9	8	10	9
IS1.3-FC147-Liquid-FB	134	10.1	11	10	11	10
OS5-FC150-Liquid-S	0.32	>30.0	9	6	8	5
OS5-FC150-Liquid-M	4.7	>30.0	104	60	50	31
OS5-FC150-Liquid-L	67	>30.0	424	289	178	127
OS5-FC150-Liquid-FB	207	>30.0	768	521	305	219
OS5-FC160-Vapour-S	0.06	19.8	4	2	3	2
OS5-FC160-Vapour-M	0.9	10.7	16	8	12	6
OS5-FC160-Vapour-L	13	10.1	107	44	111	39
OS5-FC160-Vapour-FB	40	10.0	215	92	217	88
OSBL-FC163-Liquid-S	0.5	>30.0	9	7	8	6
OSBL-FC163-Liquid-M	4.4 ^{Note 1}	12.0	18	15	16	14
OSBL-FC163-Liquid-L	4.4 ^{Note 1}	10.1	18	15	16	14
OSBL-FC163-Liquid-FB	4.4 ^{Note 1}	10.1	18	15	16	14

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Dispersion Downwind Distance (m) at 2F Wind		Dispersion Downwind Distance (m) at 5D Wind	
			½ LFL	LFL	½ LFL	LFL
OS1.1-FC164-Vapour-S	0.02	>30.0	2	1	2	1
OS1.1-FC164-Vapour-M	0.3	11.7	6	3	5	3
OS1.1-FC164-Vapour-L	4	10.1	36	15	33	13
OS1.1-FC164-Vapour-FB	23	10.0	96	46	108	43
NR: Maximum concentration below this value.						
Note 1: Release rate capped to 150% of upstream flowrate.						
Note 2: No large releases were considered if the maximum piping size in the section is <87mm						

D.5 Toxic Dispersion Results

Table D-0-5: Toxic Dispersion result (Acetaldehyde)

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Toxic Dispersion Downwind Distance (m) to AEGL-2 (340ppm)	
			2F	5D
IS1.2-FC03-Vapour-S	0.01	>30.0	NR	NR
IS1.2-FC03-Vapour-M	0.1	>30.0	NR	NR
IS1.2-FC03-Vapour-L	1.4	12.2	NR	NR
IS1.2-FC03-Vapour-FB	6.6 ^{Note 1}	10.1	96 ^{Note 3}	63 ^{Note 3}
IS1.2-FC07-Vapour-S	0.005	15.2	NR	NR
IS1.2-FC07-Vapour-M	0.1	10.4	NR	NR
IS1.2-FC07-Vapour-L	1.0	10.0	NR	NR
IS1.2-FC07-Vapour-FB	1.4	10.0	NR	NR
IS1.2-FC08-Liquid-S	0.2	>30.0	NR	NR

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Toxic Dispersion Downwind Distance (m) to AEGL-2 (340ppm)	
			2F	5D
IS1.2-FC08-Liquid-M	2.3	23.2	55	NR
IS1.2-FC08-Liquid-L	4.4 ^{Note 1}	10.9	74	26
IS1.2-FC08-Liquid-FB	4.4 ^{Note 1}	10.7	74	26
IS1.3-FC26-Vapour-S	0.05	>30.0	NR	NR
IS1.3-FC26-Vapour-M	0.7	>30.0	NR	NR
IS1.3-FC26-Vapour-L	10	12.0	NR	NR
IS1.3-FC26-Vapour-FB	89	10.2	NR	NR
IS1.2-FC28-Liquid-S	0.5	26.2	NR	NR
IS1.2-FC28-Liquid-M	6.8 ^{Note 1}	11.1	120	38
IS1.2-FC28-Liquid-FB	6.8 ^{Note 1}	10.1	120	38
IS1.2-FC31-Vapour-S	0.04	>30.0	NR	NR
IS1.2-FC31-Vapour-M	0.7	14.2	NR	NR
IS1.2-FC31-Vapour-L	9.1 ^{Note 1}	10.3	32 ^{Note 3}	26 ^{Note 3}
IS1.2-FC31-Vapour-FB	9.1 ^{Note 1}	10.1	32 ^{Note 3}	26 ^{Note 3}
IS3.1-FC30-Vapour-S	0.1	>30.0	4	3
IS3.1-FC30-Vapour-M	2.2	14.6	20	13
IS3.1-FC30-Vapour-L	7.3 ^{Note 1}	10.3	49	42
IS3.1-FC30-Vapour-FB	7.3 ^{Note 1}	10.1	49	42
IS1.3-FC32-Vapour-S	0.2	>30.0	NR	NR
IS1.3-FC32-Vapour-M	2.5	26.2	NR	NR
IS1.3-FC32-Vapour-L	4.2 ^{Note 1}	11.1	25 ^{Note 3}	24 ^{Note 3}
IS1.3-FC32-Vapour-FB	4.2 ^{Note 1}	10.2	25 ^{Note 3}	24 ^{Note 3}
IS1.3-FC33-Liquid-S	0.8	11.4	NR	NR
IS1.3-FC33-Liquid-M	2.5 ^{Note 1}	10.1	20 ^{Note 3}	23 ^{Note 3}
IS1.3-FC33-Liquid-FB	2.5 ^{Note 1}	10.0	20 ^{Note 3}	23 ^{Note 3}

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Toxic Dispersion Downwind Distance (m) to AEGL-2 (340ppm)	
			2F	5D
IS1.2-FC36-Liquid-S	0.8	16.8	NR	NR
IS1.2-FC36-Liquid-M	1.4 ^{Note 1}	10.5	41	23 ^{Note 3}
IS1.2-FC36-Liquid-L	1.4 ^{Note 1}	10.0	41	23 ^{Note 3}
IS1.2-FC36-Liquid-FB	1.4 ^{Note 1}	10.0	41	23 ^{Note 3}
IS1.3-FC39-Liquid-S	0.3	23.1	NR	NR
IS1.3-FC39-Liquid-M	3.7	10.9	65 ^{Note 3}	48 ^{Note 3}
IS1.3-FC39-Liquid-L	5.7 ^{Note 1}	10.1	132	56 ^{Note 3}
IS1.3-FC39-Liquid-FB	5.7 ^{Note 1}	10.0	132	56 ^{Note 3}
IS1.4-FC46-Vapour-S	0.03	>30.0	NR	NR
IS1.4-FC46-Vapour-M	0.4	13.3	NR	NR
IS1.4-FC46-Vapour-L	6.4	10.2	NR	NR
IS1.4-FC46-Vapour-FB	20	10.1	NR	NR
IS1.4-FC47-Liquid-S	0.3	26.2	NR	NR
IS1.4-FC47-Liquid-M	4.1	11.1	NR	NR
IS1.4-FC47-Liquid-L	2.6 ^{Note 1}	10.1	NR	NR
IS1.4-FC47-Liquid-FB	2.6 ^{Note 1}	10.0	NR	NR
IS1.2-4-FC49-Liquid-S	0.3	>30.0	NR	NR
IS1.2-4-FC49-Liquid-M	1.3 ^{Note 1}	18.1	12	18
IS1.2-4-FC49-Liquid-L	1.3 ^{Note 1}	10.6	12	18
IS1.2-4-FC49-Liquid-FB	1.3 ^{Note 1}	10.2	12	18
IS1.3-FC51-Vapour-S	0.02	>30.0	NR	NR
IS1.3-FC51-Vapour-M	0.2	27.3	NR	NR
IS1.3-FC51-Vapour-L	3.3	11.2	NR	NR
IS1.3-FC51-Vapour-FB	28	10.1	NR	NR
IS1.1-2-FC52-Liquid-S	0.8	>30.0	5	5

FAILURE CASE ID	Peak Release Rate (kg/s)	Release Duration (mins)	Toxic Dispersion Downwind Distance (m) to AEGL-2 (340ppm)	
			2F	5D
IS1.1-2-FC52-Liquid-M	7.6 ^{Note 1}	13.4	55	30
IS1.1-2-FC52-Liquid-L	7.6 ^{Note 1}	10.2	55	30
IS1.1-2-FC52-Liquid-FB	7.6 ^{Note 1}	10.2	55	30
OS5-FC138-Liquid-S	0.2	>30.0	29	19
OS5-FC138-Liquid-M	3	13.2	97	75
OS5-FC138-Liquid-L	44	10.2	331	250
OS5-FC138-Liquid-FB	134	10.1	369	288
NR: Maximum concentration of Acetaldehyde released below 340ppm. Note 1: Release rate capped to 150% of upstream flowrate. Note 2: No large releases were considered if the maximum piping size in the section is <87mm Note 3: Toxic cloud > 2m above ground				

D.6 Escalation Event Results

Table D-0-6: Escalation Results

FAILURE CASE	Event	Material	Explosion Overpressure Radii (m)			
			0.07 bar	0.14 bar	0.21 bar	0.35 bar
Domino_1	LPG Tank T-7500 BLEVE	Propane	83	52	39	29
Domino_2	Hydrogen Storage Tank V-4351/2 Catastrophic Rupture	Hydrogen	129	85	67	49
Domino_3	IS1 module escalation (Ethylene Refinement Column Reflux Drum) BLEVE	Stream 1503 (100% Ethylene)	56	36	27	20
Domino_4	IS2 module escalation (Olig 1 HP Separator) BLEVE	Stream 2203	38	24	18	13
Domino_5	IS3 module escalation (Refrigeration Package Z-3400) BLEVE	Propane	35	21	17	12