# Report

## Land Use Planning QRA for the Firlough Windfarm Hydrogen Generation Facility

## Prepared for – Mercury Renewables

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# EXECUTIVE SUMMARY

Mercury Renewables has submitted a planning application to An Bord Pleanála for the construction and operation of the proposed Firlough Wind Farm and integrated hydrogen production facility (the "Hydrogen Plant"). The Hydrogen Plant will be classed as a lower-tier COMAH site under the COMAH Regulations [1], based upon the expected maximum quantities of hydrogen on-site.

Following consultation with the Irish Health and Safety Authority ("HSA"), Mercury Renewables has contracted Risktec to produce a Land Use Planning (LUP) style Quantitative Risk Assessment (QRA). The study has been developed in accordance with the inputs, methodology and rulesets outlined in the Irish Health and Safety Authority (HSA) Guidance for Technical Land Use Planning (TLUP) [2], which has recently been updated with guidance for hydrogen installations. The associated methodology, and hence results presented in this report, are only appropriate for determining off-site risks and should not be used as a basis for determining risks close to the hazard sources.

This document presents the methodology, results and conclusions of the LUP QRA.

The main objectives of the LUP QRA study are to:

- Determine the off-site risks posed by the process hazard scenarios to enable evaluation of the suitability of the proposed location;
- Determine the proposed Consultation Distance (CD) and inner risk zones around the establishment to inform future development projects around the facility;
- Calculate the societal risk levels, if appropriate; and
- Provide recommendations for risk reduction where appropriate measures can be identified.

### Consequence Modelling Results

The HSA guidance adopts a risk-based approach to provide advice for the suitability of a facility's location, hence there are no specific criteria associated with the consequence results. Nevertheless, the extent of the hazard consequences from each of the release scenarios have been modelled using the Safeti v8.6 software (which implements Phast consequence modelling software). The results of the modelling are tabulated in Appendix D as follows:

- Distances to Lower Flammable Limits (LFL) and Upper Flammable Limits (UFL) from flammable gas dispersion (showing the flash fire extent);
- Distances to specified thermal radiation levels from jet fires; and
- Distances to specified vapour cloud explosion overpressure levels.

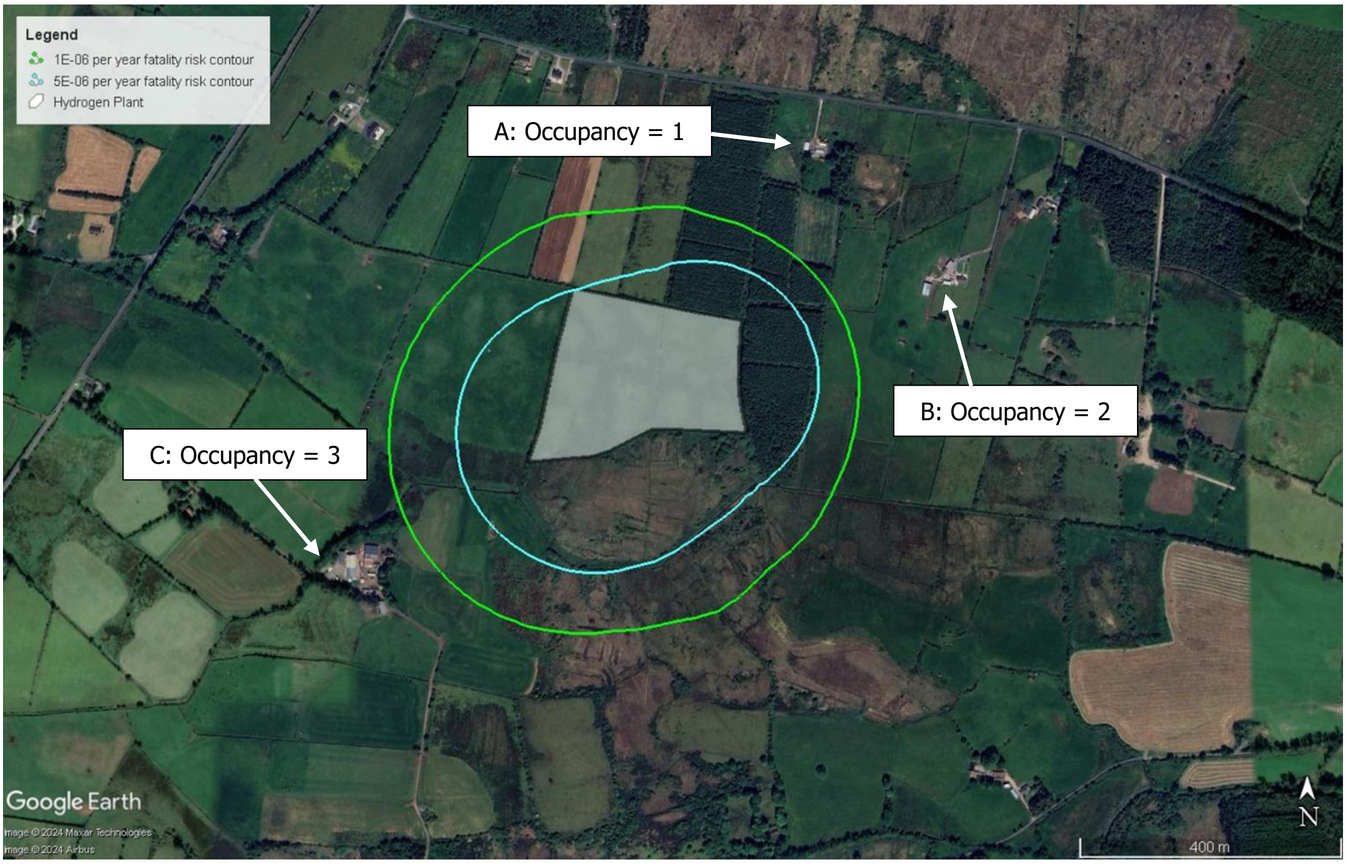
### Risk Modelling Results

The individual location-based risk contours for new establishments, not to be exceeded, are as follows:

- 1E-06 /year - maximum tolerable risk to a member of the public; and
- 5E-06 /year - maximum tolerable risk to a person at an off-site work location.

The above forms the primary evaluation criteria on which the acceptability of site location has been assessed.

Individual risk contours corresponding to these criteria, as derived from this study, are presented in the figure overleaf.




**Individual Risk Contours from the Hydrogen Plant (relevant to new establishments)**

As can be seen from the above individual risk results, there are no occupied areas or houses within the risk contours. The nearest occupied areas (which are all located outside the 1E-06 /year contour) can be summarised as follows:

- Location A (located >140 m outside the 1E-06 /year contour, to the north): Residential house with one person living in the premises. There is no elevated occupancy (e.g. contractor work) during temporary periods. A maximum occupancy of one can therefore be assigned to this location.
- Location B (located >120 m outside the 1E-06 /year contour, to the east): Premises includes farm shed that houses small number of beef cattle during winter months. The owner of the farm is also resident at the house at the premises. The farmer would be considered temporarily on-site / temporary worker as well as one further temporary worker. A maximum occupancy of two can therefore be assigned to this location.
- Location C (located >40 m outside the 1E-06 /year contour, to the south-west): Automated milking parlour which has the following occupancy:
  - One full time worker on-site seven days a week;
  - Milk collection by one person from the farm occurring once every two days; and
  - Feed delivery by one person occurring every two days.

  A maximum occupancy of three can therefore be assigned to this location, noting that coincident occupancy of the above personnel is an unlikely situation.

The above risk contours have been derived on the basis that the facility is shutdown and isolated within 60 seconds, as per the isolation points outlined in Appendix B. To determine the sensitivity of the contours to this assumption, an alternative case is presented in Appendix E for a theoretical worst case scenario whereby no isolation points are implemented. It can be seen that the worst case contours with no isolation also do not affect the nearest occupied locations.

These results provide evidence that the facility location satisfies the HSA criteria for new establishments. In addition, the following conclusions can also be drawn from this analysis:

- The Consultation Distance (CD) is estimated to extend up to a maximum of 390 m from the site boundary. The outer, middle and inner zones are estimated to extend up to a maximum of 360 m, 290 m and 130 m from the site boundary respectively. These contours should be used to inform future development feasibility; and
- Due to the very limited occupancy/populations within the 1E-09 /year contours (CD), societal risks are considered negligible.

In conclusion, the results of the analysis show that the proposed site of the Hydrogen Plant is within the tolerable risk region as per the HSA's TLUP guidance criteria for new establishments. Due to the broadly acceptable results, no recommendations are drawn from the study in relation to the proposed location of the Hydrogen Plant.

The following recommendations have been derived from this study:

- It is recommended that a detailed QRA should be undertaken as the project advances to ensure risk to workers on-site is evaluated, but note this is not a requirement at the current stage of development.
- It is recommended that the CD and inner risk zones are updated and finalised as the design progresses.

## ISSUE RECORD

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## DISTRIBUTION

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| File | Risktec Solutions Limited, Warrington, United Kingdom |

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# FIGURES

## ABBREVIATIONS

| | |
|---|---|
| ALARP | As Low As Reasonably Practicable |
| API | American Petroleum Institute |
| CD | Consultation Distance |
| CEDI | Continuous Electro-Deionisation |
| CIA | UK Chemical Industry Association |
| COMAH | Control of Major Accident Hazards |
| cpm | Chances Per Million |
| ESDV | Emergency Shutdown Valve |
| EV | Expectation Value |
| $H_2$ | Hydrogen |
| HSA | Health and Safety Authority (Irish Regulator) |
| HV | High Voltage |
| ISO | International Organization for Standardization |
| LFL | Lower Flammable Limit |
| LSIR | Location Specific Individual Risk |
| LUP | Land Use Planning |
| LV | Low Voltage |
| NNF | Not Normally Flowing |
| QRA | Quantitative Risk Assessment |
| RO | Reverse Osmosis |
| RTU | Road Transport Unit |
| TNO | The Netherlands Organisation (for applied scientific research) |
| UDM | Unified Dispersion Model |
| UFL | Upper Flammable Limit |
| VCE | Vapour Cloud Explosion |

# 1 INTRODUCTION

## 1.1 Overview

Mercury Renewables has submitted a planning application to An Bord Pleanála for the construction and operation of the proposed Firlough Wind Farm and integrated hydrogen production facility (the "Hydrogen Plant"). The Hydrogen Plant will be classed as a lower-tier COMAH site under the COMAH Regulations [1], based upon the expected maximum quantities of hydrogen on-site.

Following consultation with the Irish Health and Safety Authority ("HSA"), Mercury Renewables has contracted Risktec to produce a technical Land Use Planning (LUP) style Quantitative Risk Assessment (QRA).

## 1.2 Scope and Objectives

The main objectives of the LUP QRA study are to:

- Determine the offsite risks posed by the process hazard scenarios to enable evaluation of the suitability of the proposed location;
- Determine the proposed Consultation Distance (CD) in inner risk zones around the establishment to inform future development projects around the facility;
- Calculate the societal risk levels; and
- Provide recommendations for risk reduction where appropriate measures can be identified.

The study has been developed in accordance with the inputs, methodology and rulesets outlined in the Health and Safety Authority (HSA) guidance on land use planning [2].

The HSA guidance adopts best practice in technical land use planning, and is intended to achieve the principles of consistency, proportionality and transparency as per the European guidelines on land use planning [3]. To fulfil these principles, the methodology is deliberately not as comprehensive as a full QRA and focuses on assessment of off-site risk. The methodology, and hence results presented in this report, are not appropriate for determining risks close to the hazard sources.

# 2 HYDROGEN PLANT DESCRIPTION

## 2.1 Site Location

The proposed site of the Hydrogen Plant is approximately 6 km west of the proposed Firlough windfarm, County Sligo as shown in Figure 2-1. The footprint of the proposed site of the Hydrogen Plant is approximately 6.5 hectares.

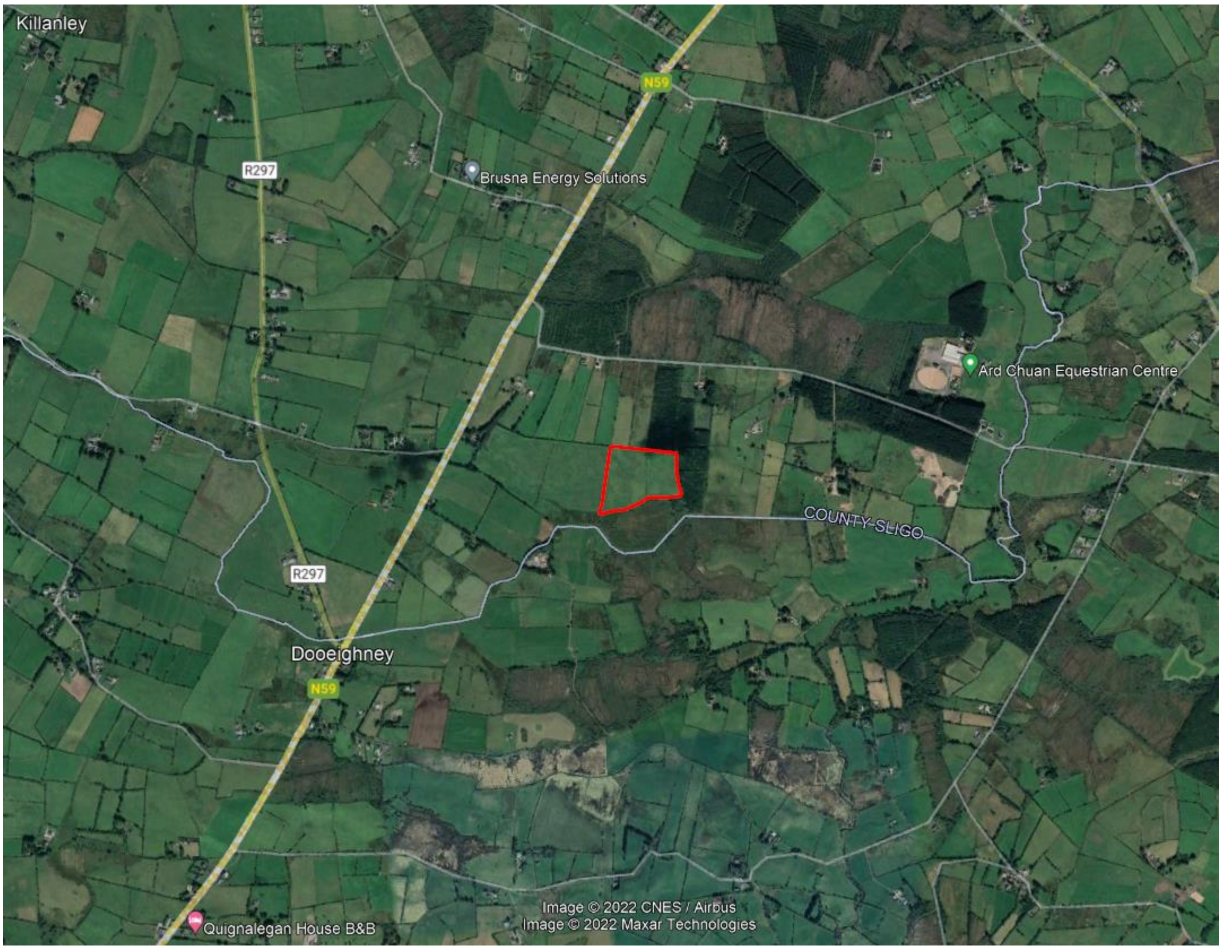



**Figure 2-1: Satellite Image Showing Proposed Location of the Hydrogen Plant**

## 2.2 Plant Description

The following sections provide a high-level description of the Hydrogen Plant, key quantities and site layout. It should be noted that all information contained here is based on design stage documents produced as supporting information for the planning application and may change as the project progresses. An overview of the system is provided in Figure 2-2.

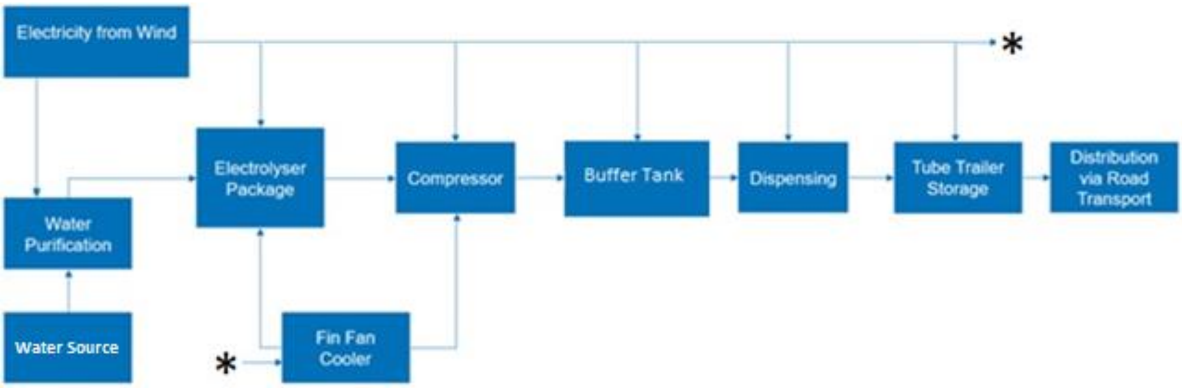



**Figure 2-2: Hydrogen Plant High Level Block Diagram**

### 2.2.1 Electricity Supply

A 110 kV, 78 MW electricity supply, routed via a dedicated power cable from the windfarm substation, will provide power to the Hydrogen Plant for the electrolytic conversion of water to hydrogen for subsequent distribution. The electricity supply will be routed to site via a dedicated high voltage (HV) and low voltage (LV) switchboard and stepdown transformer located to the east of site.

### 2.2.2 Water Source

Two on-site water extraction boreholes will provide a source of electrolyte feed water and cooling water. Electrolyte will be routed to a water purification plant, cooling water will only be required during top up of systems and will be mixed with glycol to provide a coolant solution capable of handling the generated heat and environmental temperature variation.

### 2.2.3 Water Purification

Water from the borehole will contain minerals and other impurities which, if allowed to enter the electrolyser may present a hazard to equipment. As such all feed water will be routed via a water purification plant. The water treatment process includes double pass reverse osmosis (RO) and continuous electro-deionisation (CEDI).

### 2.2.4 Electrolyser

The electrolyser uses electrical energy to convert the water-based electrolyte to hydrogen and oxygen. The low pressure hydrogen will be routed to the multistage compressor for compression to suitable pressure for storage or distribution. The produced oxygen will be vented to atmosphere via the oxygen vent.

### 2.2.5 Oxygen Vent

The oxygen vent routes gaseous by-products from the anode side of the electrolyser, to atmosphere, at a safe location. Sufficient ventilation will be installed into the electrolyser building to prevent accumulation of oxygen.

### 2.2.6 Fin Fan Cooling

Splitting of water to hydrogen and oxygen requires a large amount of energy which results in a significant amount of waste heat. To ensure optimal and safe running of the alkaline electrolyser, the excess heat will be managed via a liquid to air exchange system designed around a bank of fin fan coolers. These will be located away from the main process area.

The electrolyser elements will be housed within a water jacket, or similar direct contact exchange system, with a pumped coolant system carrying waste heat to the remote fin fans. The design incorporates nine fin fan coolers.

The fin fan coolers will also provide a heat exchange for the hydrogen compressor package cooling loop, which is separate from the electrolyser cooling system but is expected to include a similar cooling design.

### 2.2.7 HP Compressors

The 2 x 100% compressors (identical in operation) receive hydrogen from the electrolyser and compresses it to a pressure of 500bar for buffering storage. The high-pressure hydrogen will be routed from the output of the compressor to an intermediate buffer vessel for short term storage.

### 2.2.8 Buffer Tank

The buffer tank is located between the hydrogen compressor package and the road vehicle dispensing units to provide a consistent supply of hydrogen that is not reliant on the output of the electrolyser. The buffer tank will operate at 500 bar, and contain a maximum of 528 kg of hydrogen.

### 2.2.9 Dispensing

Seven road vehicle dispensing units are included in the design. The dispensing units consist of a number of gas control devices, a gas receiver, and hose work to dispense hydrogen to road approved tube trailers. Hydrogen dispensing stations are designed and will operate in accordance with established safety standards to ensure their safety (such as ISO 16964, ISO 15916 and ISO 1980).

### *2.2.10 Tube Trailer Storage and Distribution*

Compressed hydrogen will be stored on-site and distributed off-site via road tube trailers. On-site storage is planned for a maximum of 26 x 12 m tube trailers, providing a total storage capacity of 31,200 kg. The length of time a tube trailer remains on-site will vary depending on market conditions, offtake agreements and offtake purposes. Therefore it is difficult to assess the exact on-site operational storage requirements. However, the quantity of hydrogen stored on-site will be monitored, and if for any reason trailers cannot leave the site, hydrogen production will cease to ensure on-site storage does not exceed 50 tonnes.

## 2.3 Layout

A plot plan of the Hydrogen Plant is shown in Figure 2-3, with key hydrogen processing and storage locations marked.


**Figure 2-3: Plot Plan Showing Hydrogen Processing and Storage Areas**

# 3 METHODOLOGY

The following sections present a summary of the methodology adopted to develop the LUP QRA. The study has been developed in accordance with HSA guidance [2]. Where necessary, supplementary inputs and assumptions have been developed and are presented in Appendix A of this report.

## 3.1 Hazard Identification

The initial stage of analysis consists of defining the system as a discrete set of release scenarios. In essence, this activity involves dividing the system into isolatable inventories defined by Emergency Shutdown Valves (ESDVs). Within each isolatable inventory, sub-sections are defined based on variation in location, pressure, temperature and composition. The number of equipment items has been counted within each sub-section and the associated process parameters (pressure, temperature etc.) were selected from review of the available input data.

The output of the above release scenario definition is presented in Appendix B.

Note that modelling has focussed on the hydrogen inventories, since these will pose the most significant off-site hazards. The diesel and glycol inventories at site have not been modelled due to their localised hazard range and low ignition probabilities.

## 3.2 Consequence Modelling

Consequence modelling has been performed using the Safeti v8.6 software [5], which incorporates Phast; a globally adopted solution for modelling discharge, dispersion, fires and explosions from loss of containment scenarios.

The modelled leak sizes have been based on the recommended scenarios in the HSA guidance [2]. This principally includes catastrophic failures, loss of entire contents over a 10 minute period and small leaks of 10 mm diameter. In addition, loss of containment from Road Transport Units (RTU), storage vessels, loading arms and pipelines within the boundary of the site have been modelled. All release sources are assumed to be at 1 m above ground level, with effects calculated at a height of 1 m to represent the most likely impact on personnel.

In alignment with the HSA Guidance [2], gas dispersion modelling has been carried out for two weather conditions, as follows:

- Wind speed 2 m/s and Pasquill stability class 'F'; and
- Wind speed 5 m/s and Pasquill stability class 'D'.

Other meteorological data are presented in Assumption Sheet A03 in Appendix A.

The potential hazards arising from loss of containment that have been assessed are based on HSA prescribed requirements and described in further detail in Appendix D.

## 3.3 Risk Modelling

The Safeti software [5] has been used to calculate the geographic risk profile around the facility. The risk calculation necessitates incorporation of a frequency for each release scenario, ignition probability, equipment operating factors, wind direction probability and fatality probability associated with the hazardous effects.

The HSA prescribes both the release event frequency per equipment item, and the end consequence frequencies [2]. These are reproduced in Assumption Sheet A05 in Appendix A, along with the ignition probability rulesets to ensure the consequence frequencies align. The release frequency across the Hydrogen Plant has been determined by summing up the number of individual equipment items within each sub-section, and positioning release locations appropriately in the Safeti model as per the site layout.

The seven loading arms and RTUs in the loading bays have conservatively assumed to be in operation 100% of the time. It has been assumed that all twenty-six parking bays in the storage area to the south of site are permanently occupied by fully hydrogen-laden RTUs.

To ensure the total frequency of the consequence outcome (i.e. explosion, jet fire and flash fire) aligns with the HSA recommended consequence frequencies, the ignition probability data as per Assumption Sheet A05 has been incorporated into the Safeti model.

The wind directional probability (wind rose) has been derived from data collected by Met Éireann at Knock Airport from 1996 to 2022 [4] to align with HSA guidance [2], and is presented in Assumption Sheet A03 in Appendix A.

The fatality probability models, presented in Assumption Sheet A05 in Appendix A, were utilised to estimate the probability of fatality from flash fire, thermal radiation and explosion overpressure. The fatality probability models are distinct for personnel located outdoors and indoors, and it has been assumed that people are indoors 90% of the time [2].

## 3.4 Evaluation Criteria

### *3.4.1 Consequence Criteria*

The HSA guidance adopts a risk-based approach to provide advice for the suitability of facility location, hence there are no specific criteria associated with the consequence results. The consequence modelling results must be combined with the likelihood of each event to obtain a risk value, which can then be compared against criteria, as described in the following sections.

### *3.4.2 Individual Risk for New Establishments*

The risk modelling enables individual location-based risk contours to be drawn on a map of the establishment and the surrounding area. These risk lines represent the average probability per year that a fatality will occur to a person permanently present at a location.

Individual risk is expressed as the risk of fatality per year, usually using scientific notation. Risk per year can also been converted to one fatality every 'X' years by calculating one divided by the risk per year, e.g. $1 \times 10^{-6}$ fatalities per year is equivalent to 1 fatality every 1,000,000 years. Commonly used formats for these risk values are presented in Table 3-1.

**Table 3-1: Scientific Notation**

| Frequency of fatality (per year) | | Chances per million (cpm) years | 1 in 'X' years |
|---|---|---|---|
| $1 \times 10^{-6}$ | 1E-06 | 1 | 1 in a million years |
| $5 \times 10^{-6}$ | 5E-06 | 5 | 1 in 200,000 years |

In keeping with the longer-term aims for LUP under the Seveso Directive, technical advice in relation to new COMAH establishments is more stringent than that which applies to existing COMAH establishments. The individual location-based risk contours for new establishments, not to be exceeded, are as follows:

- 1E-06 /year - maximum tolerable risk to a member of the public; and
- 5E-06 /year - maximum tolerable risk to a person at an off-site work location.

The above forms the primary evaluation criteria on which the acceptability of site location has been assessed.

### *3.4.3 Consultation Distance (CD) and Inner Risk Zones*

In addition to the criteria for evaluation of new establishments (as per the previous section), it is necessary for new establishments to propose a Consultation Distance (CD) and submit it to the planning authority as part of a planning application.

Within the CD are a number of inner risk zones which are used to inform the acceptability of future developments around the facility. The CD and inner risk zones can be defined as follows:

- 1E-05 /year – risk of fatality for inner zone (Zone 1) boundary;
- 1E-06 /year – risk of fatality for middle zone (Zone 2) boundary;
- 1E-07 /year – risk of fatality for outer zone (Zone 3) boundary; and
- 1E-09 /year – Consultation Distance (CD).

Future proposed developments within the CD will be assigned a category (Level 1-4) based on their sensitivity to major hazards. The HSA-defined levels are shown in Figure 3-1, which is an extract from the HSA's LUP guidelines document [2]. Development types are expanded upon in Appendix 2 of the guidelines; Level 2 includes houses, apartments, retirement flats, bungalows, residential caravans and mobile homes.

| Level | Development type |
|---|---|
| Level 1 | Workplaces, Car parks |
| Level 2 | Development for use by the general public |
| Level 3 | Development for use by vulnerable people |
| Level 4 | Very large or sensitive development |


**Figure 3-1: Consultation Distance Categories for Proposed Developments**

The HSA LUP guideline document states: "*Broadly, the competent authority's generic technical advice to planning authorities takes the form of 'Advises against' ( ✗ ) or 'Does not advise against' ( ✓ )"* as illustrated in Figure 3-2.

| | Inner Zone (Zone 1) | Middle Zone (Zone 2) | Outer Zone (Zone 3) |
|---|---|---|---|
| Level 1 | ✓ | ✓ | ✓ |
| Level 2 | ✗ | ✓ | ✓ |
| Level 3 | ✗ | ✗ | ✓ |
| Level 4 | ✗ | ✗ | ✗ |

**Figure 3-2: HSA Advice for Proposed Developments within the Consultation Distance**

### *3.4.4 Societal Risk*

Societal risk is a measurement of the potential for accidents from the facility to affect multiple people. To take account of societal risk from the Hydrogen Plant, an estimate of the Expectation Value (EV) is necessary. The EV of a single release scenario is the product of the individual risk (expressed in chances per million) and the potential number of people affected. The EV from an entire facility is the sum of the EV from all release scenarios. The HSA define the following EV criteria [2]:

- The total off-site EV should not exceed the criterion upper limit EV of 10,000;
- Between EVs of 100 and 10,000, it should be demonstrated that all practicable efforts have been made to reduce the risk to a level that is As Low As Reasonably Practicable (ALARP); and
- Above an EV level of 450, an F-N curve will be required (as explained below).

An F-N curve shows the relationship between the number of likely fatalities (N) and the cumulative frequencies of events likely to cause N or more fatalities. The F-N criteria as per the HSA guidance [2] are presented in Figure 3-3 below, and can be explained as follows:

- F-N results residing above the red line can be considered unacceptable;
- F-N results between the two lines, operators and potential operators will be required to demonstrate that all reasonable efforts have been made to reduce the risk to a level that is As Low As Reasonably Practicable (ALARP); and
- F-N results below the blue line are considered broadly acceptable.

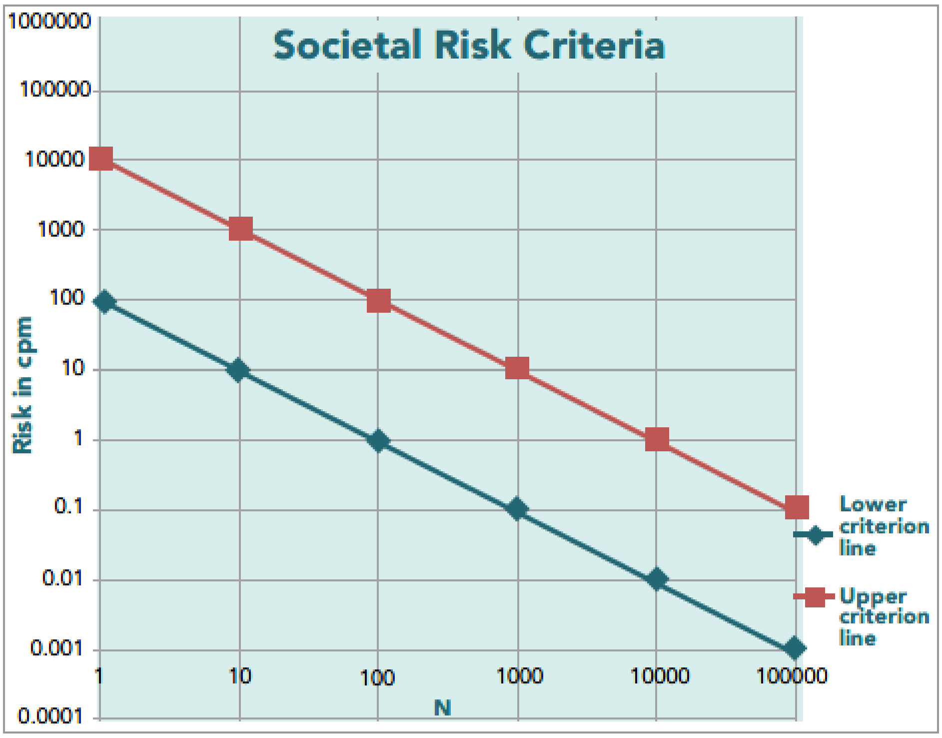



**Figure 3-3: F-N Curve Tolerability Criteria (extract from HSA LUP Guidance [2])**

# 4 RESULTS

## 4.1 Consequence Modelling Results

The extents of the hazard consequences from each of the release scenarios were modelled using the Safeti v8.6 software. The results of the modelling for each type of release are tabulated in Appendix D as follows:

- Distances to the Lower Flammability Limit (LFL) and Upper Flammability Limit (UFL) from flammable gas dispersion (showing the flash fire extent);
- Distances to specified thermal radiation levels from jet fires; and
- Distances to specified vapour cloud explosion overpressure levels.

## 4.2 Risk Contours for New Establishments

The individual location-based risk contours relevant to new establishments are presented in Figure 4-1 as follows:

- 1E-06 /year - maximum tolerable risk to a member of the public; and
- 5E-06 /year - maximum tolerable risk to a person at an off-site work location.

It can be seen from Figure 4-1 that there are no buildings or outdoor populated areas within the risk contours. The nearest occupied buildings, outside the 1E-06 /year contour as indicated in Figure 4-1, can be summarised as follows:

- Location A (located >140 m outside the 1E-06 /year contour): Residential house with one person living in the premises. There is no elevated occupancy (e.g. contractor work) during temporary periods. A maximum occupancy of one can therefore be assigned to this location.
- Location B (located >120 m outside the 1E-06 /year contour): Premises includes farm shed that houses small number of beef cattle during winter months. The owner of the farm is also resident at the house at premises. Farmer would be considered temporarily on-site / temporary worker as well as one further temporary worker. A maximum occupancy of two can therefore be assigned to this location.
- Location C (located >40 m outside the 1E-06 /year contour): Automated milking parlour which has the following occupancy:
  - One full time worker on-site seven days a week;
  - Milk collection by one person from the farm occurring once every two days;
  - Feed delivery by one person occurring every two days

  A maximum occupancy of three can therefore be assigned to this location, noting that coincident occupancy of the above personnel is an unlikely situation.

The results in Figure 4-1 have been derived on the basis that the facility is shutdown and isolated within 60 seconds, as per the isolation points depicted in Appendix B. To assess the sensitivity of the contours to this assumption, an alternative case is presented in Appendix E for a theoretical worst case scenario whereby no isolation is implemented. In this case, the entire facility hydrogen inventory can be released from any release location. It can be seen that the worst case contours with no isolation do not affect the nearest occupied locations.

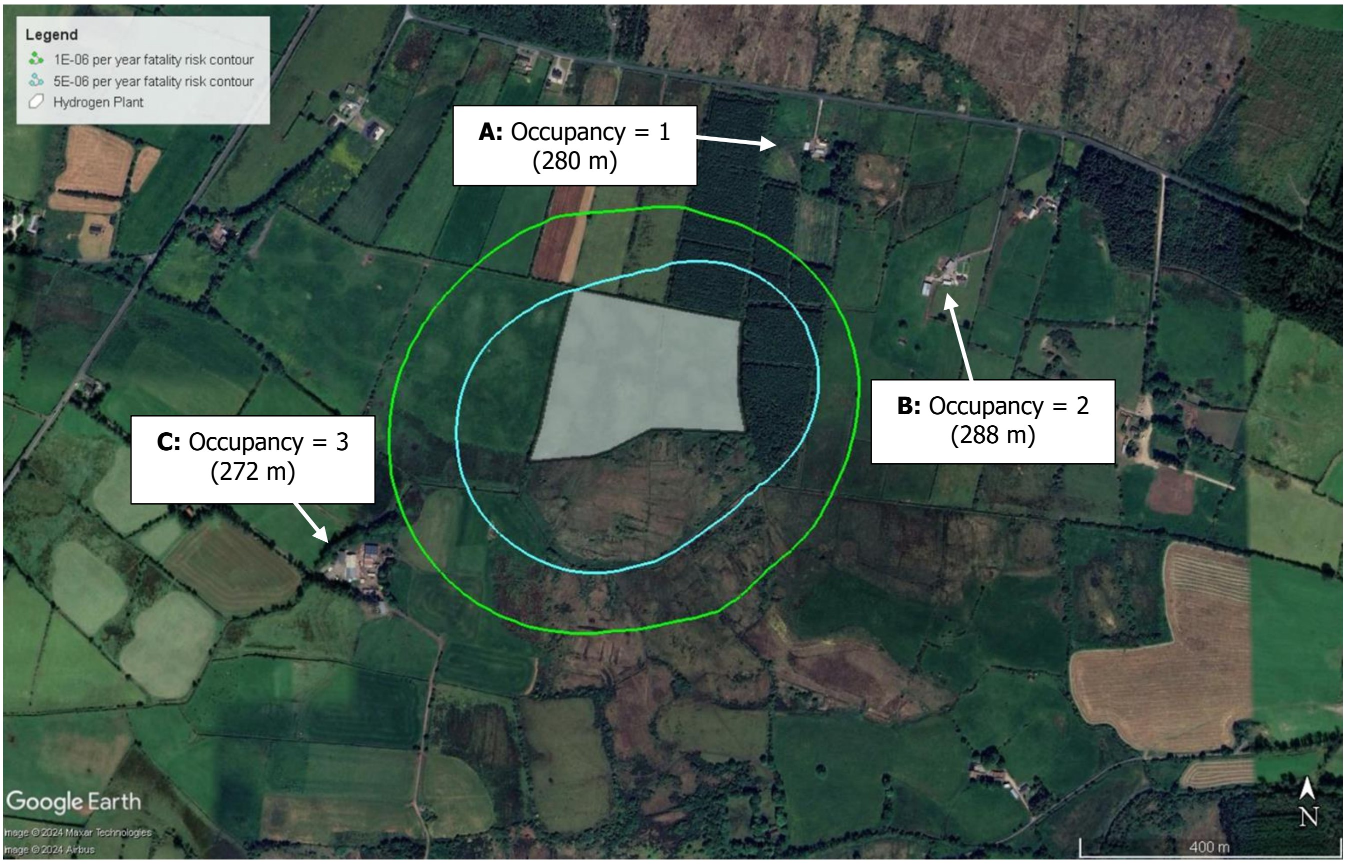



**Figure 4-1: Individual Risk Contours from the Hydrogen Plant (relevant to new establishments) with Distance from the Site Boundary to the Building**

## 4.3 Consultation Distance (CD) and Inner Risk Zones

The individual location-based risk contours relevant to establishing the CD and inner risk zones are presented in Figure 4-2 as follows:

- 1E-05 /year (10 chances per million (cpm)) – risk of fatality for inner zone (Zone 1) boundary;
- 1E-06 /year (1 cpm) – risk of fatality for middle zone (Zone 2) boundary;
- 1E-07 /year (0.1 cpm) – risk of fatality for outer zone (Zone 3) boundary; and
- 1E-09 /year (0.001 cpm) – Consultation Distance (CD).

The distance to the above levels can be summarised as follows:

- The 1E-05 /year risk contour, or inner zone, is estimated to extend up to a maximum of 130 m from the site boundary;
- The 1E-06 /year risk contour, or middle zone, is estimated to extend up to a maximum of 290 m from the site boundary;
- The 1E-07 /year risk contour, or outer zone, is estimated to extend up to a maximum of 360 m from the site boundary; and
- The 1E-09 /year risk contour, or Consultation Distance, is estimated to extend up to a maximum of 390 m from the site boundary.

The outermost (CD) contour encroaches the three locations as described in Section 4.2, however due to the minimal populations at these locations, the societal risk can considered to be negligible.

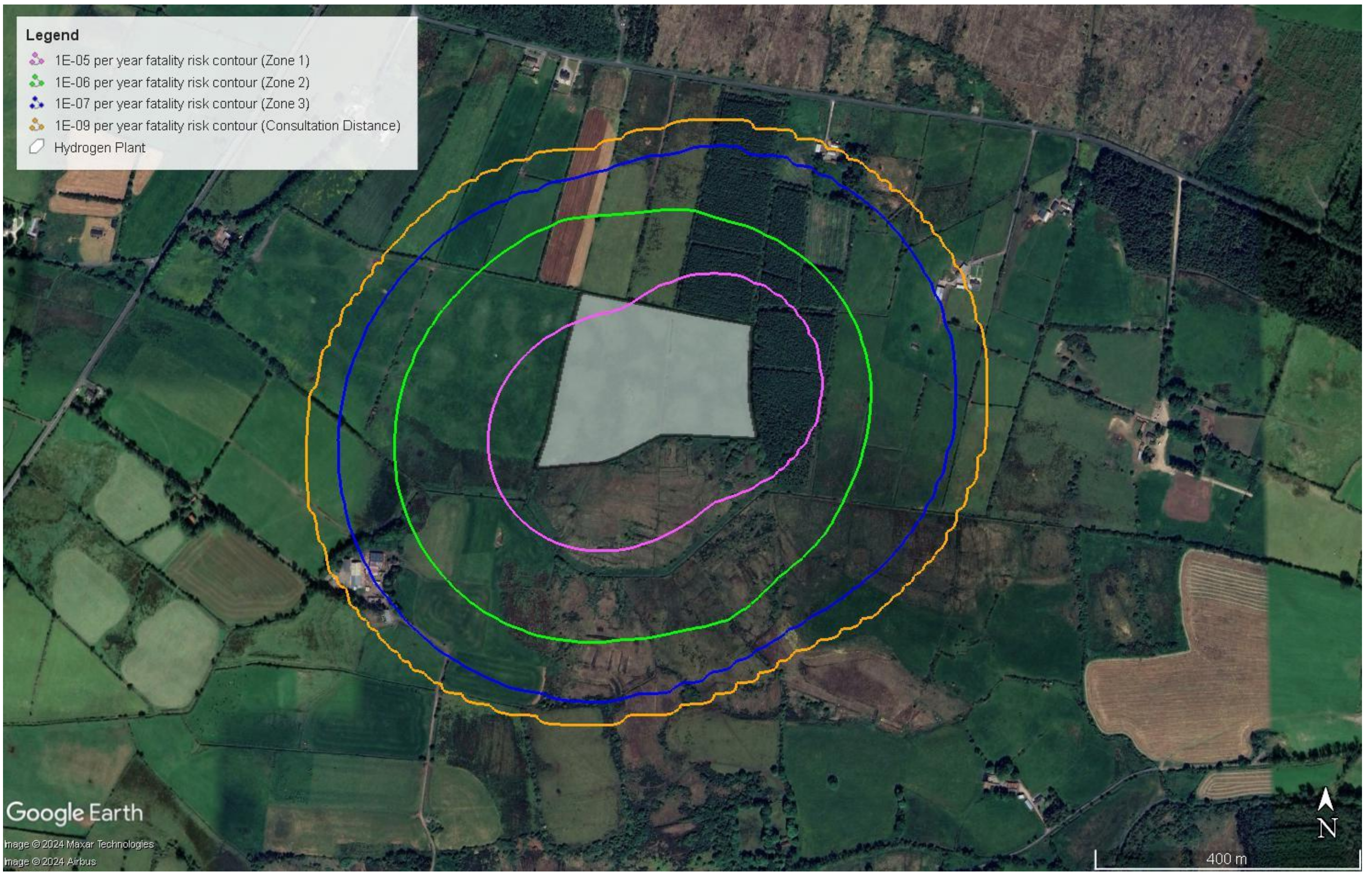



**Figure 4-2: Consultation Distance and Risk Zones**

## 4.4 Risk Contributors at Off-site Occupied Areas

The following sections provide summaries of the release scenarios that contribute the most to off-site risk.

### *4.4.1 South-West – Inner Zone*

The off-site risks within the inner zone (Zone 1) to the south-west of the site (as indicated in Figure 4-3) are dominated by the following release scenarios:

- Instantaneous failure of road transport units (located in the storage area), resulting in a vapour cloud explosion;
- Instantaneous failure of the $H_2$/Lye Separator resulting in vapour cloud explosion;
- Instantaneous failure of the Scrubber resulting in vapour cloud explosion;
- Instantaneous failure of the road transport units (located onsite in the loading bays) resulting in vapour cloud explosion; and
- Loss of entire contents through largest connection of the $H_2$ Storage resulting in vapour cloud explosion.


**Figure 4-3: Risk Ranking Point – South-West – Inner Zone**

### 4.4.2 South-West – Consultant Distance, Outer Zone and Middle Zone

The off-site risks within the consultant distance (CD), outer zone (Zone 3) and middle zone (Zone 2) to the south-west of the site (as indicated in Figure 4-4) are dominated by the following release scenario:

- Instantaneous failure of road transport units (located in the storage area), resulting in a vapour cloud explosion.

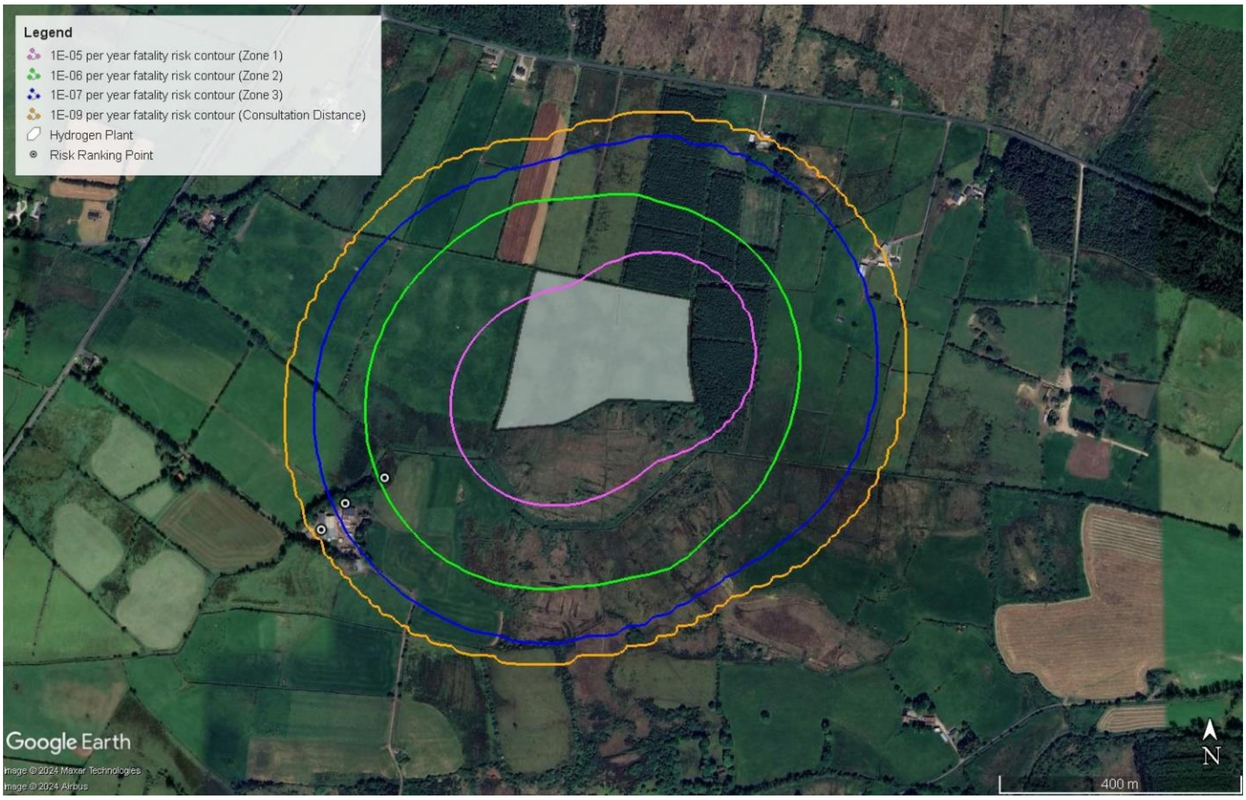



**Figure 4-4: Risk Ranking Point – South-West – Consultant Distance, Outer Zone and Middle Zone**

### *4.4.3 North-East – Consultant Distance*

The off-site risks within the Consultation Distance (CD) to the north-east of the site (as indicated in Figure 4-5) are dominated by the following release scenario:

- Instantaneous failure of road transport units (located onsite in the loading bays), resulting in a vapour cloud explosion of the flammable gas cloud.

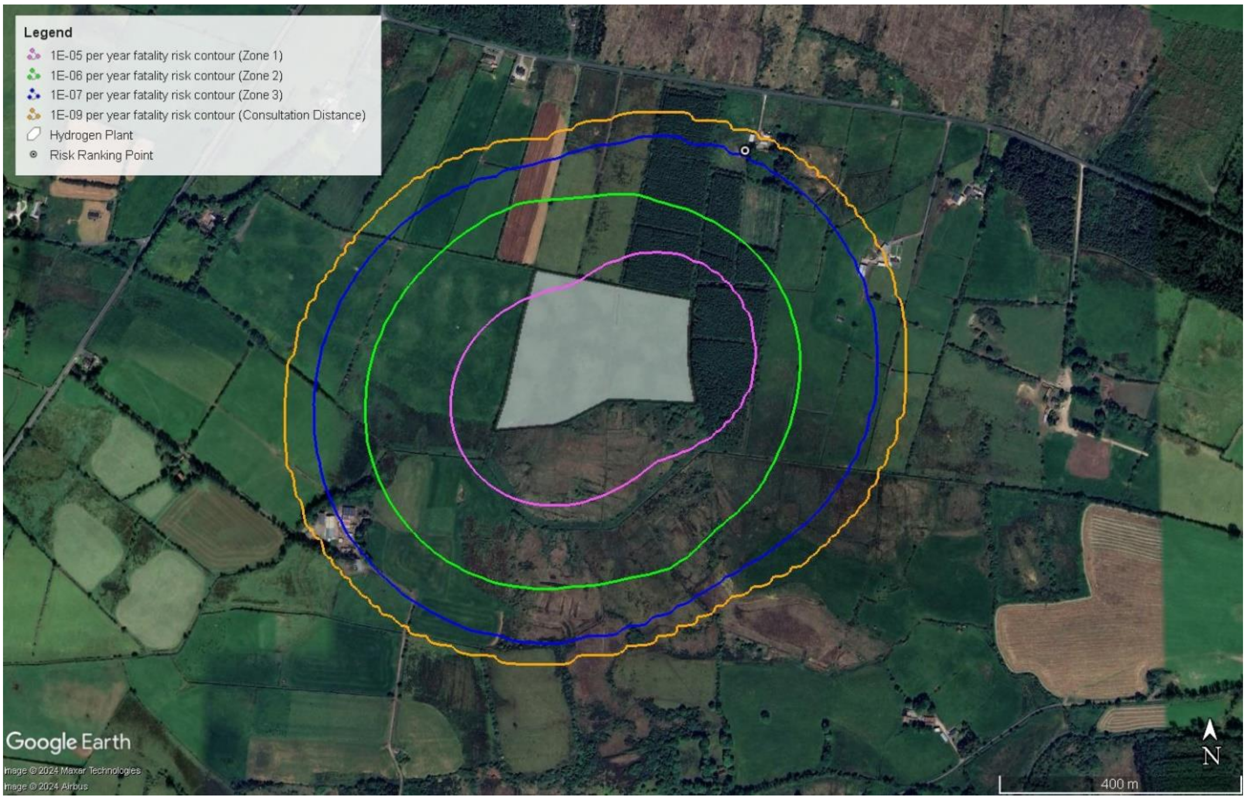



**Figure 4-5: Risk Ranking Point – North-East – Consultant Distance**

### *4.4.4 North-East – Outer Zone*

The off-site risks within the outer zone (Zone 3) to the north-east of the site (as indicated in Figure 4-6) are dominated by the following release scenarios:

- Instantaneous failure of road transport units (located onsite in the loading bays), resulting in a vapour cloud explosion; and
- Loss of entire contents through largest connection of the $H_2$ Storage resulting in vapour cloud explosion.

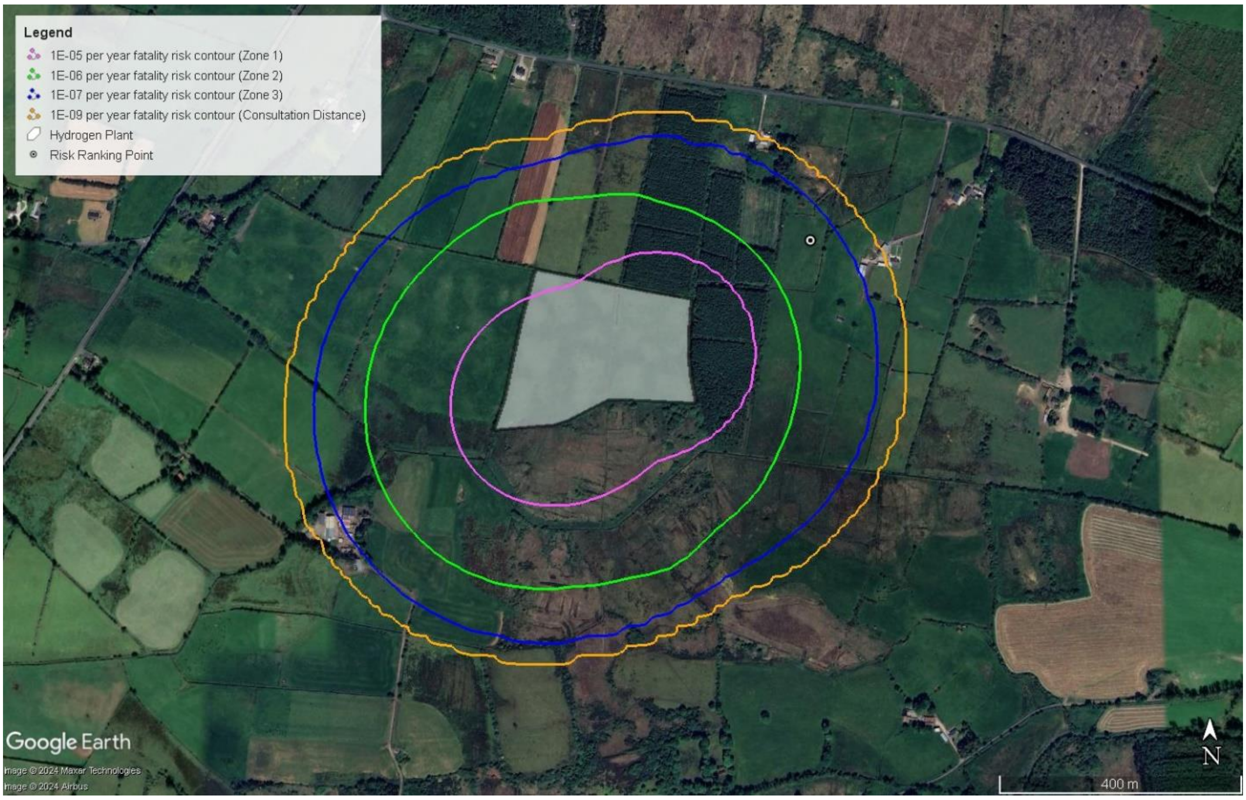



**Figure 4-6: Risk Ranking Point – North-East – Outer Zone**

### 4.4.5 North-East – Middle Zone and Inner Zone

The off-site risks within the middle zone (Zone 2) and inner zone (Zone 1) to the north-east of the site (as indicated in Figure 4-7) are dominated by the following release scenarios:

- Instantaneous failure of road transport units (located onsite in the loading bays), resulting in a vapour cloud explosion;
- Instantaneous failure of road transport units (located in the storage area), resulting in a vapour cloud explosion of the flammable gas cloud;
- Loss of entire contents through largest connection of the $H_2$ Storage resulting in vapour cloud explosion; and
- Instantaneous failure of the $H_2$ Storage, resulting in a vapour cloud explosion of the flammable gas cloud.

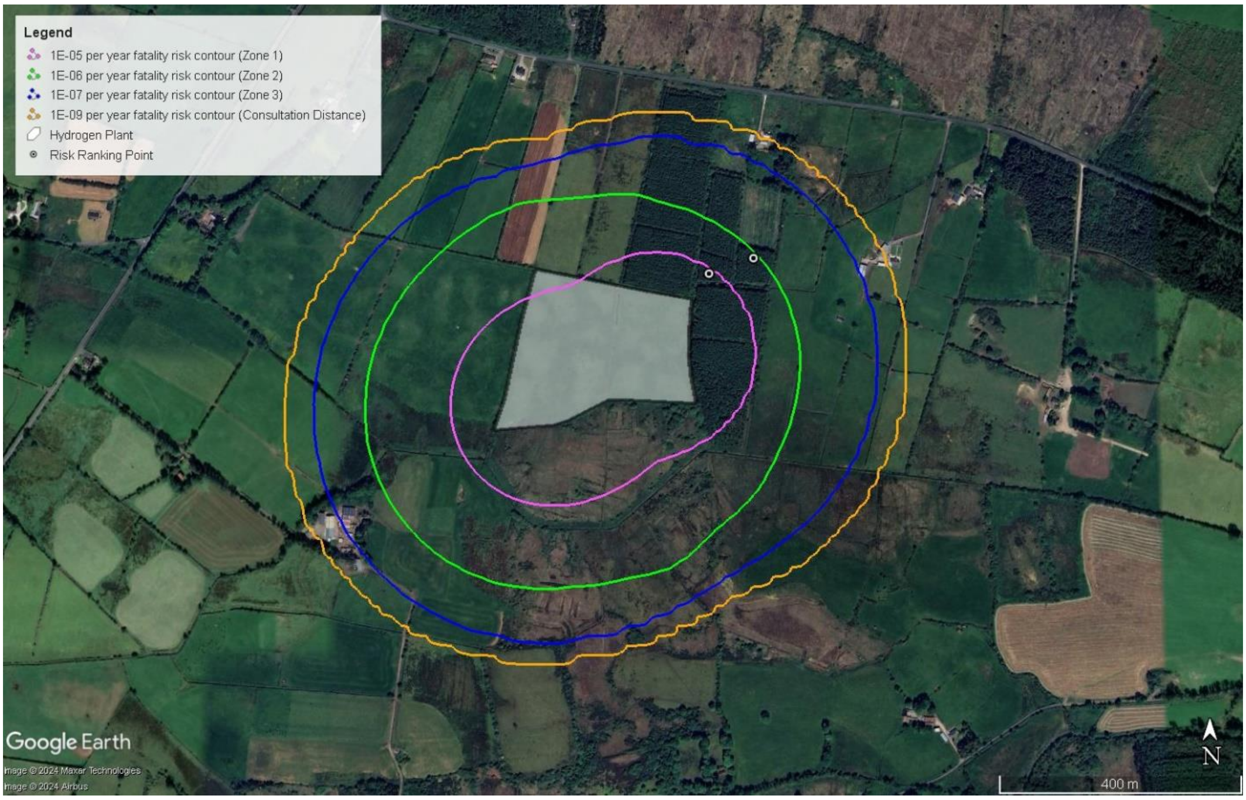



**Figure 4-7: Risk Ranking Point – North-East – Middle Zone and Inner Zone**

# 5 CONCLUSIONS

In support of the planning application for the Hydrogen Plant associated with the proposed Firlough Wind Farm project, this report presents the results of a LUP QRA, based on the inputs, methodology and rulesets prescribed in HSA Guidance on technical land use planning [2]. This document supports the Firlough Wind Farm and Hydrogen Plant planning application submitted to An Bord Pleanála and will also be appended to the Major Accident Prevention Policy to demonstrate the suitability of the proposed site location in terms of process hazard risk posed to the public.

The following conclusions can be drawn from the study:

- There are no buildings or outdoor populated areas within the predicted 1E-06 /year individual risk contour. The nearest occupied building is the house to the automated milking parlour, which is >40 m outside of the 1E-06 contour. It can be concluded therefore that the site location is acceptable. To further justify this conclusion, a theoretical worst case scenario with no process isolation points is presented in Appendix E, where it can be seen that the criteria remains satisfied.
- The Consultation Distance (CD) is estimated to extend up to a maximum of 390 m from the site boundary. The outer, middle and inner zones are estimated to extend up to a maximum of 360 m, 290 m and 130 m from the site boundary respectively. These contours should be used to inform future development feasibility; and
- Due to the very limited occupancy/populations within the 1E-09 /year contours (CD), societal risks are considered negligible.

The following recommendations have been derived from this study:

- It is recommended that a detailed QRA should be undertaken as the project advances to ensure risk to workers on-site is evaluated, but note that this is not a requirement at the current stage of development.
- It is recommended that the CD and inner risk zones are updated and finalised as the design progresses.

# 6 REFERENCES

1. Irish regulation. *Chemicals Act (Control of Major Accident Hazards Involving Dangerous Substances) Regulations 2015* S.I. No. 209 of 2015

2. HSA. *Guidance on technical land-use planning advice for planning authorities and COMAH establishment operators*
HSA0512, ISBN 978-1-84496-287-7, February 2023

3. MAHB. *Land Use Planning Guidelines in the Context of Article 12 of the Seveso II Directive 96/82/EC as amended by Directive 105/2003/EC EC, Brussels*

4. Met Éireann. *Irish Meteorological Service Historical Data, Knock Airport, County Mayo*
https://www.met.ie/climate/available-data/historical-data

5. DNV. *Safeti Software*
Version 8.6

6. Mercury Renewables. *Email from Tim Bills of Mercury Renewables to Jonathan Wiseman of Risktec Solutions*
03 February 2023

# APPENDIX A ASSUMPTIONS REGISTER

The assumptions used in the QRA are provided in the following sections. Table 6-1 presents the topics that are addressed.

**Table 6-1: Assumption Sheets**

| ID | Topic |
|---|---|
| A01 | Release Scenario Definition |
| A02 | Source Term |
| A03 | Meteorological Data |
| A04 | Consequence Modelling |
| A05 | Event Frequencies |
| A06 | Vulnerability Assessment |
| A07 | Risk Acceptance Criteria |

| **Assumption Sheet ID** | **A01** |
|---|---|
| **Topic/Worksheet:** | **Release Scenario Definition** |
| **Data/Rule Set:** | |
| The initial stage of analysis consists of defining the system as a set of release scenarios to be addressed in the study. In essence, this activity involves dividing the system into release inventories defined by Emergency Shutdown Valves (ESDVs). Within each isolatable inventory, the number of equipment items were counted and the associated process parameters (pressure, temperature etc.) were selected from review of the available input data.<br>The output of the above release scenario definition is presented in Appendix B. | |

| **Assumption Sheet ID** | **A02** |
|---|---|
| **Topic/Worksheet:** | **Source Term** |
| **Data/Rule Set:** | |

**Release Hole Sizes**

The source terms for each release scenario will be input into DNV's consequence modelling software PHAST v8.6 [5], which models the consequences based on standard fluid flow equations for gas flow using the pressure, temperature, material composition and size of release.

The leak sizes modelled will be based on the recommended scenarios in the HSA guidance [2], and will include:

- Equipment item located outdoors or indoors:
  - Instantaneous failure;
  - Continuous leak over 10 minutes (total inventory); and
  - 10 mm pipe leak over 10 minutes;
- Road Transport Unit (RTU):
  - Instantaneous failure; and
  - Loss of ensure contents through largest connection.
- Loading hose / arm:
  - Rupture of loading / unloading arm / hose; and
  - Leak of loading / unloading arm / hose (10% of loading hose diameter);
- Pipelines within the establishment:
  - Pipeline rupture; and
  - Pipeline leak of 0.1D (max 50mm).

**Release Location and Orientation**

All release sources are assumed to be at 1m above ground level, with effect height also at 1m to represent the most likely impact on personnel. All releases shall be modelled as horizontal un-impinged.

**Inventory**

The static inventory for each section shall be calculated based on the available documentation and will include estimated pipe lengths and vessel sizes associated with the section. The additional dynamic inventory entering the section pre-isolation shall be determined based on the minimum of either the initial release rate or normal processing flow rate. The time to isolation shall be assumed to be 1 minute.

A sensitivity case shall be assessed assuming no isolation is implemented in the study to understand the effect on the contours.

| **Assumption Sheet ID** | **A03** |
|---|---|
| **Topic/Worksheet:** | **Meteorological Data** |
| **Data/Rule Set:** | |

## Wind Speed and Atmospheric Stability

In alignment with the HSA guidance, consequence modelling will be carried out for two weather conditions:

- Wind speed 2 m/s and Pasquill stability class 'F' – F2; and
- Wind speed 5 m/s and Pasquill stability class 'D' – D5.

Stability category F represents a temperature inversion, occurring on a clear night, and typically leads to worst-case dispersion distances. F stability class cannot occur with wind speeds above a few metres per second.

Stability category D represents a moderate windy day, with cloud cover, and represents conditions that occur frequently, giving average dispersion distances.

In accordance with the HSA guidance, weather category F2 is applied for 20% of the time, and category D5 is applied for 80% of the time. Risk modelling will take into consideration the distribution of wind speeds and directional probability (wind rose), derived from data collected by Met Éireann at Knock Airport from 1996 to 2022 [4].

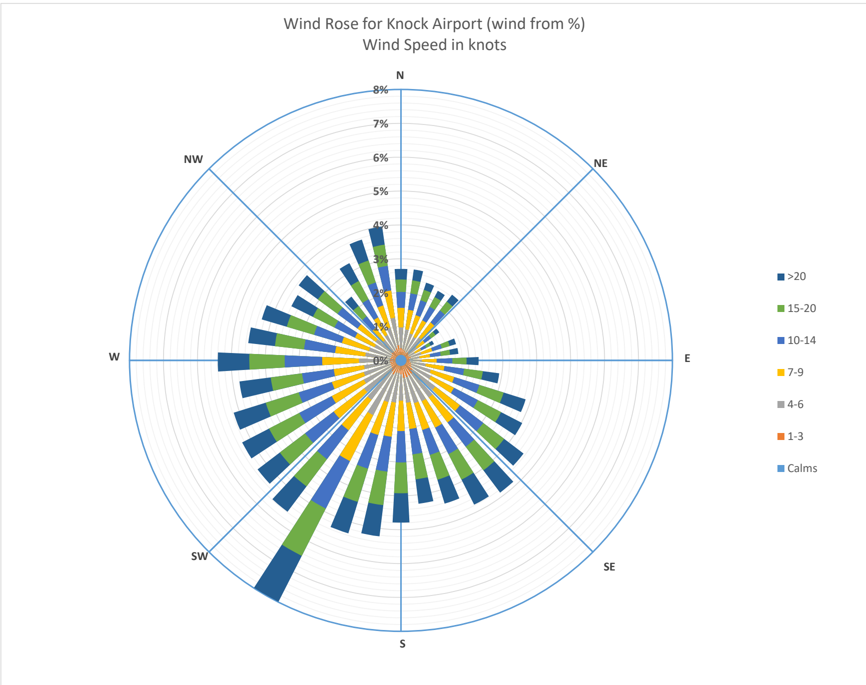



**Figure 6-1: Site Specific Wind Rose**

| Category | Percentage of time Wind Blows "from" Direction (degrees, North = 0) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **0** | **30** | **60** | **90** | **120** | **150** | **180** | **210** | **240** | **270** | **300** | **330** | **Total** |
| **F2** | 1.90% | 1.09% | 0.99% | 0.90% | 1.75% | 2.96% | 2.36% | 2.22% | 1.47% | 1.42% | 1.37% | 1.56% | **20.00%** |
| **D5** | 4.35% | 2.71% | 1.64% | 3.36% | 6.39% | 8.43% | 9.08% | 12.07% | 9.42% | 9.86% | 7.35% | 5.33% | **80.00%** |

## Meteorological Parameters

In addition to the weather categories, certain meteorological constants are defined as inputs to the consequence modelling, as follows:

- Average ambient atmospheric temperature: 15°C for D5 conditions and 10°C for F2 conditions [1];
- Average relative humidity: 87.9% [4];
- Surface temperature: same as atmospheric; and
- Surface roughness of 100mm (Occasional Large Obstacles).

| **Assumption Sheet ID** | **A04** |
|---|---|
| **Topic/Worksheet:** | **Consequence Modelling** |
| **Data/Rule Set:** | |

Safeti v8.6 [4] includes a range of validated models for assessment of the physical effects of hazardous releases. The consequence models expected to be used for the QRA are summarised in the following sections.

**Flammable Gas Dispersion (Flash Fire)**

The Unified Dispersion Model (UDM) shall be used for the flammable gas dispersion modelling in open areas. A dispersion averaging times of 18.75 seconds flammable releases (i.e. the default value in Safeti for flammable averaging time) shall be adopted.

**Vapour Cloud Explosion**

Overpressures generated by Vapour Cloud Explosions (VCE) shall be assessed using the TNO multi-energy model in the Safeti v8.6 software [4]. The TNO multi-energy model consists of a family of blast curves for peak overpressures to determine positive overpressure and impulse as a function of distance from the explosion source.

Vapour cloud explosions shall be assessed as follows:

- For indoor releases (i.e. within the electrolyser building and compressor house) it shall be assumed that the entire flammable cloud ignites with an explosion source of TNO curve 7 [2]. Dilution of the flammable cloud due to ventilation effects shall not be accounted; and
- For releases outdoors, 40% of the total flammable cloud volume shall be used to define an explosion source with TNO curve 7 equivalent overpressure [2].

**Jet Fire**

Gaseous jet fires will modelled in Safeti based on the Miller model which is an extension of the Chamberlain and Johnson models specifically for horizontal, vertical and angled low luminosity / non-hydrocarbon jet fires (such as hydrogen jet fires).

**Fireball**

For near-instantaneous releases, fireballs will be modelled using the default methodology in Safeti (Martinsen Time Varying).

| **Assumption Sheet ID** | **A05** |
|---|---|
| **Topic/Worksheet:** | **Event Frequencies** |
| **Data/Rule Set:** | |

The HSA specifies event and consequence frequencies [2], which are reproduced in this assumption sheet.

**Outdoor fixed installations (e.g. buffer tank):**

| LOC Scenario | Frequency (/yr) | Consequence | Consequence frequency (/yr) |
|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-6}$ | VCE/Fireball | $5 \times 10^{-6}$ |
| Continuous leak over 10 minutes (total inventory)* | $1 \times 10^{-5}$ | Jet fire<br>VCE<br>Flash fire | $7 \times 10^{-6}$<br>$1.2 \times 10^{-6}$<br>$1.8 \times 10^{-6}$ |
| 10mm pipe leak over 10 minutes* | $5 \times 10^{-4}$ | Jet Fire<br>VCE<br>Flash Fire | $3.5 \times 10^{-4}$<br>$6 \times 10^{-5}$<br>$9 \times 10^{-5}$ |

*The above consequence frequencies for continuous releases are based on the following ignition probability assumptions [2]:

- Overall ignition probability of 100%;
- Immediate ignition probability of 70% with a jet fire.
- Delayed ignition probability of 30%, which splits into a conditional probability of 40% of a VCE and 60% of a flash fire scenario.

**Indoor fixed installations (e.g. electrolysers, compressors):**

| LOC Scenario | Frequency (/yr) | Consequence | Consequence frequency (/yr) |
|---|---|---|---|
| Instantaneous failure | $5 \times 10^{-6}$ | VCE/Fireball | $5 \times 10^{-6}$ |
| Continuous leak over 10 minutes (total inventory)* | $1 \times 10^{-5}$ | Jet Fire<br>VCE | $7 \times 10^{-6}$<br>$3 \times 10^{-6}$ |
| 10mm pipe leak over 10 minutes* | $5 \times 10^{-4}$ | Jet Fire<br>VCE | $3.5 \times 10^{-4}$<br>$1.5 \times 10^{-4}$ |

*The above consequence frequencies for continuous releases are based on the following ignition probability assumptions [2]:

- Overall ignition probability of 100%;
- Immediate ignition probability of 70% with a jet fire.
- Delayed ignition probability of 30% with a conditional probability of 100% for VCE.

**Road tankers (Number of cylinders per road tanker = N):**

| LOC Scenario | Frequency (/yr) | Consequence | Consequence frequency (/yr) |
|---|---|---|---|
| Instantaneous failure | $N \times 5 \times 10^{-7}$ | VCE/Fireball | $N \times 5 \times 10^{-7}$ |
| Loss of entire contents (complete cylinder array) through largest connection* | $N \times 5 \times 10^{-7}$ | Jet Fire<br>Flash Fire<br>VCE | $N \times 2 \times 10^{-7}$<br>$N \times (1.8 \times 10^{-7})$<br>$N \times (1.2 \times 10^{-7})$ |

*The above consequence frequencies for continuous releases are based on the following ignition probability assumptions [2]:

- Overall ignition probability of 100%;
- Delayed ignition probability of 60% with a VCE probability of 40% for delayed ignition events instead of a flash fire scenario.

It shall be assumed that there are 50 cylinders per road tanker.

It shall be assumed that the RTU parking area to the south of the site has all RTUs present at all times.

| **Assumption Sheet ID** | **A05** |
|---|---|
| **Topic/Worksheet:** | **Event Frequencies** |

**Road tanker loading bays:**

| **LOC Scenario** | **Arm Leak Frequency (/hour)** | **Hose Leak Frequency (/hour)** |
|---|---|---|
| | **Arm** | **Hose** |
| Rupture of loading/unloading arm/hose* | $3 \times 10^{-8}$ | $4 \times 10^{-6}$ |
| Leak from loading/unloading arm/hose (10% diameter)* | $3 \times 10^{-7}$ | $4 \times 10^{-5}$ |

*The consequence frequencies for continuous releases shall be based on the following ignition probability assumptions, as per road tankers [2]:

- Overall ignition probability of 100%;
- Delayed ignition probability of 60% with a VCE probability of 40% for delayed ignition events.

It shall be assumed that each loading bay is occupied with a fully laden RTU at all times. The leak frequency for loading hoses shall be adopted for the study.

**Above Ground Pipelines (within the establishment):**

| **Scenario** | **Frequency $m^{-1} yr^{-1}$** | | |
|---|---|---|---|
| | **D < 75 mm** | **75 ≤ D ≥ 150 mm** | **D>150 mm** |
| Pipeline rupture* | $1 \times 10^{-6}$ | $3 \times 10^{-7}$ | $1 \times 10^{-7}$ |
| Pipeline leak of 0.1D (max 50 mm)* | $5 \times 10^{-6}$ | $2 \times 10^{-6}$ | $5 \times 10^{-7}$ |

*VCE consequence frequencies for continuous releases shall be based on the following ignition probability assumptions (as per external equipment):

- Overall ignition probability of 100%; and
- Delayed ignition probability of 30% with a VCE probability of 40% for delayed ignition events.

**Below Ground Pipelines (within the establishment):**

| **Scenario** | **Frequency $m^{-1} yr^{-1}$** | | |
|---|---|---|---|
| | **D < 75 mm** | **75 ≤ D ≥ 150 mm** | **D>150 mm** |
| Pipeline rupture* | $1 \times 10^{-7}$ | $3 \times 10^{-8}$ | $1 \times 10^{-8}$ |
| Pipeline leak of 0.1D (max 50 mm)* | $5 \times 10^{-7}$ | $2 \times 10^{-7}$ | $5 \times 10^{-8}$ |

*VCE consequence frequencies for continuous releases shall be based on the following ignition probability assumptions (as per external equipment):

- Overall ignition probability of 100%; and
- Delayed ignition probability of 30% with a VCE probability of 40% for delayed ignition events.

The diameter of the pipeline (D) is assumed to be 50 mm.

| **Assumption Sheet ID** | **A06** |
| --- | --- |
| **Topic/Worksheet:** | **Vulnerability Assessment** |

**Data/Rule Set:**

The following vulnerability models will be used for fatality estimation. To determine the contribution to risk for both outside and indoor occupancy, it shall be assumed that people are indoors 90% of the time [1].

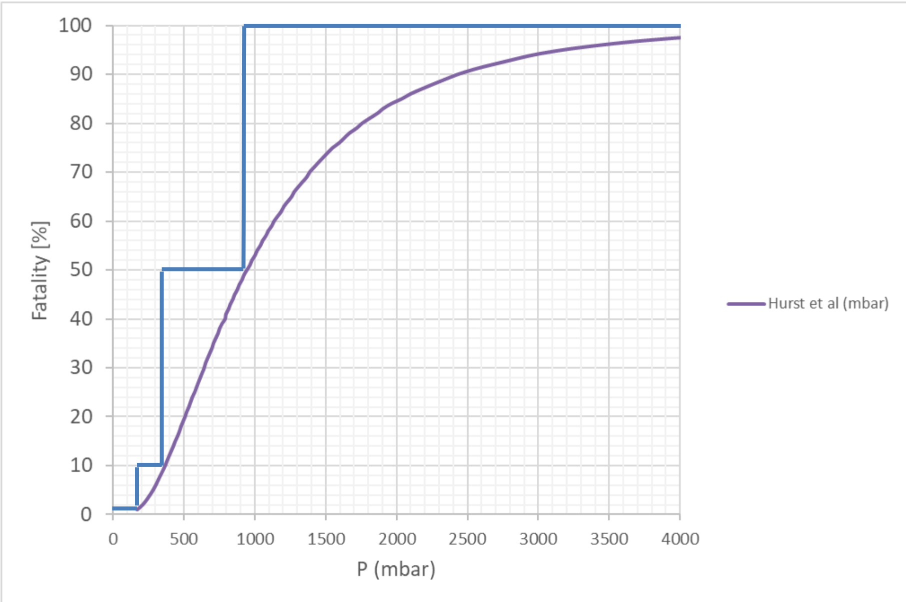
**Explosion Overpressures**

**Outdoor Vulnerability**

The HSA [1] proposes the following vulnerabilities for personnel located outdoors:

- 168 mbar (2.44 psi) overpressure - 1% lethality;
- 365 mbar (5.29 psi) overpressure - 10% lethality; and
- 942 mbar (13.66 psi) overpressure - 50% lethality.

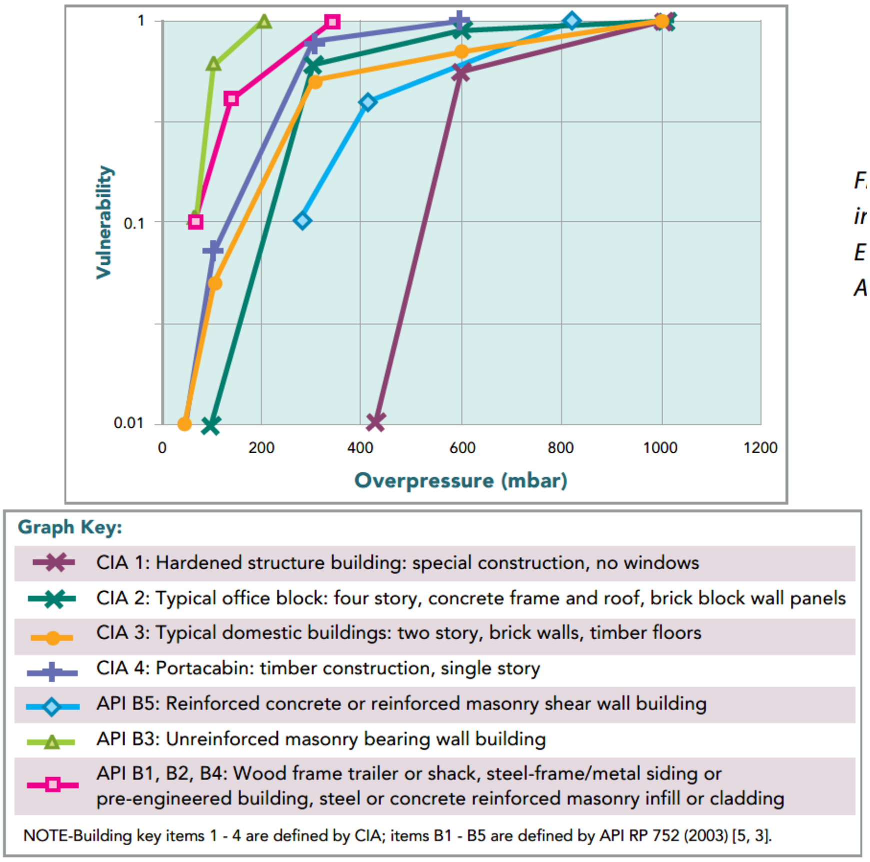
The modelling applies a threshold approach to outdoor overpressure vulnerability based on the Hurst probit function values above, whereby the vulnerability is always set conservatively at or above the equivalent Hurst value as illustrated by the blue line below. (This simplifying assumption has been made to streamline the process of generating individual risk contours within the Safeti software, taking into account a weighting of 90% occupancy indoors and 10% occupancy outdoors to achieve a single set of vulnerability levels.)




**Indoor Vulnerability**

For the indoor personnel, the following correlations [1] will be used:

| **Assumption Sheet ID** | **A06** |
|---|---|
| **Topic/Worksheet:** | **Vulnerability Assessment** |




Category 3 Curve (typical domestic building: two-storey, brick walls, timber floors) will in most circumstances provide a reasonably conservative basis for assessing the risk of fatality to most residential populations, and shall be adopted to assess the risk to the public located indoors. The following indoor vulnerability ruleset shall therefore be adopted for people located indoors (as per the CIA-3 building type in the above graph):

- >50 mbar – 1% lethality;
- >100 mbar – 5% lethality;
- >300 mbar – 50% lethality;
- >600 mbar – 70% lethality; and
- >1000 mbar – 100% lethality.

**Building Damage**

Risks to physical structures will adopt the following overpressure damage values are [1]:

- >10 mbar - glass breakage;
- >35 mbar - light;
- >170 mbar - moderate;
- >350 mbar - severe; and
- >830 mbar - total destruction.

**Flash Fires**

**Outdoor Vulnerability**

Personnel located outdoors within the LFL contours are assumed to be fatally injured; those outside are unharmed.

**Indoor Vulnerability**

Personnel located indoors within the LFL contours are assumed to experience a 10% lethality.

| **Assumption Sheet ID** | **A06** |
|---|---|
| **Topic/Worksheet:** | **Vulnerability Assessment** |

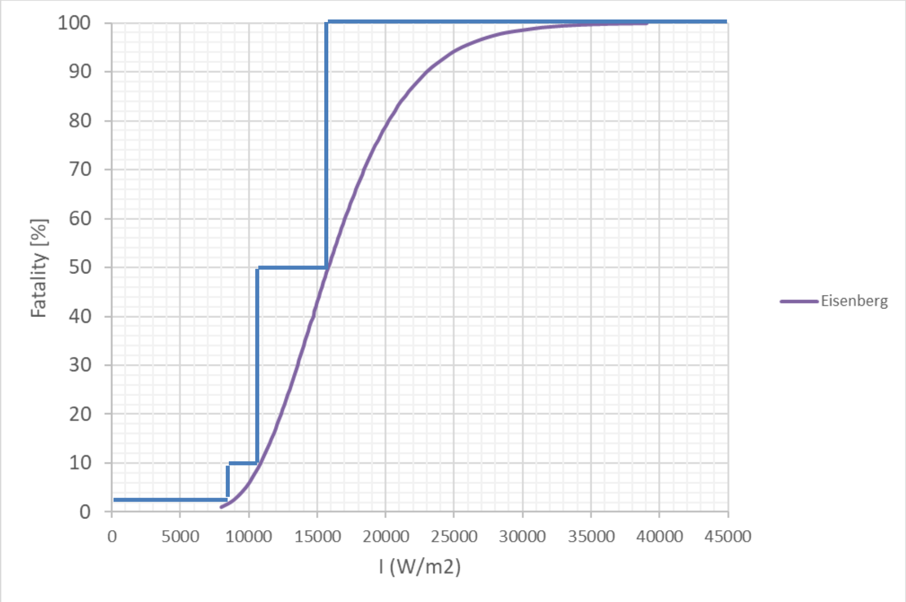
**Thermal Radiation**

**Outdoor Vulnerability**

As described in the HSA guidance [1], thermal radiation effects on people outdoors are assessed using the Eisenberg probit function with the following thermal radiation effects (assuming an exposure of 60 seconds):

- 8.02 kW/m$^2$ - 1% lethality;
- 10.9 kW/m$^2$ - 10% lethality; and
- 15.9kW/m$^2$ - 50% lethality.

The modelling applies a threshold approach to radiation vulnerability based on the Eisenberg probit function values above, whereby the vulnerability is always set conservatively at or above the equivalent Eisenberg value as illustrated by the blue line below. (This simplifying assumption has been made to streamline the process of generating individual risk contours within the Safeti software, taking into account a weighting of 90% occupancy indoors and 10% occupancy outdoors to achieve a single set of vulnerability levels.)




**Indoor Vulnerability**

Thermal radiation effects to people indoors are as follows [1]:

- <12.7 kW/m$^2$ - 0% lethality;
- >15.9kW/m$^2$ - 50% lethality; and
- >25.6 kW/m$^2$ - building catches fire, 100% lethality to occupants.

Thresholds have been applied as step functions in the same way as explained above for outdoor vulnerability.

**Property Damage**

Thermal radiation effects to property are as follows [1]:

- >37.5 kW/m$^2$ - sufficient to cause damage to process equipment;
- >25.6 kW/m$^2$ - minimum heat flux to ignite wood at indefinitely long exposures (non-piloted); and
- >14.7 kW/m$^2$ - minimum heat flux for piloted ignition of wood, melting of plastic tubing.

| **Assumption Sheet ID** | **A07** |
|---|---|
| **Topic/Worksheet:** | **Risk Acceptance Criteria** |
| **Data/Rule Set:** | |

**Location Specific Individual Risk (LSIR) – new establishment criteria**

LSIR is the individual risk for a hypothetical person present at a location for 100% of the time. The LSIR is therefore the sum of the frequency of each hazard event multiplied by the probability of fatality from that event at the location of interest. The QRA uses LSIR to evaluate the tolerability of risk for areas within and around the facility. The HSA guidance [1] states that the individual LSIR contours for new establishments, not to be exceeded, are as follows:

- 1 x $10^{-6}$ per year – maximum tolerable risk to a member of the public; and
- 5 x $10^{-6}$ per year – maximum tolerable risk to a person at an off-site work location.

The above risk contours that therefore be developed as part of the study to determine whether any areas of public occupancy reside within the contours.

**Location Specific Individual Risk (LSIR) – developments within the vicinity**

To enable establishment of the protective Consultation Distance (CD) for potential future developments of specific types within the vicinity of the establishment, risk contours down to 1 x $10^{-9}$ per year shall also be plotted. Notable LSIR zones are as follows:

- 1 x $10^{-5}$ per year – Risk of fatality for inner zone (Zone 1) boundary;
- 1 x $10^{-6}$ per year – Risk of fatality for middle zone (Zone 2) boundary;
- 1 x $10^{-7}$ per year – Risk of fatality for outer zone (Zone 3) boundary; and
- 1 x $10^{-9}$ per year – Consultation Distance.

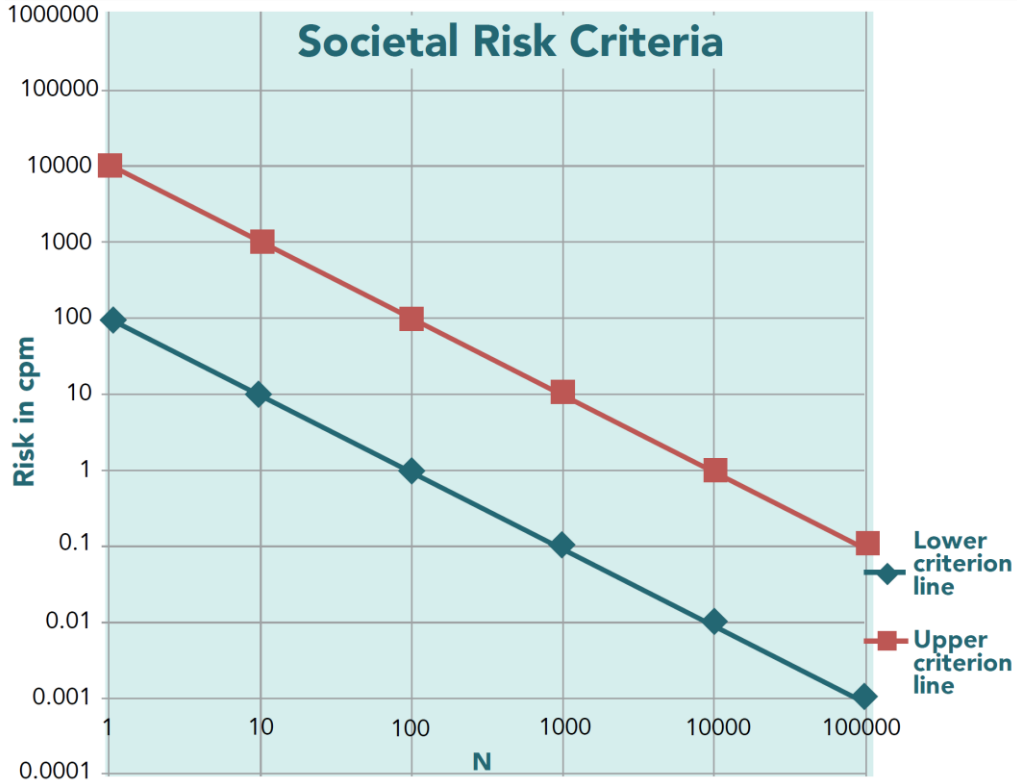
**Societal Risk**

To determine the societal risk to the public, off-site areas of public occupancy within the 1 x $10^{-9}$ per year shall be identified. The Expectation Value (EV) to these populations shall be determined and assessed in accordance with the following criteria:

- EV greater than 10,000 – intolerable;
- Between EVs of 100 and 10,000 - it should be demonstrated that all practicable efforts have been made to reduce the risk to a level that is as low as reasonably practicable; and
- EV less than 100 – broadly acceptable.

In addition, a F-N curve shall be developed and evaluated in accordance within the following criteria:

| **Assumption Sheet ID** | **A07** |
|---|---|
| **Topic/Worksheet:** | **Risk Acceptance Criteria** |



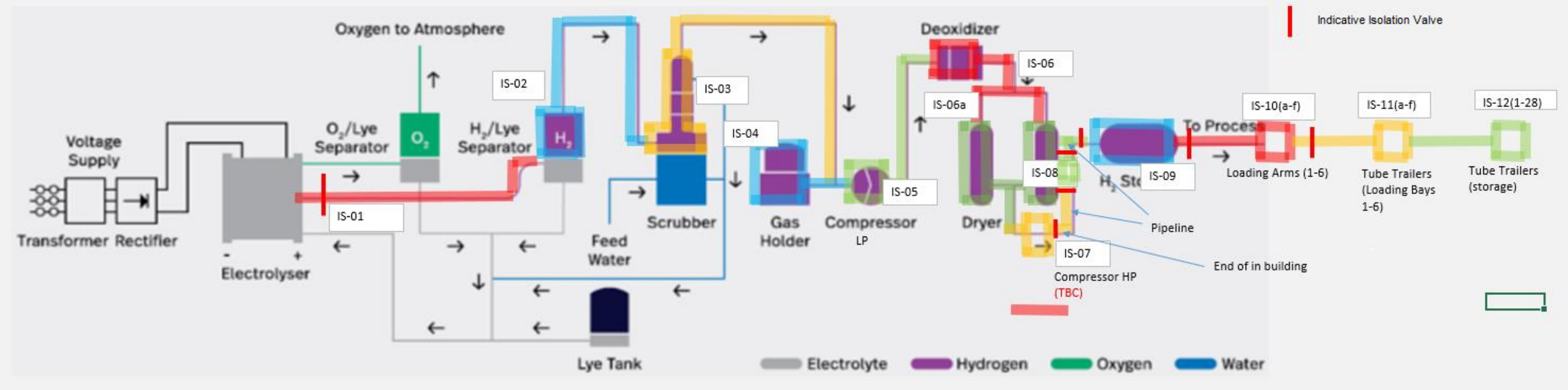
# APPENDIX B RELEASE SCENARIOS

**Main Release Scenario Parameters**

| Release Scenario ID | Release Scenario Description | Modelled Stream Composition | Pressure | Temperature | Flow Rate | Total Inventory | Pipe Diameter | Notes |
|---|---|---|---|---|---|---|---|---|
| | | | (barg) | (°C) | (kg/hr) | (kg) | (mm) | |
| IS-01 | Per Electrolyser Hydrogen Outlet | $H_2$ | 0.02 | 80.0 | 81.25 | 1.4 | 80 | 1,300 kg/hr peak daily flow rate for the total system. Divided by 16 gives 81.25 kg/hr per electrolyser. |
| IS-02 | $H_2$/Lye Separator | $H_2$ | 0.02 | 80.0 | 1300.00 | 145.7 | 300 | |
| IS-03 | Scrubber | $H_2$ | 0.02 | 80.0 | 1300.00 | 145.7 | 300 | |
| IS-04 | Gas Holder | $H_2$ | 0.02 | 25.0 | 1300.00 | 145.7 | 300 | |
| IS-05 | Compressor (LP) | $H_2$ | 30.0 | 25.0 | 1300.00 | 145.7 | 80 | |
| IS-06 | Deoxidiser | $H_2$ | 30.0 | 25.0 | 1300.00 | 145.7 | 80 | |
| IS-06a | Dryers | $H_2$ | 30.0 | 25.0 | 1300.00 | 145.7 | 80 | |
| IS-07 | Compressor (HP) | $H_2$ | 30.0 | 25.0 | 1300.00 | 145.7 | 80 | |
| IS-08 | Compressor (A/B) | $H_2$ | 500 | 26 | 1300.00 | 23.3 | 50 | |
| IS-09 | $H_2$ Storage | $H_2$ | 500 | 10 | 1300.00 | 551.4 | 50 | |
| IS-10 | Loading Arms and Manifold (1-7) | $H_2$ | 380 | 10 | 1300.00 | 24.9 | 50 | It is conservatively assumed that flow into $H_2$ storage equals flow out. |
| IS-11 | Per Tube Trailer On-site | $H_2$ | 380 | 10 | 260.00 | 1204.3 | | Flow rate divided by 7, assuming 7 loading arms all operational at all times |

| Release Scenario ID | Release Scenario Description | Modelled Stream Composition | Pressure | Temperature | Flow Rate | Total Inventory | Pipe Diameter | Notes |
|---|---|---|---|---|---|---|---|---|
| | | | (barg) | (°C) | (kg/hr) | (kg) | (mm) | |
| IS-12 | Per Tube Trailer Storage | $H_2$ | 380 | 10 | | 1200.0 | | |
| PW-13 | Cross Site Pipework to H2 Storage | $H_2$ | 30.0 | 25.0 | 1300.00 | 21.7 | 50 | |

## Release Scenario Mark-Up (with Indicative Isolation Valve Location)



## APPENDIX C RELEASE AND CONSEQUENCE FREQUENCY ASSESSMENT RESULTS

Release frequencies are calculated in reference to the frequencies in Assumption Sheet A05 (see Appendix A). The base frequencies have been adjusted to account for the following factors:

- The number of equipment sources per release point in Safeti (this is typically one equipment item per release point, with the exception of the Dryers (2), Compressors A/B (2) and loading arms (7)).
- The operating factor for each equipment item. All equipment operates 100% of the time with the exception of the Dryers and Compressors A/B where there is 100% standby (i.e. one operating, one standby), hence a 50% operating factor has been applied to each of these.
- The number of cylinders "N" per cylinder storage array as per HSA LUP guidance Table 38.
- Conversion of loading arm leak frequencies from "per hour" to "per year".

**Equipment Releases**

| Source ID | Release Sources in Safeti | Release Source Description | Equipment Number per Source | Operating Factor | Equipment Type (as per HSA) | LOC Scenario | Scenario ID | Hole Size (mm) | LOC Frequency (/yr) | Consequence | Scenario Frequency (/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IS-01 | 16 | Per Electrolyser Hydrogen Outlet | 1 | 100% | Indoor fixed installations | Instantaneous failure | IS-01-IF | | 5.00E-06 | VCE/Fireball | 5.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-01-CL | | 1.00E-05 | VCE | 3.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-01-CL | | 1.00E-05 | Jet Fire | 7.00E-06 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-01-PL | 10 | 5.00E-04 | VCE | 1.50E-04 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-01-PL | 10 | 5.00E-04 | Jet Fire | 3.50E-04 |
| IS-02 | 1 | H2/Lye Separator | 1 | 100% | Indoor fixed installations | Instantaneous failure | IS-02-IF | | 5.00E-06 | VCE/Fireball | 5.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-02-CL | | 1.00E-05 | VCE | 3.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-02-CL | | 1.00E-05 | Jet Fire | 7.00E-06 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-02-PL | 10 | 5.00E-04 | VCE | 1.50E-04 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-02-PL | 10 | 5.00E-04 | Jet Fire | 3.50E-04 |
| IS-03 | 1 | Scrubber | 1 | 100% | Indoor fixed installations | Instantaneous failure | IS-03-IF | | 5.00E-06 | VCE/Fireball | 5.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-03-CL | | 1.00E-05 | VCE | 3.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-03-CL | | 1.00E-05 | Jet Fire | 7.00E-06 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-03-PL | 10 | 5.00E-04 | VCE | 1.50E-04 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-03-PL | 10 | 5.00E-04 | Jet Fire | 3.50E-04 |
| IS-04 | 1 | Gas Holder | 1 | 100% | Indoor fixed installations | Instantaneous failure | IS-04-IF | | 5.00E-06 | VCE/Fireball | 5.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-04-CL | | 1.00E-05 | VCE | 3.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-04-CL | | 1.00E-05 | Jet Fire | 7.00E-06 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-04-PL | 10 | 5.00E-04 | VCE | 1.50E-04 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-04-PL | 10 | 5.00E-04 | Jet Fire | 3.50E-04 |
| IS-05 | 1 | Compressor (LP) | 1 | 100% | Indoor fixed installations | Instantaneous failure | IS-05-IF | | 5.00E-06 | VCE/Fireball | 5.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-05-CL | | 1.00E-05 | VCE | 3.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-05-CL | | 1.00E-05 | Jet Fire | 7.00E-06 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-05-PL | 10 | 5.00E-04 | VCE | 1.50E-04 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-05-PL | 10 | 5.00E-04 | Jet Fire | 3.50E-04 |

| Source ID | Release Sources in Safeti | Release Source Description | Equipment Number per Source | Operating Factor | Equipment Type (as per HSA) | LOC Scenario | Scenario ID | Hole Size (mm) | LOC Frequency (/yr) | Consequence | Scenario Frequency (/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IS-06 | 1 | Deoxidiser | 1 | 100% | Indoor fixed installations | Instantaneous failure | IS-06-IF | | 5.00E-06 | VCE/Fireball | 5.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-06-CL | | 1.00E-05 | VCE | 3.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-06-CL | | 1.00E-05 | Jet Fire | 7.00E-06 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-06-PL | 10 | 5.00E-04 | VCE | 1.50E-04 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-06-PL | 10 | 5.00E-04 | Jet Fire | 3.50E-04 |
| IS-06a | 1 | Dryers | 2 | 50% | Indoor fixed installations | Instantaneous failure | IS-06a-IF | | 5.00E-06 | VCE/Fireball | 5.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-06a-CL | | 1.00E-05 | VCE | 3.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-06a-CL | | 1.00E-05 | Jet Fire | 7.00E-06 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-06a-PL | 10 | 5.00E-04 | VCE | 1.50E-04 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-06a-PL | 10 | 5.00E-04 | Jet Fire | 3.50E-04 |
| IS-07 | 1 | Compressor (HP) | 1 | 100% | Indoor fixed installations | Instantaneous failure | IS-07-IF | | 5.00E-06 | VCE/Fireball | 5.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-07-CL | | 1.00E-05 | VCE | 3.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-07-CL | | 1.00E-05 | Jet Fire | 7.00E-06 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-07-PL | 10 | 5.00E-04 | VCE | 1.50E-04 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-07-PL | 10 | 5.00E-04 | Jet Fire | 3.50E-04 |
| IS-08 | 1 | Compressor (A/B) | 2 | 50% | Indoor fixed installations | Instantaneous failure | IS-08-IF | | 5.00E-06 | VCE/Fireball | 5.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-08-CL | | 1.00E-05 | VCE | 3.00E-06 |
| | | | | | | Continuous leak over 10 minutes (total inventory) | IS-08-CL | | 1.00E-05 | Jet Fire | 7.00E-06 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-08-PL | 10 | 5.00E-04 | VCE | 1.50E-04 |
| | | | | | | 10mm pipe leak over 10 minutes | IS-08-PL | 10 | 5.00E-04 | Jet Fire | 3.50E-04 |

**Storage, Tankers and Loading**

| Source ID | Release Sources in Safeti | Release Source Description | Equipment Number per Source | Operating Factor | LOC Scenario | Scenario ID | Hole Size (mm) | LOC Frequency (/yr) | Consequence | Scenario Frequency (/yr) | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IS-09 | 1 | H2 Storage | 1 | 100% | Instantaneous failure | IS-09-RTIF | | 1.80E-05 | VCE/Fireball | 1.80E-05 | Modelled as an RTU as per the guidance. 36 cylinders. |
| | | | | | Loss of entire contents through largest connection | IS-09-RTEC | 50 | 1.80E-05 | VCE | 4.32E-06 | |
| | | | | | Loss of entire contents through largest connection | IS-09-RTEC | 50 | 1.80E-05 | Jet Fire | 7.20E-06 | |
| | | | | | Loss of entire contents through largest connection | IS-09-RTEC | 50 | 1.80E-05 | Flash Fire | 6.48E-06 | |
| IS-10 | 1 | Loading Arms and Manifold (1-7) | 7 | 100% | Rupture of loading/unloading hose | IS-10-LHR | 50 | 2.45E-01 | VCE/Fireball | 5.89E-02 | 7 loading arms, all operational at all times |
| | | | | | Rupture of loading/unloading hose | IS-10-LHR | 50 | 2.45E-01 | Jet Fire | 9.81E-02 | |
| | | | | | Rupture of loading/unloading hose | IS-10-LHR | 50 | 2.45E-01 | Flash Fire | 8.83E-02 | |
| | | | | | Leak from loading/unloading hose (10% diameter) | IS-10-LHL | 5 | 2.45E+00 | VCE/Fireball | 5.89E-01 | |
| | | | | | Leak from loading/unloading arm (10% diameter) | IS-10-LHL | 5 | 2.45E+00 | Jet Fire | 9.81E-01 | |
| | | | | | Leak from loading/unloading hose (10% diameter) | IS-10-LHL | 5 | 2.45E+00 | Flash Fire | 8.83E-01 | |
| IS-11 | 7 | Per Tube Trailer On-site | 1 | 100% | Instantaneous failure | IS-11-RTIF | | 2.50E-05 | VCE/Fireball | 2.50E-05 | 7 loading arms, all operational at all times.<br>50 cylinders per tube trainer. |
| | | | | | Loss of entire contents through largest connection | IS-11-RTEC | 50 | 2.50E-05 | VCE | 6.00E-06 | |
| | | | | | Loss of entire contents through largest connection | IS-11-RTEC | 50 | 2.50E-05 | Jet Fire | 1.00E-05 | |
| | | | | | Loss of entire contents through largest connection | IS-11-RTEC | 50 | 2.50E-05 | Flash Fire | 9.00E-06 | |
| IS-12 | 26 | Per Tube Trailer Storage | 1 | 100% | Instantaneous failure | IS-12-RTIF | | 2.50E-05 | VCE/Fireball | 2.50E-05 | All 26 RTUs on-site at all times.<br>50 cylinders per tube trainer. |
| | | | | | Loss of entire contents through largest connection | IS-12-RTEC | 50 | 2.50E-05 | VCE | 6.00E-06 | |
| | | | | | Loss of entire contents through largest connection | IS-12-RTEC | 50 | 2.50E-05 | Jet Fire | 1.00E-05 | |
| | | | | | Loss of entire contents through largest connection | IS-12-RTEC | 50 | 2.50E-05 | Flash Fire | 9.00E-06 | |

**Pipelines**

| Release Source Description | Equipment Number Per Source | Operating Factor | Equipment Type (as per HSA) | LOC Scenario | Scenario ID | Hole Size mm | LOC Frequency (/yr/m) | Consequence | Scenario Frequency (/yr) |
|---|---|---|---|---|---|---|---|---|---|
| Cross Site Pipework to H2 Storage | 1 | 100% | Above Ground Pipeline | Pipeline rupture (D < 75mm) | PW-13-PR | 50 | 1.00E-06 | VCE/Fireball | 1.20E-07 |
| | | | | Pipeline rupture (D < 75mm) | PW-13-PR | 50 | 1.00E-06 | Jet Fire | 7.00E-07 |
| | | | | Pipeline rupture (D < 75mm) | PW-13-PR | 50 | 1.00E-06 | Flash Fire | 1.80E-07 |
| | | | | Pipeline leak of 0.1D | PW-13-PL | 5 | 5.00E-06 | VCE/Fireball | 6.00E-07 |
| | | | | Pipeline leak of 0.1D | PW-13-PL | 5 | 5.00E-06 | Jet Fire | 3.50E-06 |
| | | | | Pipeline leak of 0.1D | PW-13-PL | 5 | 5.00E-06 | Flash Fire | 9.00E-07 |

# APPENDIX D TABULATED CONSEQUENCE MODELLING RESULTS

The following potential hazards arising from loss of containment have been assessed:

- Flammable Gas Dispersion / Flash Fire - the extent of the areas covered by concentration of flammable gas to the Lower Flammability Limit (LFL) was calculated to determine the potential flash fire hazard area.
- Jet Fire - the extent of thermal radiation from jet fires arising from immediately ignited continuous releases was determined. Jet fires were modelled based on the Miller model which is an extension of the Chamberlain and Johnson models specifically for horizontal, vertical and angled low luminosity / non-hydrocarbon jet fires (such as hydrogen).
- Fireball - the size of thermal radiation from a fireball following immediately ignited catastrophic ruptures was assessed.*
- Vapour Cloud Explosion (VCE) - the explosions resulting from a delayed ignition of hydrogen were analysed as follows:
    - For indoor releases (i.e. within the electrolyser building and compressor house) it was assumed that the entire flammable cloud ignites with an explosion source of TNO curve 7 [2]. Dilution of the flammable cloud due to ventilation within the building have not been accounted; and
    - For releases outdoors, 40% of the total flammable cloud volume were used to define an explosion source with TNO curve 7 equivalent overpressure [2].

*Note that fireballs have not been assessed in the risk modelling since they are bounded by the explosion hazard.

**Flammable Dispersion**

| Scenario ID | Equipment Description | Release Description | Weather | Distance to LFL (m) | Distance to UFL (m) |
|---|---|---|---|---|---|
| IS-01a-IF | Per Electrolyser Hydrogen Outlet | Instantaneous failure | Category 5/D | 7.8 | 0.9 |
| IS-01a-IF | Per Electrolyser Hydrogen Outlet | Instantaneous failure | Category 2/F | 3.9 | 0.9 |
| IS-01a-CL | Per Electrolyser Hydrogen Outlet | Continuous leak over 10 minutes (total inventory) | Category 5/D | 1.8 | 0.1 |
| IS-01a-CL | Per Electrolyser Hydrogen Outlet | Continuous leak over 10 minutes (total inventory) | Category 2/F | 1.9 | 0.1 |
| IS-01a-PL | Per Electrolyser Hydrogen Outlet | 10mm pipe leak over 10 minutes | Category 5/D | 1.2 | 0.1 |
| IS-01a-PL | Per Electrolyser Hydrogen Outlet | 10mm pipe leak over 10 minutes | Category 2/F | 1.4 | 0.1 |
| IS-02-IF | H2/Lye Separator | Instantaneous failure | Category 5/D | 23.2 | 4.7 |
| IS-02-IF | H2/Lye Separator | Instantaneous failure | Category 2/F | 17.9 | 4.7 |
| IS-02-CL | H2/Lye Separator | Continuous leak over 10 minutes (total inventory) | Category 5/D | 9.4 | 0.4 |
| IS-02-CL | H2/Lye Separator | Continuous leak over 10 minutes (total inventory) | Category 2/F | 7.7 | 0.4 |
| IS-02-PL | H2/Lye Separator | 10mm pipe leak over 10 minutes | Category 5/D | 1.2 | 0.1 |

| Scenario ID | Equipment Description | Release Description | Weather | Distance to LFL (m) | Distance to UFL (m) |
|---|---|---|---|---|---|
| IS-02-PL | H2/Lye Separator | 10mm pipe leak over 10 minutes | Category 2/F | 1.4 | 0.1 |
| IS-03-IF | Scrubber | Instantaneous failure | Category 5/D | 23.2 | 4.7 |
| IS-03-IF | Scrubber | Instantaneous failure | Category 2/F | 17.9 | 4.7 |
| IS-03-CL | Scrubber | Continuous leak over 10 minutes (total inventory) | Category 5/D | 9.4 | 0.4 |
| IS-03-CL | Scrubber | Continuous leak over 10 minutes (total inventory) | Category 2/F | 7.7 | 0.4 |
| IS-03-PL | Scrubber | 10mm pipe leak over 10 minutes | Category 5/D | 1.2 | 0.1 |
| IS-03-PL | Scrubber | 10mm pipe leak over 10 minutes | Category 2/F | 1.4 | 0.1 |
| IS-04-IF | Gas Holder | Instantaneous failure | Category 5/D | 23.6 | 4.4 |
| IS-04-IF | Gas Holder | Instantaneous failure | Category 2/F | 17.7 | 4.4 |
| IS-04-CL | Gas Holder | Continuous leak over 10 minutes (total inventory) | Category 5/D | 9.8 | 0.4 |
| IS-04-CL | Gas Holder | Continuous leak over 10 minutes (total inventory) | Category 2/F | 8.0 | 0.4 |
| IS-04-PL | Gas Holder | 10mm pipe leak over 10 minutes | Category 5/D | 1.3 | 0.1 |
| IS-04-PL | Gas Holder | 10mm pipe leak over 10 minutes | Category 2/F | 1.5 | 0.1 |
| IS-05-IF | Compressor (LP) | Instantaneous failure | Category 5/D | 25.8 | 3.1 |
| IS-05-IF | Compressor (LP) | Instantaneous failure | Category 2/F | 18.9 | 3.1 |
| IS-05-CL | Compressor (LP) | Continuous leak over 10 minutes (total inventory) | Category 5/D | 14.0 | 0.5 |
| IS-05-CL | Compressor (LP) | Continuous leak over 10 minutes (total inventory) | Category 2/F | 15.7 | 0.5 |
| IS-05-PL | Compressor (LP) | 10mm pipe leak over 10 minutes | Category 5/D | 9.1 | 0.4 |
| IS-05-PL | Compressor (LP) | 10mm pipe leak over 10 minutes | Category 2/F | 11.1 | 0.4 |
| IS-06-IF | Deoxidiser | Instantaneous failure | Category 5/D | 25.8 | 3.1 |
| IS-06-IF | Deoxidiser | Instantaneous failure | Category 2/F | 18.9 | 3.1 |
| IS-06-CL | Deoxidiser | Continuous leak over 10 minutes (total inventory) | Category 5/D | 14.0 | 0.5 |
| IS-06-CL | Deoxidiser | Continuous leak over 10 minutes (total inventory) | Category 2/F | 15.7 | 0.5 |
| IS-06-PL | Deoxidiser | 10mm pipe leak over 10 minutes | Category 5/D | 9.1 | 0.4 |
| IS-06-PL | Deoxidiser | 10mm pipe leak over 10 minutes | Category 2/F | 11.1 | 0.4 |
| IS-06a-IF | Deoxidiser | Instantaneous failure | Category 5/D | 25.8 | 3.1 |
| IS-06a-IF | Deoxidiser | Instantaneous failure | Category 2/F | 18.9 | 3.1 |

| Scenario ID | Equipment Description | Release Description | Weather | Distance to LFL (m) | Distance to UFL (m) |
|---|---|---|---|---|---|
| IS-06a-CL | Deoxidiser | Continuous leak over 10 minutes (total inventory) | Category 5/D | 14.0 | 0.5 |
| IS-06a-CL | Deoxidiser | Continuous leak over 10 minutes (total inventory) | Category 2/F | 15.7 | 0.5 |
| IS-06a-PL | Deoxidiser | 10mm pipe leak over 10 minutes | Category 5/D | 9.1 | 0.4 |
| IS-06a-PL | Deoxidiser | 10mm pipe leak over 10 minutes | Category 2/F | 11.1 | 0.4 |
| IS-07-IF | Compressor (HP) | Instantaneous failure | Category 5/D | 25.8 | 3.1 |
| IS-07-IF | Compressor (HP) | Instantaneous failure | Category 2/F | 18.9 | 3.1 |
| IS-07-CL | Compressor (HP) | Continuous leak over 10 minutes (total inventory) | Category 5/D | 14.0 | 0.5 |
| IS-07-CL | Compressor (HP) | Continuous leak over 10 minutes (total inventory) | Category 2/F | 15.7 | 0.5 |
| IS-07-PL | Compressor (HP) | 10mm pipe leak over 10 minutes | Category 5/D | 9.1 | 0.4 |
| IS-07-PL | Compressor (HP) | 10mm pipe leak over 10 minutes | Category 2/F | 11.1 | 0.4 |
| IS-08-IF | Compressor (A/B) | Instantaneous failure | Category 5/D | 12.5 | 1.2 |
| IS-08-IF | Compressor (A/B) | Instantaneous failure | Category 2/F | 9.8 | 1.2 |
| IS-08-CL | Compressor (A/B) | Continuous leak over 10 minutes (total inventory) | Category 5/D | 5.0 | 0.3 |
| IS-08-CL | Compressor (A/B) | Continuous leak over 10 minutes (total inventory) | Category 2/F | 5.7 | 0.3 |
| IS-08-PL | Compressor (A/B) | 10mm pipe leak over 10 minutes | Category 5/D | 47.3 | 1.0 |
| IS-08-PL | Compressor (A/B) | 10mm pipe leak over 10 minutes | Category 2/F | 41.4 | 1.2 |
| IS-09-RTIF | H2 Storage | Instantaneous failure | Category 5/D | 39.1 | 3.6 |
| IS-09-RTIF | H2 Storage | Instantaneous failure | Category 2/F | 30.0 | 3.6 |
| IS-09-RTEC | H2 Storage | Loss of entire contents through largest connection | Category 5/D | 150.4 | 2.9 |
| IS-09-RTEC | H2 Storage | Loss of entire contents through largest connection | Category 2/F | 129.3 | 3.6 |
| IS-10-LHR | Loading Arms and Manifold (1-6) | Rupture of loading/unloading hose | Category 5/D | 93.9 | 2.2 |
| IS-10-LHR | Loading Arms and Manifold (1-6) | Rupture of loading/unloading hose | Category 2/F | 68.6 | 2.6 |
| IS-10-LHL | Loading Arms and Manifold (1-6) | Leak from loading/unloading hose (10% diameter) | Category 5/D | 19.2 | 0.6 |
| IS-10-LHL | Loading Arms and Manifold (1-6) | Leak from loading/unloading hose (10% diameter) | Category 2/F | 20.0 | 0.6 |

| Scenario ID | Equipment Description | Release Description | Weather | Distance to LFL (m) | Distance to UFL (m) |
|---|---|---|---|---|---|
| IS-11(1)-RTEC | Per Tube Trailer On-site | Loss of entire contents through largest connection | Category 5/D | 19.2 | 0.6 |
| IS-11(1)-RTEC | Per Tube Trailer On-site | Loss of entire contents through largest connection | Category 2/F | 20.0 | 0.6 |
| IS-11(1)-RTIF | Per Tube Trailer On-site | Instantaneous failure | Category 5/D | 51.6 | 4.9 |
| IS-11(1)-RTIF | Per Tube Trailer On-site | Instantaneous failure | Category 2/F | 39.7 | 4.9 |
| IS-12(1)-RTEC | Per Tube Trailer Storage | Loss of entire contents through largest connection | Category 5/D | 19.2 | 0.6 |
| IS-12(1)-RTEC | Per Tube Trailer Storage | Loss of entire contents through largest connection | Category 2/F | 20.0 | 0.6 |
| IS-12(1)-RTIF | Per Tube Trailer Storage | Instantaneous failure | Category 5/D | 51.5 | 4.9 |
| IS-12(1)-RTIF | Per Tube Trailer Storage | Instantaneous failure | Category 2/F | 39.6 | 4.9 |

## Jet Fire

| Scenario ID | Equipment Description | Release Description | Jet fire mass rate (kg/s) | Flame length (m) | Distance downwind to intensity level 1 (8.02 kW/m²) (m) | Distance downwind to intensity level 2 (10.9 kW/m²) (m) | Distance downwind to intensity level 3 (12.7 kW/m²) (m) | Distance downwind to intensity level 4 (15.9 kW/m²) (m) | Distance downwind to intensity level 5 (25.6 kW/m²) (m) |
|---|---|---|---|---|---|---|---|---|---|
| IS-01a-CL | Per Electrolyser Hydrogen Outlet | Continuous leak over 10 minutes (total inventory) | 0.002 | 2.5 | 2.3 | 2.2 | 2.1 | 2.0 | 1.9 |
| IS-01a-PL | Per Electrolyser Hydrogen Outlet | 10mm pipe leak over 10 minutes | 0.001 | 2.2 | 2.3 | 2.3 | 2.3 | 2.3 | n/a |
| IS-02-CL | H2/Lye Separator | Continuous leak over 10 minutes (total inventory) | 0.243 | 14.6 | 15.0 | 13.8 | 13.2 | 12.3 | 10.6 |
| IS-02-PL | H2/Lye Separator | 10mm pipe leak over 10 minutes | 0.001 | 2.2 | 2.3 | 2.3 | 2.3 | 2.3 | n/a |
| IS-03-CL | Scrubber | Continuous leak over 10 minutes (total inventory) | 0.243 | 14.6 | 15.0 | 13.8 | 13.2 | 12.3 | 10.6 |
| IS-03-PL | Scrubber | 10mm pipe leak over 10 minutes | 0.001 | 2.2 | 2.3 | 2.3 | 2.3 | 2.3 | n/a |
| IS-04-CL | Gas Holder | Continuous leak over 10 minutes (total inventory) | 0.243 | 14.7 | 14.8 | 13.6 | 12.9 | 12.1 | 10.3 |
| IS-04-PL | Gas Holder | 10mm pipe leak over 10 minutes | 0.001 | 2.9 | 2.8 | 2.8 | 2.8 | 2.8 | n/a |
| IS-05-CL | Compressor (LP) | Continuous leak over 10 minutes (total inventory) | 0.243 | 9.3 | 13.2 | 12.3 | 11.9 | 11.4 | 10.4 |
| IS-05-PL | Compressor (LP) | 10mm pipe leak over 10 minutes | 0.130 | 6.9 | 9.7 | 9.0 | 8.8 | 8.4 | 7.7 |
| IS-06-CL | Deoxidiser | Continuous leak over 10 minutes (total inventory) | 0.243 | 9.3 | 13.2 | 12.3 | 11.9 | 11.4 | 10.4 |
| IS-06-PL | Deoxidiser | 10mm pipe leak over 10 minutes | 0.130 | 6.9 | 9.7 | 9.0 | 8.8 | 8.4 | 7.7 |
| IS-06a-CL | Dryers | Continuous leak over 10 minutes (total inventory) | 0.243 | 9.3 | 13.2 | 12.3 | 11.9 | 11.4 | 10.4 |

| Scenario ID | Equipment Description | Release Description | Jet fire mass rate (kg/s) | Flame length (m) | Distance downwind to intensity level 1 (8.02 kW/m²) (m) | Distance downwind to intensity level 2 (10.9 kW/m²) (m) | Distance downwind to intensity level 3 (12.7 kW/m²) (m) | Distance downwind to intensity level 4 (15.9 kW/m²) (m) | Distance downwind to intensity level 5 (25.6 kW/m²) (m) |
|---|---|---|---|---|---|---|---|---|---|
| IS-06a-PL | Dryers | 10mm pipe leak over 10 minutes | 0.130 | 6.9 | 9.7 | 9.0 | 8.8 | 8.4 | 7.7 |
| IS-07-CL | Compressor (HP) | Continuous leak over 10 minutes (total inventory) | 0.243 | 9.3 | 13.2 | 12.3 | 11.9 | 11.4 | 10.4 |
| IS-07-PL | Compressor (HP) | 10mm pipe leak over 10 minutes | 0.130 | 6.9 | 9.7 | 9.0 | 8.8 | 8.4 | 7.7 |
| IS-08-CL | Compressor (A/B) | Continuous leak over 10 minutes (total inventory) | 0.039 | 3.8 | 4.8 | 4.5 | 4.4 | 4.3 | 4.0 |
| IS-08-PL | Compressor (A/B) | 10mm pipe leak over 10 minutes | 1.925 | 23.0 | 31.9 | 29.7 | 28.8 | 27.5 | 25.3 |
| IS-09-RTEC | H2 Storage | Loss of entire contents through largest connection | 49.281 | 98.8 | 141.0 | 130.7 | 126.1 | 120.0 | 108.8 |
| IS-10-LHR | Loading Arms and Manifold (1-6) | Rupture of loading/unloading hose | 38.303 | 88.8 | 127.1 | 117.9 | 113.7 | 108.2 | 98.1 |
| IS-10-LHL | Loading Arms and Manifold (1-6) | Leak from loading/unloading hose (10% diameter) | 0.383 | 11.2 | 15.3 | 14.3 | 13.8 | 13.3 | 12.2 |
| IS-11(1)-RTEC | Per Tube Trailer On-site | Loss of entire contents through largest connection | 0.383 | 11.2 | 15.3 | 14.3 | 13.8 | 13.3 | 12.2 |
| IS-12(1)-RTEC | Per Tube Trailer Storage | Loss of entire contents through largest connection | 0.383 | 11.2 | 15.3 | 14.3 | 13.8 | 13.3 | 12.2 |

### Vapour Cloud Explosion

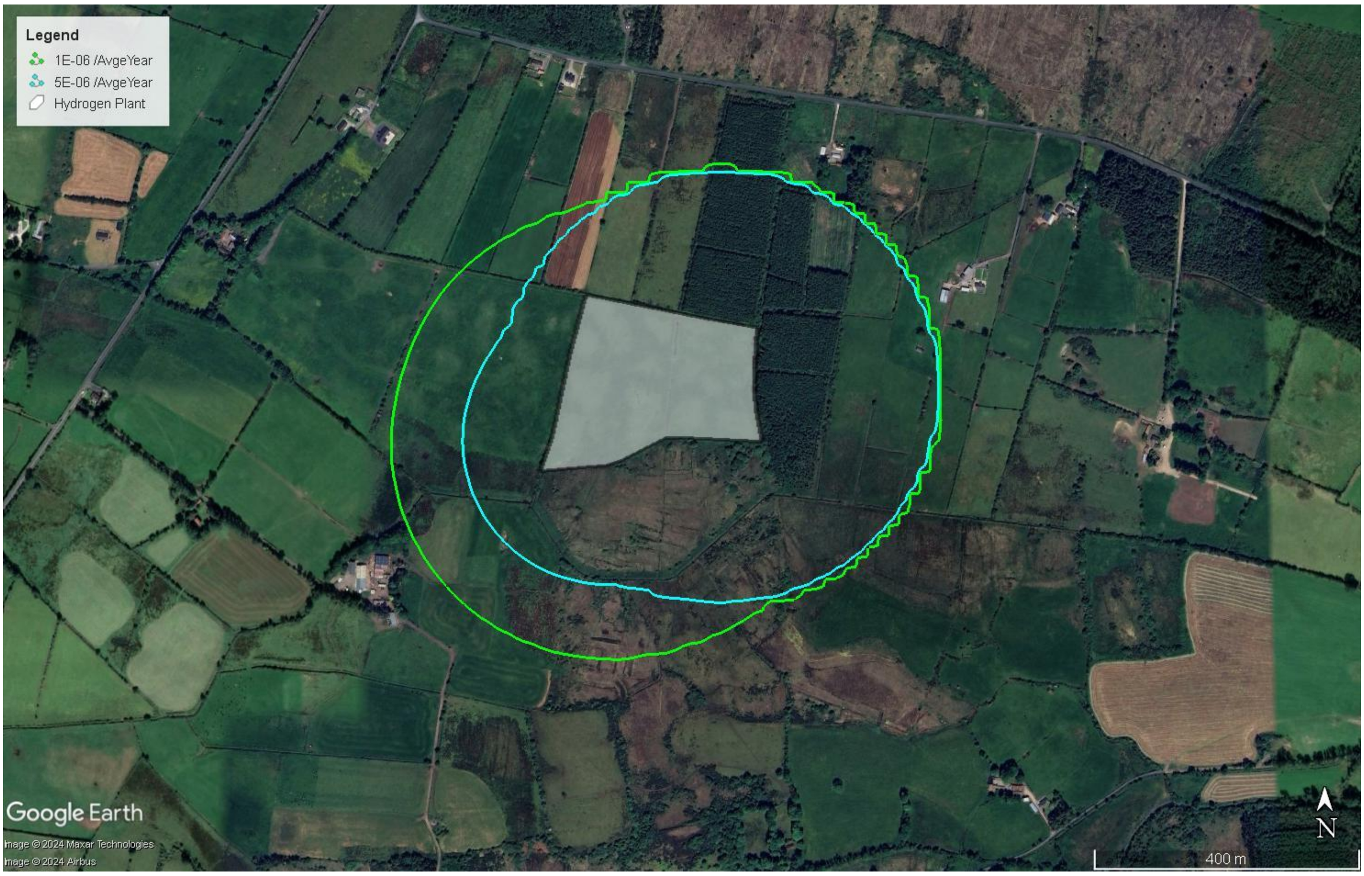
| Scenario ID | Equipment Description | Release Description | Distance downwind to overpressure 1 (168 mbar) (m) | Distance downwind to overpressure 2 (365 mbar) (m) | Distance downwind to overpressure 3 (942 mbar) (m) |
|---|---|---|---|---|---|
| IS-01a-IF | Per Electrolyser Hydrogen Outlet | Instantaneous failure | 24.0 | 18.5 | 13.7 |
| IS-02-IF | H2/Lye Separator | Instantaneous failure | 117.7 | 81.8 | 56.1 |
| IS-02-CL | H2/Lye Separator | Continuous leak over 10 minutes (total inventory) | 23.8 | 18.4 | 13.7 |
| IS-03-IF | Scrubber | Instantaneous failure | 117.7 | 81.8 | 56.1 |
| IS-03-CL | Scrubber | Continuous leak over 10 minutes (total inventory) | 23.8 | 18.4 | 13.7 |
| IS-04-IF | Gas Holder | Instantaneous failure | 117.8 | 83.0 | 57.9 |
| IS-04-CL | Gas Holder | Continuous leak over 10 minutes (total inventory) | 23.9 | 18.5 | 13.7 |
| IS-05-IF | Compressor (LP) | Instantaneous failure | 108.7 | 73.9 | 43.7 |
| IS-05-CL | Compressor (LP) | Continuous leak over 10 minutes (total inventory) | 19.1 | 15.5 | 12.4 |
| IS-06-IF | Deoxidiser | Instantaneous failure | 108.7 | 73.9 | 43.7 |
| IS-06-CL | Deoxidiser | Continuous leak over 10 minutes (total inventory) | 19.1 | 15.5 | 12.4 |
| IS-06a-IF | Dryers | Instantaneous failure | 108.7 | 73.9 | 43.7 |
| IS-06a-CL | Dryers | Continuous leak over 10 minutes (total inventory) | 19.1 | 15.5 | 12.4 |
| IS-07-IF | Compressor (HP) | Instantaneous failure | 108.7 | 73.9 | 43.7 |
| IS-07-CL | Compressor (HP) | Continuous leak over 10 minutes (total inventory) | 19.1 | 15.5 | 12.4 |
| IS-08-IF | Compressor (A/B) | Instantaneous failure | 59.3 | 39.9 | 23.2 |
| IS-08-PL | Compressor (A/B) | 10mm pipe leak over 10 minutes | 77.3 | 66.6 | 57.3 |
| IS-09-RTIF | H2 Storage | Instantaneous failure | 135.7 | 93.3 | 57.8 |
| IS-09-RTEC | H2 Storage | Loss of entire contents through largest connection | 271.3 | 238.2 | 211.2 |
| IS-10-LHR | Loading Arms and Manifold (1-6) | Rupture of loading/unloading hose | 128.0 | 113.1 | 100.1 |

| Scenario ID | Equipment Description | Release Description | Distance downwind to overpressure 1 (168 mbar) (m) | Distance downwind to overpressure 2 (365 mbar) (m) | Distance downwind to overpressure 3 (942 mbar) (m) |
|---|---|---|---|---|---|
| IS-10-LHL | Loading Arms and Manifold (1-6) | Leak from loading/unloading hose (10% diameter) | 29.3 | 25.7 | 22.5 |
| IS-11(1)-RTEC | Per Tube Trailer On-site | Loss of entire contents through largest connection | 29.3 | 25.6 | 22.5 |
| IS-11(1)-RTIF | Per Tube Trailer On-site | Instantaneous failure | 178.0 | 121.0 | 75.6 |
| IS-12(1)-RTEC | Per Tube Trailer Storage | Loss of entire contents through largest connection | 29.3 | 25.6 | 22.5 |
| IS-12(1)-RTIF | Per Tube Trailer Storage | Instantaneous failure | 177.8 | 120.9 | 75.6 |

# APPENDIX E NEW ESTABLISHMENT CRITERIA - ALTERNATIVE CASE

The following contours present the theoretical worst case contours from the facility, relevant for new establishments, assuming emergency shutdown and isolation is not implemented into the design. This scenario therefore represents the case whereby the entire process inventory can be released from any point in the process. It can be seen from the figure below, that whilst the contours are significantly larger than the base case presented in Section 4.2, the three nearest occupied properties remain unaffected, providing further justification that the new establishment criteria are satisfied.

**Individual Risk Contours for New Establishments**



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