| Material/ Substance | CAS Number | Hazard | Amount Stored | Annual Usage | Nature of Use | Risk Phrase, R | Safety Phrase, S |
|---|---|---|---|---|---|---|---|
| Hydrogen | 1333-74-0 | Extremely flammable | 105 bottles | 510 bottles | Generator cooling | 12 | 9-16-33 |
| Ion Exchange Resins |  | None | None | As required | Water treatment |  |  |
| Molybdate 3 Reagent |  | Irritant | 15 litres | 15 litres | Silica monitor reagent |  |  |
| Nesslers Reagent (1.25% HgCl)4 |  | Toxic | 5 litres | 5 litres | Laboratory analysis | 35, 26-27-28-33 |  |
| Nicerol 3% protein foam concentrate |  |  | 1000 litres | As required | Fire suppression |  |  |
| Nitrogen | 7727-37-9 | None | 60 bottles$^{3}$ | 465 bottles$^{3}$ | Boiler waterside protection |  |  |
| Oxygen | 7782-44-7 | Oxidising | 10 bottles$^{3}$ | 20 bottles$^{3}$ | Mechanical use | 8 | 17 |
| Propane | 74-98-6 | Flammable | 1 tonne | 2 tonnes | Ignition fuel | 12 | 9, 16, 33 |
| Propane | 74-98-6 | Flammable | 6 Bottles | 6 Bottles | Mechanical use | 12 | 9, 16, 33 |
| Sodium Hydroxide solution (30%) | 1310-73-2 | Corrosive | 1 tonne | 2 tonnes | WTP regeneration | 35 | 26, 37/39, 45 |
| Sodium Hydroxide solution (47%) | 1310-73-2 | Corrosive | 30 tonnes | 100 tonnes | WTP regeneration | 35 | 26, 37/39, 45 |
| Sodium Hypochlorite solution | 7681-52-9 | Corrosive | 2 tonnes | 5 tonnes | Cooling water treatment | 31, 34 | 2, 28, 45, 50 |
| Sulphuric Acid (Bulk) | 7664-93-9 | Corrosive | 40 tonnes | 100 tonnes | WTP regeneration | 35 | 2, 26, 30 |
| Sulphuric Acid | 7664-93-9 | Corrosive | 1 tonne | 2 tonnes | Neutralisation sump | 35 | 2,26,30 |

The loss of containment of the other materials is also not considered to give rise to a major accident event. For instance, although some of the materials, such as the sodium hydroxide and sulphuric acid will be stored in large quantities of up to 30 and 40 tonnes, they are classified as being corrosive and their loss of containment would not constitute a major accident. The quantities of other materials, such as the hydrogen and acetylene, which are classified as extremely flammable and explosive respectively, will be stored in bottles well below their threshold levels of 10 and 5 tonnes respectively for lower tier Seveso sites.

## 2.2 HISTORICAL MAJOR ACCIDENTS

In the past there have been a number of fires and explosions that have occurred at major hazardous installations and pipelines conveying flammable materials. Two examples of accident events are outlined here – explosions and fires that resulted from the overflow of petroleum from a storage tank at the Buncefield Oil Terminal in the UK and a gas pipeline rupture that occurred in Belgium. The lessons learned from these accidents and the implications for the design and operation of Combined Cycle Power Plant at Great Island are then discussed.

### 2.2.1 Buncefield Oil Storage Terminal, United Kingdom

In the early hours of Sunday 11th December 2005, a number of explosions occurred at Buncefield Oil Storage Depot, Hemel Hempstead, Hertfordshire, UK. At least one of the initial explosions was of massive proportions and there was a large fire, which engulfed 23 large fuel storage tanks over a high proportion of the Buncefield site. The incident caused injuries to 43 people and although no one was seriously hurt, the fires and explosions resulted in significant damage to both commercial and residential properties near the Buncefield site. The fire burned for several days, destroying most of the site and emitting large clouds of black smoke into the atmosphere that dispersed over southern England and beyond. About 2000 people were evacuated from their homes and sections of the M1 motorway were closed. The fire burned for five days, destroying most of the site and emitting a large plume of smoke into the atmosphere.

Late on Saturday 10 December 2005 a delivery of unleaded petrol started to arrive at Tank 912 in bund A. The safety systems in place to shut off the supply of petrol to the tank to prevent overfilling failed to operate. Petrol cascaded down the side of the tank, collecting at first in bund A. As overfilling continued, the vapour cloud formed by the mixture of petrol and air, flowed over the bund wall, dispersed and flowed west off site towards the Maylands Industrial Estate. A white mist was observed in CCTV replays. The exact nature of the mist is not known with certainty: it may have been a volatile fraction of the original fuel such as butane, or ice particles formed from the chilled, humid air as a consequence of the evaporation of the escaping fuel.

### 2.2.2 Gas Pipeline Rupture, Belgium

In July 2004, an accident occurred involving a high pressure gas pipeline at Ghislenghien, Belgium. A high pressure natural gas pipeline ruptured and the leaking gas ignited, causing 25 fatalities and over 150 injuries, together with extensive damage to nearby factory buildings. Investigations revealed that the pipeline had been damaged by construction work taking place in the vicinity.

Accounts of the accident indicate that an odour of gas was first detected at around 07:30, but that the 'explosion' of the pipeline did not occur until 08:56. It seems possible that the incident started as a relatively small leak that later propagated into a rupture of the pipeline (the 'explosion' referred to by observers). The sudden rupture of the pipeline, coupled with ignition to give a fireball, would seem to account for the observations recorded.

A 'burn radius' of around 400 m (equating to a burn area of 502,655 $m^2$) is quoted in one source, although other sources give lower values of around 200 to 300m (equating to burn areas of 125,664 $m^2$ and 282,743 $m^2$ respectively).

### 2.2.3 *Implications for the Great Island Establishment*

The main explosion at Buncefield was unusual because it generated much higher overpressures than would usually have been expected from a vapour cloud explosion. The mechanism of the violent explosion is not fully understood and further scientific investigation has been commissioned to explain what occurs in large flammable vapour clouds (7).

However, the distillate stored in bulk at Great Island has a low volatility and so an explosion arising from a loss of containment similar to the one caused at Buncefield is considered to be very unlikely. In order to prevent overfilling, a robust shut-off system will be installed to stop the flow if distillate oil from the jetty in the event that the liquid level in the tank reaches a specified level. Furthermore, the operating envelope will be clearly defined in that the filling levels, temperatures, pressures and flow rates, for example, will remain within defined limits. An inspection regime will also be developed to ensure that the integrity of the storage tank is maintained.

The magnitude of the consequences of an accident similar those arising from the high pressure gas pipeline rupture at Ghislenghien, Belgium is deemed unlikely to occur at Great Island. This is because the natural gas onsite will be conveyed in smaller diameter pipelines and will be at lower pressures than the Belgium transmission pipeline.

## 2.3 *MAJOR ACCIDENT SCENARIOS*

Information about the distillate and natural gas contained within the isolatable sections of the plant at Great Island are reported in *Table* 2.3. The QRA performed by ERM included releases from all of the plant areas listed in *Table* 2.3 and therefore potential accidental releases from all parts of the site have been considered in the analysis.

The pressure of the gas arriving at the site can be up to 70barg. However, it should be noted that the incoming gas pipeline has not been included in the analysis. This is because it will be owned and operated by Bord Gáis, who will have their own measures in place to minimise the risks from accidental releases.

***Table 2.3 Process and Inventory Information***

| Node | Description | Information | Notes |
|---|---|---|---|
| A01 | AGI | Pressure of gas delivered to AGI normally at 40 barg.. | The Bord Gáis pipeline will normally deliver gas at a pressure of around 40barg. The pressure may however at times be higher or lower than this. The maximum pressure would be 70 barg and it is guaranteed that the pressure of the gas supplied would not be less than 19 barg. When necessary, the pressure will be reduced at the AGI to the pressure required by the gas turbine. |
| G01 | Gas pipeline from AGI to gas compressor | 250 mm underground flowline, at 40barg | |
| GCB01 | Gas compressors | Pressure of compressed gas up to 50 barg depending on gas turbine generator selected. | If necessary, the gas is compressed before being fed the gas turbine generator. |
| G02 | Gas pipeline from gas compressor to gas turbine | 300 mm above ground flowline, up to 50 barg depending on turbine selected. | |
| TR01 | Transformers | Oil-filled | Overheating of transformer oil. |
| J01 | Jetty unloading arms | | Backup distillate fuel will be delivered to the site via the jetty for the primary filling but will be tankered by road for annual refills of minor volumes infrequently (no more than once per year). |
| T01 | Distillate storage tank | 17,000 $m^3$ capacity | No more than 11,000$m^3$ of distillate fuel will be stored in the refurbished storage tank at any one time. The tank will be fitted with an automatic trip during filling when the capacity of the tank has reached 11,000m3. |
| DP01 | Distillate flowlines | Ambient conditions | Flowlines convey distillate fuel from jetty to storage and from storage to power plant. |

The accident scenarios considered in the QRA are summarised in *Table 2.4*. The impact of these potential major accidents on both personnel safety and the environment has been assessed.

***Table 2.4 Major Accident Scenarios***

| Section | Scenario |
|---|---|
| **AGI and gas line from AGI to gas compressor (40 barg)** | |
| | 4mm diameter hole leading to jet fire |
| | 25mm diameter hole leading to jet fire |
| | 1/3 diameter hole (approximately 80mm) leading to jet fire |
| | 250mm rupture leading to jet fire |
| **Gas compressors** | |
| | Release of gas into compressor building leading to a VCE |
| **Gas line from gas compressor to gas turbine (up to 50 barg)** | |

| Section | Scenario |
|---|---|
|  | 4mm diameter hole leading to jet fire<br>25mm diameter hole leading to jet fire<br>1/3 diameter hole (approximately 80mm) leading to jet fire<br>300mm rupture leading to jet fire |
| **Gas Turbine Building** |  |
|  | Release of gas into gas turbine building leading to a jet flame |
| **Distillate storage tank** |  |
|  | Full bund fire<br>Overtopped bund fire |
| **Jetty unloading arms** |  |
|  | Large release of distillate into the marine environment |
| **Distillate flowlines** |  |
|  | 1/3 diameter hole (approximately 80mm) leading to jet fire<br>300mm rupture leading to jet fire |
| **Transformers** |  |
|  | Overheating of oil leading to fire and explosion |

However, for the purpose of calculating the risk levels, the pressure of the gas in the line from the AGI to the compressor was also assumed to be at 50 barg, which is considered to be conservative.

### *2.3.1 Causes of Major Accidents*

There can be a number of different causes leading to losses of containment from the AGI, distillate storage, gas pipelines and jetty facilities. The typical causes of potential major accidents for the various hazardous areas of the site are set out in *Table 2.5*.

In addition there are potential external causes that are common to all sections of the plant. These include for instance extreme weather conditions, lightning strikes, seismic activity, aircraft impact and sabotage/vandalism.

One other cause that is considered when assessing the risks from major accidents arises from the consequences of an accident at an adjacent facility (i.e. an escalated event). However, there are no other hazardous installations in the vicinity of the Great Island site and so the risks of escalation from accidents at an adjacent facility were discounted from the analysis. Similarly, the potential for escalation at other establishments caused by releases of gas and distillate at Great Island were also considered no further.

*Table 2.5* *Summary of Causes of Potential Major Accidents*

| Plant Section | Causes of Failure |
|---|---|
| AGI and gas lines from AGI to compressor and from compressor to gas turbine | • Impact from dropped object<br>• Vehicle impact<br>• Third party activities |
| Distillate oil flowlines | • Overpressure<br>• Defective/wrong materials used during construction<br>• Corrosion<br>• Failure of gas line supports<br>• Human error<br>• Incorrectly fitted gasket/ defective gasket installed |
| Compressor failures | • Impact from dropped object<br>• Overpressure<br>• Low suction pressure<br>• High/low temperature beyond design limits<br>• Corrosion<br>• Excessive vibration<br>• Human error |
| Jetty unloading arms | • Poor connection<br>• Loading arm failure due to excessive movement of moored vessel<br>• Overpressure<br>• Incorrectly fitted gasket/ defective gasket installed<br>• Human error |
| Distillate storage tank | • Impact from dropped object<br>• Overfilling<br>• Overpressure<br>• Defective/wrong materials used during construction<br>• Corrosion |
| Transformer | • Overheated transformer oil |

The failure rates considered in the frequency analysis in *Section 3* encompass all causes.

### 2.3.2 *Screening of major accident Events*

A number of potential major accident scenarios identified above were discounted from further detailed assessment. This was done on the basis that they were judged to not lead to a major accident event or the risks were deemed to be insignificant in terms of their impact on land use planning in the vicinity of the installation.

It is expected that the transfer of the distillate oil from the jetty to bulk storage would only take place once and it is expected that the operation would take less than 24 hours. Since the distillate oil flowlines would be purged and maintained in a dry condition once transfer has been completed, they are only likely to contain any distillate for around 0.3% of the time. Therefore, the scenario of a pipeline failure leading to a significant loss of distillate has not been included in the analysis because it is judged to have a very low likelihood.

One of the major accident scenarios considered in the analysis is overheating of the oil in the transformers giving rise to a fire and possible explosion. However, there are protection systems incorporated into the design of modern transformers that would activate their shutdown in the event of overheating. Therefore, fires and explosions arising from an overheated transformer are considered to be extremely unlikely and if there were such an accident event, the extent of the consequences would not extend to offsite areas where people would be present. The transformer bund is designed to minimise contamination across the site.

# 3 *FREQUENCY ANALYSIS*

## 3.1 *RELEASE FREQUENCIES*

The frequency of releases from equipment has been determined by high level parts counting and application of generic frequency data. The parts count was performed using the Process Flow Diagrams (PFDs).

The frequency data have been taken from the Health and Safety Executive Failure Rate and Event Data (FRED), contained within their Planning Case Assessment Guide (2). Where appropriate, event frequencies quoted in the recently published Policy & Approach of the Health & Safety Authority to COMAH Risk-based Land-use Planning(1) have also been considered in the frequency analysis. With respect to the frequency of releases of the distillate at the jetty, the frequency of failure of unloading arms have been derived from work performed by the Advisory Committee on Dangerous Substances (ACDS) in the UK(8).

### 3.1.1 *Pipes*

The failure frequencies for conventional single-walled pipework are a function of pipe diameter and length. The values used are shown in *Table 3.1* (the highlighted column indicates the set of frequencies applicable to the gas line from the AGI to the gas turbine).

***Table 3.1 Failure Frequencies: Pipework***

| Release Hole Size (mm) | Failure Frequency (per metre year) for Pipe Diameter (mm) | | | | |
|---|---|---|---|---|---|
| | <50 | 50-149 | 150-299 | 300-499 | 500-1000 |
| 3 | $1 \times 10^{-5}$ | $2 \times 10^{-6}$ | | | |
| 4 | | | $1 \times 10^{-6}$ | $8 \times 10^{-7}$ | $7 \times 10^{-7}$ |
| 25 | $5 \times 10^{-6}$ | $1 \times 10^{-6}$ | $7 \times 10^{-7}$ | $5 \times 10^{-7}$ | $4 \times 10^{-7}$ |
| 1/3 pipe diameter | | | $4 \times 10^{-7}$ | $2 \times 10^{-7}$ | $1 \times 10^{-7}$ |
| Full bore | $1 \times 10^{-6}$ | $5 \times 10^{-7}$ | $2 \times 10^{-7}$ | $7 \times 10^{-8}$ | $4 \times 10^{-8}$ |

### 3.1.2 *Tanks*

The HSA Policy & Approach to COMAH Risk-based Land-use Planning does not give failure rates specifically for tank failures. For large scale flammable storage, a frequency of $1 \times 10^{-3}$ per year is quoted for pool fires, which cover the entire surface of the bund. Also, a frequency of not less than $1 \times 10^{-4}$ per year should be used for a major uncontained pool fire extending up to 100m from the bund wall. These frequency figures are higher than the failure rates in FRED for single walled storage tanks that are shown in *Table 3.2*. Furthermore, the probability of ignition would then need to be applied to the figures given in *Table 3.2* to obtain the frequency of a pool fire.

*Table 3.2 Failure Frequencies: Single Walled Storage Tanks*

| Scenario | Frequency (per tank year) |
|---|---|
| Catastrophic failure | $4 \times 10^{-5}$ |
| 1000 mm hole at base | $1 \times 10^{-4}$ |
| 300 mm hole at base | $8 \times 10^{-5}$ |

It should be noted that the frequency figures given in the HSA policy document relate to a storage area containing 10 tanks. The pool fire frequencies quoted by the HSA, which have been used in the analysis, are regarded as being conservative since there are only 5 storage tanks at the Great Island site.

### 3.1.3 *Compressor*

The release of gas from the compressor has been derived from figures quoted in the E&P Forum (9) and for release sizes greater than 1 kg/s the failure frequency would be $9.45 \times 10^{-4}$ per annum. In order to account for gas releases within the compressor enclosure from associated valves, piping and fittings beyond the first flange the failure frequency has been doubled. However, since the compressor enclosure would be a zoned area, the probability of ignition would be low, and if a figure of 0.07 is assumed (10), the frequency of an ignited gas release within the compressor enclosure would be:

$0.07 \times 2 \times 9.45 \times 10^{-4} = 1.325 \times 10^{-4}$ per annum.

### 3.1.4 *Unloading Arms*

The failure rates used in the analysis have been based on work performed by the Advisory Committee on Dangerous Substances (ACDS) in the UK (8). This study considers the risks from the transport of dangerous substances, including the transfer of hazardous cargoes from ship to shore.

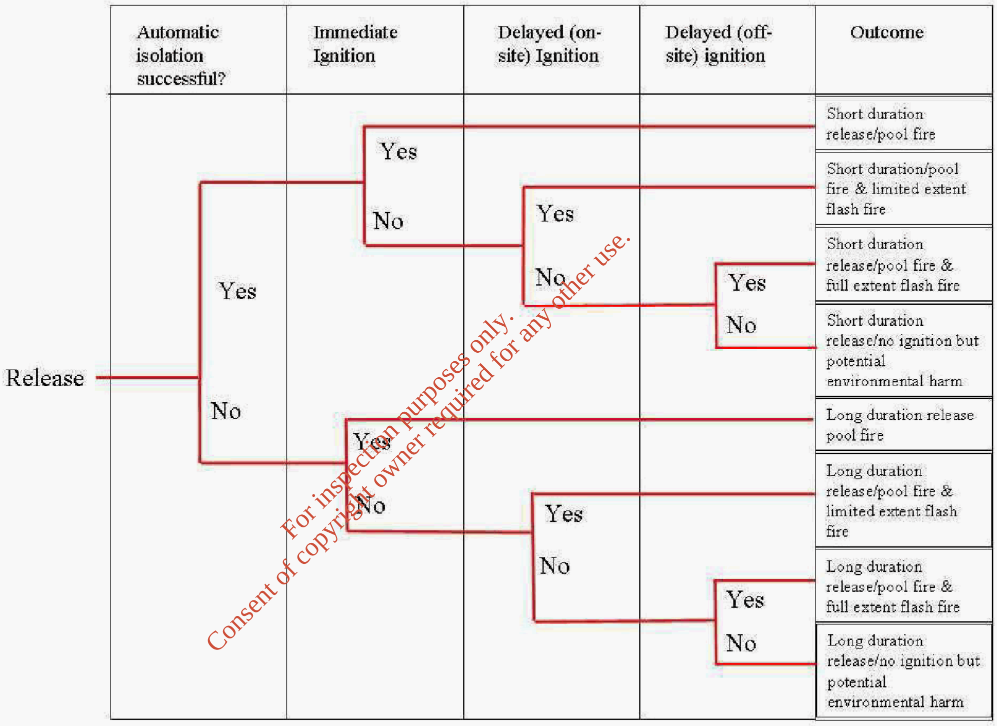
The ACDS Port Study gives the spill frequency per cargo transferred from historical data of ports in the UK and quotes frequencies of: $7.6 \times 10^{-5}$ and $1.8 \times 10^{-4}$ for LPG and low flash products respectively. For the purpose of predicting the frequency of a release, the distillate is considered to be represented by low flash products. Therefore, the spill frequency used in the analysis was $1.8 \times 10^{-4}$ per transfer. Since there will only be a once-off transfer (assuming a one in ten year potential emergency use of all distillate and subsequent refill from the jetty), this equates to a failure frequency of $1.8 \times 10^{-5}$ per year.

## 3.2 *RELEASE OUTCOME FREQUENCY*

A given release of flammable or combustible material may ultimately result in a variety of outcomes, depending on a number of factors, including whether automatic isolation is successful, whether ignition of the release occurs immediately or whether it is delayed. Ordinarily event outcome frequencies are calculated using a simplified event tree and *Figure 3.1* is typical for a release of flammable liquid. In the event of a distillate release, which is not classified as a flammable liquid, the generation of a flammable vapour, and hence a flash fire is considered to be very unlikely.

With respect to pool fires, the ignition probabilities are accounted for in the frequencies quoted in the HSA Policy & Approach to COMAH Risk-based Land-use Planning.

***Figure 3.1*** ***Simplified Event Tree***



All gas releases are assumed to ignition; an immediate ignition probability of 0.5 and a delayed ignition probability of 1 have been used.

## 3.3 FATALITY PROBABILITY

Fatality probabilities have been specified for the purposes of calculating individual risk and the societal risk of fatality to the population surrounding the proposed installation. The risk to people, both outdoors and indoors from exposure to thermal radiation from fires and the blast effects from VCEs have been considered in the analysis.

The relationship between the level of consequence and the probability of fatality is generally characterized by a probit relationship that can be used to estimate the proportion of the population that may be affected by exposure to a particular harm.

The Probits referenced in the HSA Policy & Approach document were used in determining the fatality probabilities from the exposure to the effects of fires and blast overpressures generated by VCEs.

### 3.3.1 *Thermal Radiation*

*Fatality Probability - People Outdoors*

The Probit most commonly used to determine the risk from thermal radiation is the Eisenberg Probit (11), i.e.

Probit = $-14.9 + 2.56 \ln (I^{1.33} t)$ with I in $kW/m^2$ and t in seconds

This relationship applies to people exposed outdoors. However, it can be reasonably applied for most exposed population.

For long duration fires, such as pool fires and jet fires, it is generally reasonable to assume exposure duration of 75 seconds (to take account of the time required to escape). Hence, based on the above, the fatality probabilities for people outdoors are listed in *Table 3.3*.

**Table 3.3** ***Fatality Probabilities from Thermal Radiation, People Outdoors***

| Thermal Flux ($kW.m^{-2}$) | Fatality Probability |
|---|---|
| 13.4 | 0.5 |
| 9.23 | 0.1 |
| 6.8 | 0.01 |

*Fatality Probability - People Indoors*

In order to estimate the fatality probability of people indoors, it is necessary to determine the effect that different levels of thermal radiation will have on the building. A British Code of Practice on fire precautions in chemical plant (BS 5908:1990) suggests that spontaneous (non-piloted) ignition of wood could occur at fluxes of 25 $kW.m^{-2}$, with piloted ignition of wood occurring at 12.5 $kW.m^{-2}$. Ignition of wood, textiles or other combustible materials in a building would result in secondary fires in the building, potentially causing direct harm to the occupants or forcing them to escape and be exposed to the incident thermal radiation as a result.

It is conservatively assumed that a building would catch fire quickly if it becomes exposed to a thermal flux of more than 25.6$kW.m^{-2}$ and is considered to result in a high probability of fatality. Between thermal flux levels of 12.7 and 25.6$kW.m^{-2}$ people are assumed to escape outdoors, and the probability of fatality is assumed to correspond to that for people outdoors. At thermal flux levels below 12.7$kWm^{-2}$ building occupants are assumed to be protected.

Taking these factors into consideration, the fatality probabilities for people indoors were established, as shown in *Table 3.4*.

***Table 3.4*** ***Fatality Probabilities from Thermal Radiation, People Indoors***

| **Thermal Flux (kW.m$^{-2}$)** | **Fatality Probability** |
|---|---|
| >25.6 | 1.0 |
| 12.7 to 25.6 | As for people outdoors |
| <12.7 | 0.0 |

### 3.3.2 Blast Overpressure

One of the most commonly used Probits to determine the risk from blast overpressure is the relationship put forward by Hurst, Nussey and Pape (12):

Probit = 1.47 + 1.35 ln (P) with P in psi (NB 1 psi = 68.947573 mbar)

This relationship only applies to people exposed outdoors, and implies the fatality probabilities set out in *Table 3.5*:

***Table 3.5*** ***Fatality Probabilities from Blast Overpressures, People Outdoors***

| **Blast Overpressure** | | **Fatality Probability** |
|---|---|---|
| psi | mbar | |
| 2.44 | 168 | 0.01 |
| 5.29 | 365 | 0.10 |
| 13.66 | 942 | 0.50 |

People outdoors could either be more or less vulnerable to the effects of overpressures generated by a VCE, depending on the type of structure. The Chemicals Industry Association (CIA) has published relationships between fatality probabilities for people inside four different categories of building (13), namely,

- Category 1: hardened structure building
- Category 2: typical office block;
- Category 3: typical domestic building; and
- Category 4: portacabin type timber construction

The CIA Category 3 Curve (typical domestic building: two-storey, brick walls, timber floors) provides a reasonably conservative basis for assessing the risk of fatality to most residential populations. The table below gives the fatality probabilities associated with various levels of overpressure for people inside a category 3 type building.

*Table 3.6 Fatality Probabilities from Blast Overpressures, People Indoors*

| Blast Overpressure | | Fatality Probability |
|---|---|---|
| psi | mbar | |
| 14.5 | 1000 | 1.0 |
| 8.70 | 600 | 0.70 |
| 4.35 | 300 | 0.50 |
| 1.45 | 100 | 0.05 |
| 0.725 | 50 | 0.01 |
| 0.145 | 10 | 0 |

# 4 *CONSEQUENCE MODELLING*

Losses of containment of the hazardous substances present at the Great Island site have the potential to harm both people and the environment. The QRA carried out for the site has used the DNV *Phast* (Process Hazard Analysis Software Tool) suite of consequence models (version 6.53). Also, the Jo and Ahn method was used for assessing the risks associated with natural gas pipelines. A number of methods for predicting bund overtopping volumes and their application are described. The results in terms of the distances to specified fatality probabilities from jet fires, thermal flux levels from pool fires and overpressure levels from gas explosions are presented. The percentage overtopping of the storage tank bund using different methodologies and arrangements are also given together with the environmental cost liabilities.

## 4.1 *RELEASE DURATIONS*

### 4.1.1 *Releases from Pipes*

Releases from pipes have been assumed to continue for:

- one minute plus the time taken to empty the contents of the inventory for isolated cases (the valves have been designed to close 60 seconds after being activated); and
- 10 minutes plus the time taken to empty the contents of the inventory for non-isolated cases.

These estimated release durations are based on judgements around the closing time of emergency valves. The detection systems to be provided at the facility would enable leaks to be detected rapidly.

### 4.1.2 *Releases from Distillate Storage Tanks*

The duration of a release from a storage tank has been assumed to be equal to the time taken to empty the tank contents.

## 4.2 *HUMAN IMPACT MODELLING SOFTWARE*

The impact of the outcomes from losses of containment of the hazardous materials on people has been assessed by using the DNV *Phast* (Process Hazard Analysis Software Tool) suite of consequence models (version 6.53). *Phast* is a comprehensive hazard analysis software tool for all stages of design and operation.

*Phast* examines the progress of a potential incident from the initial release to far-field dispersion including modelling of pool spreading and evaporation, and flammable and toxic effects.

*Phast* is designed to comply with the regulatory requirements of many countries. For example, specific modules have been included to ensure compliance with the Dutch Yellow Book, US EPA and UK HSE regulations.

*Phast* contains models tailored for hazard analysis of offshore and onshore industrial installations. These include:

- Discharge and dispersion models, including a Unified Dispersion Model (UDM);
- Flammable models, including resulting radiation effects, for jet fires, pool fires and BLEVEs; and
- Explosion models, to calculate overpressure and impulse effects. Available models include the Baker Strehlow, TNO Multi-Energy and TNT explosion models.

## 4.3 DISPERSION OF FLAMMABLE VAPOURS

Dispersion of natural gas can be dependent on several parameters, including: surface roughness, averaging time, material properties, wind speed and weather conditions. However, the gas delivered to the site will normally be at a pressure of 40 barg, with a minimum guaranteed supply pressure of 19 barg, but on occasions, could be as high as 70 barg. The pressure of the gas discharged from the compressor and fed to the gas turbine would normally be in the order of 50 barg. For the purpose of the analysis, the pressure in all of the gas pipeline from the AGI to the gas turbine, via the compressor was taken to be 50 barg. Any releases would not therefore be strongly influenced by the meteorological conditions.

A flammable vapour cloud is considered only to be formed in the event of a natural gas release losing its momentum from impact with the ground or surrounding structures and equipment, which then disperses as a low density gas.

### *Averaging Time*

When using gas dispersion models the 'averaging time' is a description of the time over which a gas concentration is averaged. At a particular point in space the concentration of a gas cloud at equilibrium will vary for two reasons. Firstly, as the wind direction is not perfectly constant the plume will meander about a mean value. Secondly, there are 'in-cloud' fluctuations due to the turbulence inherent in the atmosphere. As dispersion models aim to show a 'time averaged' concentration at a particular point, this average will depend on the length of time over which the concentration was 'sampled'. The situation is made more complicated because the different types of dispersion model assume different definitions of 'averaging time'.

The use of a short averaging time will maximise the recorded concentration at a given point, whereas a longer averaging time will give a lower value. This is because the use of a short averaging time captures the concentration 'peaks' at a location.

In this study an averaging time of 18.75 s has been used (this is the *Phast* recommended value for flammable gases).

The concentrations of interest for gas dispersion outputs are 5% v/v and 2.5% v/v methane in air; corresponding to the lower flammable limit (LFL) and ½LFL respectively.

*Meteorological conditions*

Within a risk assessment, weather conditions are usually described as a combination of a letter with a number, such as 'F2'. The letter denotes the Pasquill stability class and the number gives the wind speed in metres per second.

The Pasquill stability classes describe the amount of turbulence present in the atmosphere and range from A to F. Stability class A corresponds to 'unstable' weather, with a high degree of atmospheric turbulence, as would be found on a bright sunny day. Stability class D describes 'neutral' conditions, corresponding to an overcast sky with moderate wind. A clear night with little wind would be considered to represent 'stable' conditions, denoted by stability class F.

Wind speeds range from light (1-2 m/s) through moderate (around 5 m/s) to strong (10 m/s or more). The probability of the wind blowing from a particular direction is commonly displayed graphically as a 'wind rose'.

Event consequences have been modelled in 2m/s and 5m/s wind speeds with the largest being applied in the risk model.

## 4.4 HUMAN IMPACT CRITERIA

The impact criteria for thermal radiation from fires were discussed in *Section 3.3*.

## 4.5 BUND OVERTOPPING

Tanks used for bulk storage of hazardous liquids are often completely surrounded by a wall or earth embankment with the aim of providing secondary containment for any spillage from the tank. If the walls of the bunded area have been designed, built and maintained in line with current standards then they will provide full containment of the more likely spills, but they will not contain the surge of liquid that would follow a catastrophic failure of the tank; even if the surge does not destroy the bund wall, the flood wave is likely to overtop it.

The bunds or earth banks that commonly surround tanks used for storing hazardous liquids are often designed with a capacity equal to 110% of the capacity of the largest storage tank within the bund, the excess height being claimed in part to prevent liquid surging over the top of the bund following sudden failure of a tank. In reality, whilst a 110% capacity bund will contain the release for less extreme modes of failure, it is unlikely to do so for more extreme modes. A series of experiments reported in HSE Contract Research Report 405/2002, in which the contents of a model storage tank were released gently into a 110% bund over a period of 30 seconds, showed that the bund was overtopped in almost every case. More severe modes of release would clearly give more overtopping.

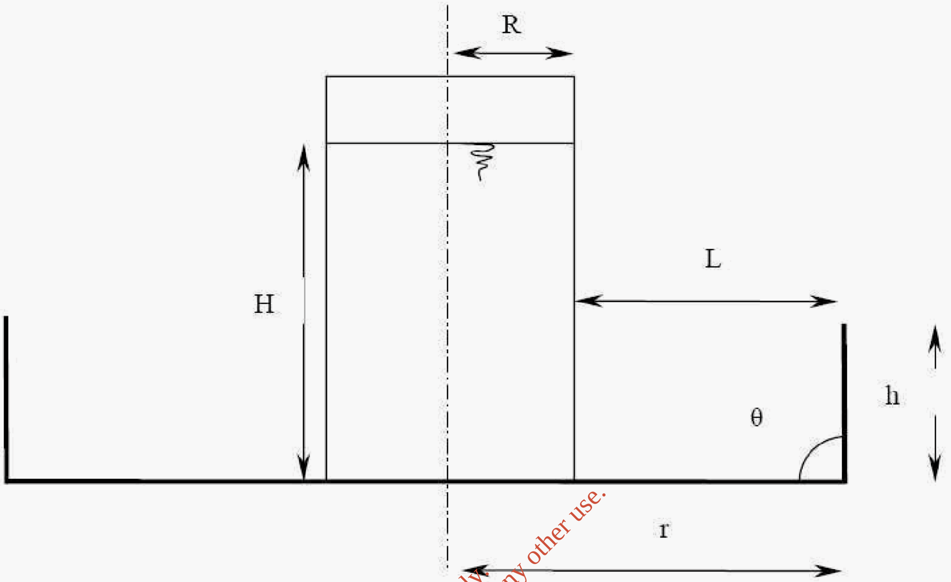
Whilst catastrophic failure of bulk storage tanks is rare, the consequences for site personnel, any local community and the environment can be severe. Such failures have occurred in the USA, in Greece and in Lithuania, for example. Specific examples include the following:

- Floreffe, January 1988 – failure of a 4 million gallon tank of fuel oil at Ashland Oil released a wave of oil that surged through the bunded area damaging another tank and overtopping the bund.
- Iowa, March 1997 – failure of a 1 million gallon tank of ammonium phosphate.
- Michigan, July 1999 – a 1 million gallon tank of ammonium polyphosphate ruptured and damaged three other tanks.
- Ohio, August 2000 – a 1 million gallon tank of liquid fertilizer ruptured and damaged nearby tanks. The resulting wave of liquid broke through a concrete bund and hit five tractor-trailer rigs, pushing them into the Ohio River.
- Ohio, August 2000 – later that month a 1.5 million gallon tank of ammonium phosphate ruptured at the same storage facility. It damaged three other tanks causing them to leak, with liquid overflowing the bund. A total of 450,000 gallons of contaminated water was reclaimed from the sewers and the public drinking water system was feared contaminated, resulting in the widespread use of bottled water as reported by the United States Environmental Protection Agency (2001).

There have been a number of research projects investigating bund overtopping; Greenspan and Johansson carried out experiments and published papers in the early 1980s and Liverpool John Moores University completed a Research Report for the UK Health and Safety Executive in 2005.

All of the experimental projects applied the nomenclature shown in *Figure 4.1*.

***Figure 4.1*** ***Tank and Bund Nomenclature for Circular Geometry***



### 4.5.1 *Greenspan and Johansson*

The major finding from Greenspan and Johansson indicated that the overtopping was dependant mainly on h/H, the ratio of the height of the barrier to the height of the fluid released from the tank with little dependence on L/R, the ratio of tank wall/barrier separation and the distance from the back of the tank to the sliding wall. This was found to be true for all combinations of barrier and tank heights in the range $0.33 \leq L/R \leq 4$. It was also determined that the height of the fluid plume exceeded the initial height of fluid in the tank with the flight of particles from the leading edge of the surge reaching three times the height of the tank fill level.

Greenspan and Johansson (1981) (14) stated that the manner in which the wave overtops the barrier depends upon the shape of the dyke or bund. The fluid may vault an inclined embankment or accumulate rapidly behind a vertical bund and then overtop.

The tests were axisymmetric in nature with an instantaneous release of fluid from the storage tank, whereby a stationary column of fluid was allowed to fall and spread under the action of gravity. The Greenspan and Johansson experiments, led to a conclusion that simple formulae to estimate the overtopping fraction could probably be based on dimensionless combinations of parameters:

$$Q = Q(h/H, r/H, R/H, \theta)$$

Two sets of researchers have proposed functions based on the small-scale test data of Greenspan and Johansson. Clark put forward the following relationship to predict the overtopping fraction, $Q_C$:

$$Q_c = e^{[-p.(h/H)]}$$

Where, p = 3.89, 2.43 or 2.28 when $\theta = 90^\circ, 60^\circ$ or $30^\circ$.

Generally, it was found that the overtopping fraction $Q_C$ and the relationship with h/H held true over the range $0.33 \leq (r - R) / R \leq 4$.

Independently, Hirst derived formulae fitted to the same test data to predict the overtopping fraction, $Q_H$

$$Q_H = A + [B.\ln(h/H)] + [C.\ln(r/H)]$$

Where $A = 0.044, B = -0.264 \;\&\; C = -0.116$ for $\theta = 90^\circ$
$A = 0.287, B = -0.229 \;\&\; C = -0.191$ for $\theta = 60^\circ$
$A = 0.155, B = -0.360 \;\&\; C = -0.069$ for $\theta = 30^\circ$

Both Clark's and Hirst's correlations gave good fits to the data of Greenspan and Johansson on which they were based.

### 4.5.2 *Liverpool John Moores' Correlation*

The Methodology and Standards Development Unit of the United Kingdom Health and Safety Executive (HSE) contracted Liverpool John Moores University (LJMU) to construct a laboratory facility and to conduct a series of tests simulating the sudden failure of a tank such as is used industrially for the storage of hazardous liquids. Such failures are rare. However, history has shown that when they occur a large proportion of the liquid is likely to escape over the surrounding bund wall or embankment, even if the force of the wave impact does not damage the retaining structures.

This research was entitled "an experimental investigation of bund wall overtopping and dynamic pressures on the bund wall following catastrophic failure of a storage vessel".

The LJMU results are separated into three groups corresponding to different levels of tank fill called "squat", "medium" and "tall". The researchers found that the Clark correlation seems to be in keeping with most of the LJMU test results when the plot of overtopping fraction against h/H is considered for squat tanks. However, at lower ratios of h/H and higher bund containment ratios, the Hirst correlation gives better agreement.

For medium tanks, both correlations show general agreement with the test results.

For tall tanks, the Clark correlation most closely fits the test results, with both Clark and Hirst correlations approaching the test results at smaller values of h/H.

New correlations were derived by LJMU to fit the LJMU test results. The following base function was derived:

$$Q = A \times \exp\left[-B \times (h / H)\right]$$

This is of the same form as the Clark correlation. The range of validity is $0.66 \le (r - R) / R \le 5.32$. It should be noted that high-collar bunds are excluded from the range of validity, as the overtopping fraction is negligible, usually less than 5%. Omitting the high-collar bunds improves the quality of fit for the smaller bunds at greater radii, where frictional forces start to affect the result.

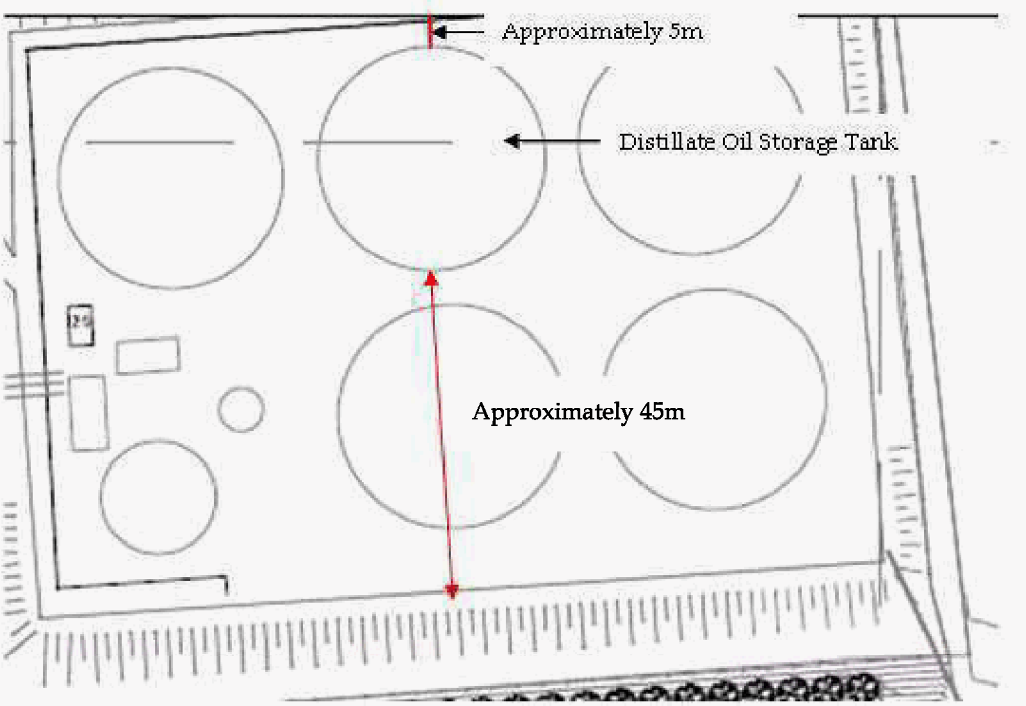
The refurbished tank at Great Island would be classed as 'squat' because of the ratio of liquid height to diameter. Values of A and B for squat tanks are shown in *Table 4.1*.

***Table 4.1*** ***LJMU Parameters***

| Tank Type | Bund Capacity (%) | A | B |
|---|---|---|---|
| Squat | 110 | 0.5789 | 2.0818 |
| Squat | 120 | 0.5193 | 1.9671 |
| Squat | 150 | 0.3978 | 2.0051 |
| Squat | 200 | 0.1824 | 0.4972 |

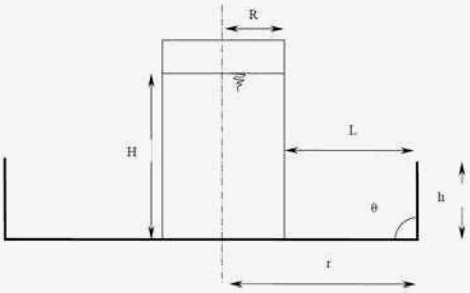
The storage tank area at Great Island is provided with a bund for the purpose of providing secondary containment of any releases that may occur from tanks and process equipment. The bund has the approximate dimensions of 140m x 100 m x 2.5 m deep.

*Figure 4.2* *Layout of Great Island Tank Bunds*



The facility at Great Island will be required to store enough backup fuel to meet at least five days operating capacity, this equates to approximately 10,000 tonnes or 11,000m³. It will be Endesa Ireland's policy to store no more distillate fuel than this legal minimum amount.

Based on a distillate volume of 11,000m³



H = 9.7m
R = 19m
h = 2.5m
$L_{min}$ = 5m
$L_{max}$ = 45m

### 4.5.3 *Codes used by the UK HSE*

The UK HSE has two codes available for estimating the volume of material that may overtop a bund following catastrophic tank failure; OVERTOP and LSMS. Both OVERTOP and LSMS estimate the fraction of the liquid released that overtops a surrounding bund following catastrophic failure of an atmospheric storage vessel which is surrounded by a concentric circular bund.

*OVERTOP*

HSE internal guidance(14) states that "*the results and the graphs* [from Greenspan and Johansson] *must be treated with caution. A major uncertainty is the applicability of the results to full-scale industrial facilities. In addition, the combinations of parameters investigated in the tests were limited, and the form of presentation of the results does not allow easy interpolation between them.*"

To overcome the latter problem the full test results were reconstructed using the graphs and other information, and a fitting algorithm derived and encoded in the OVERTOP computer program. The algorithm developed by HSE is that presented above by Hirst. The HSE goes on to say that the algorithm "*reproduces the test data on which it is based extremely well, and gives plausible results when applied to real storage tanks*".

*LSMS*

LSMS (Liquid Spill Modelling System) is a computer code developed by Cambridge Environmental Research Consultants Ltd to calculate the spreading and vaporisation of a liquid pool, with sponsorship by BG, Gaz de France, the US Gas Research Institute and HSE. It solves the hydrodynamic shallow-layer equations in one (x or r) dimension and includes interaction with a vertical retaining bund wall, including overtopping and further spreading of liquid beyond the bund. It allows a solid, porous or liquid substrate.

All of the methods described above have been used to estimate the volume of material overtopping the bund following catastrophic tank failure. The most appropriate model to represent the Great Island bund case is the Hirst method (implemented by HSE as the OVERTOP model). This is because at lower ratios of h/H and higher bund containment ratios, the Hirst correlation gives better agreement than Clark and it also allows the slope of the bund embankment to be modelled.

### 4.5.4 *Environmental Cost Estimation*

The US Environment Protection Agency (EPA) Basic Oil Spill Cost Estimation Model (BOSCEM) was developed to provide the EPA Oil Program with a methodology for estimating oil spills costs, including response costs and environmental and socioeconomic damages, for actual or hypothetical spills.

EPA BOSCEM was created as a custom modification to the proprietary cost modelling program, EPC BOSCEM, created by extensive analyses of oil spill response, socioeconomic, and environmental damage cost data from historical oil spill case studies and oil spill trajectory and impact analyses(15).

The model requires the specification of oil type and amount and primary response methodology and effectiveness to determine base costs. Cost modifiers based on location medium type, location-specific relative socioeconomic/cultural value category, location-specific freshwater use, location-specific habitat and wildlife sensitivity category are then applied to the base costs.

The following assumptions were made when estimating costs using the EPA BOSCEM.

| | |
|---|---|
| Oil Type: | Light Fuel |
| Response Method: | Mechanical with 90% effectiveness |
| Location Medium Type Category: | Open Water/Shore giving a cost modifier of 1.0 |
| Socioeconomic and cultural value ranking: | Very High (e.g. national park/reserves for ecotourism/nature viewing; historic areas) giving a cost modifier of 1.7 |
| Freshwater vulnerability category: | Wildlife use giving a cost modifier of 1.7 |
| Habitat and wildlife sensitivity category: | River/stream giving a cost modifier of 1.5 |

### 4.6 *RELEASES ON THE JETTY*

The unloading lines run from the jetty head and along the jetty before reaching land. Clearly, in the case of a release from the unloading line on the jetty, there is the potential for at least a proportion of the release to fall on to water.

In the event of a leak, it would be necessary for the escaping liquid to make its way through the hole in pipework and through the surrounding insulation. In this process the release would lose momentum and fall to the surface beneath rather than be projected as a jet. Hence smaller leaks from these pipes have been treated as falling on to the jetty surface (considered to be concrete) rather than on to water.

However, in the event of a large failure or rupture, it is considered that the emerging liquid would retain significant momentum and that at least some of the liquid would spill on to the water.

In view of the above discussions, the following approach has been adopted:

- Smaller leaks have been modelled as falling on to the jetty surface (considered to be concrete); and
- Large leaks and ruptures have been modelled as falling on to water.

The quantity of distillate released into the water arising from jetty failures is estimated from the transfer rate of 7.64m$^3$/min (assuming that 11,000m$^3$ is transferred over a period of 24 hours) and the duration of the release, which is determined from the time taken to identify that there is a release and stop the transfer.

## 4.7 HUMAN CONSEQUENCE RESULTS

The results obtained for the consequence analysis are presented in *Table 4.2*, *Table 4.3*, and *Table 4.4* for pool fires, jet flames and flash fires respectively and in *Table 4.5* for overpressures arising from gas explosions within the compressor enclosure.

### *Table 4.2 Pool Fire Consequence Results*

| **Scenario** | **Distance to Thermal Flux Level (m)** | | | | |
|---|---|---|---|---|---|
| | **25.6 KW $m^{-2}$** | **13.4 KW $m^{-2}$** | **12.7 KW $m^{-2}$** | **9.23 KW $m^{-2}$** | **6.8 KW $m^{-2}$** |
| Bund Fire | Not reached | 47 | 48 | 65 | 89 |
| Overtopped poolfire | Not reached | 51 | 53 | 70 | 96 |

### *Table 4.3 Jet Fire Consequence Results*

| **Release** | **Distance to Fatality Probability (m)** | | | |
|---|---|---|---|---|
| **Scenario** | **0.99** | **0.50** | **0.10** | **0.01** |
| **AGI and gas line from AGI to gas compressor (40 barg, but assumed to be 50 barg for analysis)** | | | | |
| 4mm hole | 1 | 2 | 2 | 2 |
| 25mm hole | 9 | 12 | 14 | 17 |
| 1/3 diameter | 29 | 45 | 52 | 60 |
| Rupture | 85 | 122 | 148 | 172 |
| **Gas line from gas compressor to gas turbine (50 barg)** | | | | |
| 4mm hole | 1 | 2 | 2 | 2 |
| 25mm hole | 9 | 12 | 14 | 17 |
| 1/3 diameter | 29 | 45 | 52 | 60 |
| Rupture | 85 | 122 | 148 | 172 |

### *Table 4.4 Flash Fire Results*

| **Release Scenario** | **Hazard Distances (m)** | | | |
|---|---|---|---|---|
| | **LFL** | | **0.50LFL** | |
| | **Downwind** | **Crosswind** | **Downwind** | **Crosswind** |
| **AGI and gas line from AGI to gas compressor (40 barg, but assumed to be 50 barg for analysis)** | | | | |
| 4mm hole | Not reached | Not reached | Not reached | Not reached |
| 25mm hole | Not reached | Not reached | 36 | 1 |
| 1/3 diameter | 77 | 2 | 158 | 6 |
| Rupture | 235 | 10 | 346 | 16 |
| **Gas line from gas compressor to gas turbine (50 barg)** | | | | |
| 4mm hole | Not reached | Not reached | Not reached | Not reached |
| 25mm hole | Not reached | Not reached | 36 | 1 |
| 1/3 diameter | 97 | 4 | 185 | 7 |
| Rupture | 270 | 12 | 386 | 19 |

Although the downwind distances to the LFL and 0.5LFL could reach up to 270 and 385m respectively, the flammable clouds would only be 'thin' in that the corresponding crosswind distances would only be 12 and 19m.

*Table 4.5* *Overpressure Consequence Results*

| | **Distance to Fatality Probability (m)** | | | | | |
|---|---|---|---|---|---|---|
| | **1.0** | **0.70** | **0.50** | **0.10** | **0.05** | **0.01** |
| Outdoors | Not reached | - | Not reached | 15 | - | 32 |
| Indoors | Not reached | 3 | 18 | - | 55 | 100 |

Domino effects are the effects arising from an event at one establishment which could initiate a major accident at another establishment in the vicinity. Since the distances to consequence levels quoted in the above tables do not extend to any other establishments in the vicinity, there is no escalation potential.

## 4.8 ENVIRONMENTAL CONSEQUENCE RESULTS

### 4.8.1 *Bund Overtopping*

Overtopping results have been generated using each of the methods described above. The percentage overtopping (of 11,000$m^3$) and corresponding volumes predicted by each method are reported in *Table 4.6* and *Table 4.7* shows the BOSCEM cost liabilities estimated using the parameters described in *Section 4.5.4*. The angle of the bund for the storage tanks at Great Island is $60^0$ and was used to determine the overtopping fraction (except for the LSMS method which only considers vertical bunds).

*Table 4.6* *Base Case Overtopping Volumes*

| **Method** | **Distance to Bund Wall** | **Bund Wall Angle (°)** | **Percentage Overtopping** | **Overtopping volume (m3)** |
|---|---|---|---|---|
| Clark | Not a variable | 60 | 53.5% | 5880 |
| Hirst (OVERTOP) | Long | 60 | 23.7% | 2608 |
| | Short | 60 | 24.4% | 2683 |
| LJMU* | Not a variable | 60 | 23.7% | 2608 |
| LSMS* | Long | 90 | 7.5% | 825 |

* these methods are based on a vertical bund wall only

As shown in *Figure 4.2* the storage tank being considered for storage of distillate is not located in the centre of the bund. Also, the height of the bund wall on the northern side is 5.5m and 2.5m on the southern side of the bund. The 'long' and 'short' distances in *Table 4.6* relate to the nearest and furthest distances between the storage tank and bund wall. The results in *Table 4.6* show that the overtopping fractions determined using the Hirst method are similar on the northern and southern sides of the bund and are also similar to the amount of overtopping calculated using LJMU, which assumes a vertical wall only.

However, the Clark and LJMU methods do not take the distance between the tank and bund wall into account in determining the overtopping fraction and therefore are not considered appropriate in this case, but are presented for comparison.

The LSMS method assumes that the spread of a spill is the same in all directions (i.e. a circle) and originates in the centre of the bund. The storage tank identified for conversion (middle tank on the northern side of the storage area) is not positioned within a circular bund and not located at the centre of the bund. The short separation between the tank and the north bund wall could not be modelled directly because the subsequent circular bund would have a volume less than the volume of the material being released. The furthest distance from the tank to the bund wall was modelled to represent overtopping over the southern side of the bund, using a separation distance which gave a bund volume equal to the actual bund volume. The results obtained using the LSMS method are perceived to be overly optimistic when compared with overtopping volumes calculated using the other methodologies.

*Table 4.7* *Base Case Environmental Cost Liability*

| **Method** | **Spill Response and Cleanup (€)** | **Socioeconomic (€)** | **Environment (€)** | **Total Cost Liability (€)** |
|---|---|---|---|---|
| Clark | €40,388,644 | €237,671,636 | €62,136,375 | €340,196,655 |
| Hirst (OVERTOP) | €43,943,972 | €120,491,537 | €34,021,1407 | €198,456,648 |
| LJMU* | €42,746,653 | €117,208,565 | €33,094,183 | €193,049,401 |
| LSMS* | €13,512,403 | €37,050,137 | €10,461,215 | €61,023,755 |

* these methods are based on a vertical bund wall only, 2.5m high

The Hirst methodology is considered to be the most relevant for Great Island. This is because it accounts for the different separation distances between the storage tank and the bund wall and because the overtopping results are within the highest and lowest estimated volumes using the other methods. Therefore, the results obtained using Hirst were used to assess the benefits of the considered options for reducing the overtopping risks.

### 4.8.2 *Jetty Releases*

The ACDS document states that transfer spill incidents are often quite minor and so it can be interpreted that most of the releases arising from transfer spills would not have a significant environmental impact. ACDS also gives probabilities of different release durations for large and small leaks. *Table 4.8* gives the spill volumes for the durations for the large releases, assumed to be equivalent to full bore.

*Table 4.8 Distillate Spill Sizes (Full bore releases)*

| **Release duration (mins)** | **Spill Volume (m$^3$)** |
|---|---|
| 2 | 15.3 |
| 5 | 38 |
| 10 | 76 |
| 20 | 153 |

The volumes of the distillate spillages at the jetty are considerably less than those obtained for bund overtopping resulting from the catastrophic failure of a distillate storage tank.

# 5 RISK CRITERIA

## 5.1 INDIVIDUAL RISK CRITERIA FOR LUP

The HSA policy in relation to proposals for new major hazard establishments is as follows (1):

- Individual risk of fatality not to exceed 5 x $10^{-6}$ per year for non-residential neighbours;
- Individual risk of fatality not to exceed 1 x $10^{-6}$ per year at nearest residential property.

In addition, the HSA will also consider the existing land use within three concentric zones around the proposed establishment. The zone boundaries are established as follows:

- Innermost Zone (Zone 1): within 1 x $10^{-5}$ per year individual risk of fatality contour;
- Middle Zone (Zone 2): between 1 x $10^{-5}$ and 1 x $10^{-6}$ per year individual risk of fatality contours;
- Outermost Zone (Zone 3): between 1 x $10^{-6}$ and 1 x $10^{-7}$ per year individual risk of fatality contours.

The acceptability of different land uses within these zones is summarised in the HSA advice matrix for different PADHI sensitivity levels shown in *Table* 5.1. Typical developments for each of the PADHI sensitivity levels are set out in *Table 5.2.*

*Table 5.1* *Acceptable Land Uses within Risk Zones*

| Sensitivity | Zone 1 (Inner) | Zone 2 (Middle) | Zone 3 (Outer) |
|---|---|---|---|
| Level 1 | √ | √ | √ |
| Level 2 | X | √ | √ |
| Level 3 | X | X | √ |
| Level 4 | X | X | X |

*Table 5.2* *PADHI Sensitivity Levels*

| Sensitivity level | Development Type | Examples |
|---|---|---|
| 1 | Work places<br>Parking areas | Offices, factories, farm buildings, non-retail markets<br>Car parks, truck parks, lock-up garages |
| 2 | Housing<br>Hotels/ holiday accommodation | Houses, flats, residential caravans<br>Hotels, motels, youth hostels, halls of residences, holiday caravan and camping sites. |

| Sensitivity level | Development Type | Examples |
|---|---|---|
| | Transport links | Motorway, dual carriageways |
| | Indoor use by public | Restaurants, cafes, shops, libraries, colleges of further education, bus and train stations, leisure centres, conference centres |
| | Public outdoor use | Picnic areas, markets, theme parks, playing fields |
| 3 | Institutional accommodation and education | Nursing and old people's homes (with warden on site or on call), schools for children up to school leaving age |
| | Prisons | Prison, remand centres |
| 4 | Institutional accommodation | Large hospitals, convalescent homes, nursing homes |
| | Very large outdoor use by public | Large sports stadia, pop festivals, open air markets |

## 5.2 *SOCIETAL RISK OF FATALITY*

Societal risk can be defined as the relationship between the frequency and the number of people exposed to a specified level of harm, such as thermal radiation from fires, explosion overpressures, and doses of toxic gas in a given population.

The risk integral (RI) concept can be used when assessing major hazard installations and is able to provide an indication of the level of societal risk without the need for detailed analysis. It is defined as:

$$RI = \sum_{N=1}^{Nmax} f(N).N^{a}$$

Where, f(N) is the frequency in chances per million (cpm) of events leading to N fatalities and 'a' is a constant, which is usually set at 1.4. RI values of 2000 are judged to be broadly acceptable and are interpreted as being significant if the value is 500,000 or greater.

One estimation of the level of societal risk, which is best used as an initial screening tool, is to calculate the Societal Risk Index (SRI);

SRI = (P x R x T)/A
Where,

P = population factor, defined as $(n + n^2)/2$
n = number of people at the development
R = average level of individual risk (cpm)
T = proportion of time that the development is occupied by n persons
A = area of the development in hectares

A more detailed analysis for calculating societal risk is by determining the number of fatalities by each accident event and summing all the frequencies that give a specified number, or more of fatalities. The results are presented in graphical form by plotting cumulative frequencies (F) of giving N or more fatalities against N and is often referred to as the F/N curve.

With regard to societal risk, the HSE document(16) states that:

*"…the risk of an accident causing the death of 50 people or more in a single event should be regarded as intolerable if the frequency is estimated to be more than one in five thousand per annum."*

This gives a criterion 'point' from which intolerable, tolerable and broadly acceptable regions can be extrapolated when considered in conjunction with individual risk criteria. It should be noted that:

- taken in context, the criterion refers to fatalities among members of the public from accidents at a 'single major industrial activity'; and

- the criterion appears to be referring to a cumulative frequency (since it refers to '50 people or more') rather than the single value associated with a single release outcome.

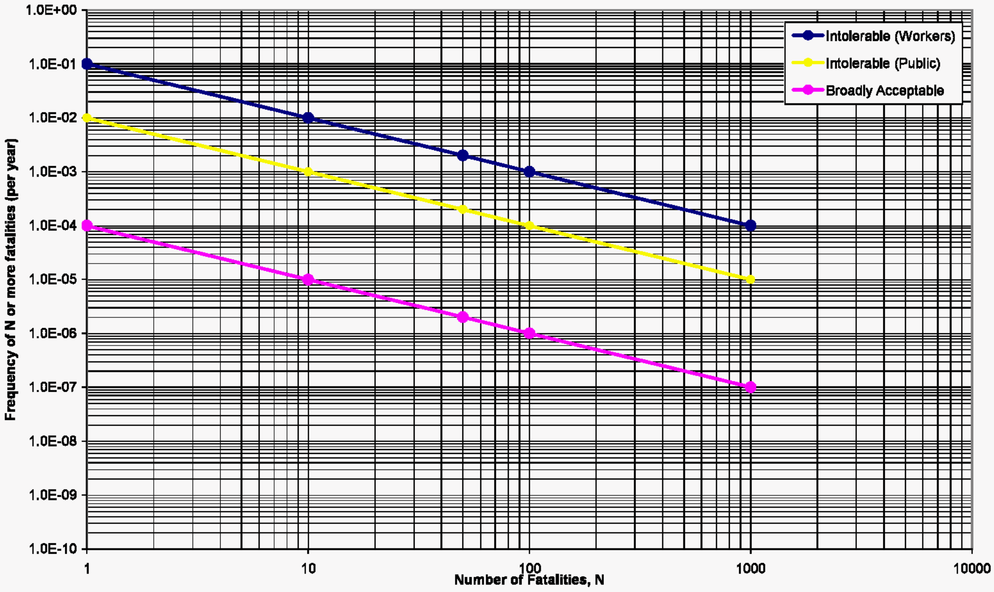
With this in mind, the following extrapolations have been performed:

- the criterion for workers at the site is taken to be ten times higher than that for members of the public, i.e. – the risk of an accident causing the death of 50 workers or more should be regarded as intolerable if the frequency is greater than one in five hundred per annum;

- the broadly acceptable region is taken to be two orders of magnitude lower than the criterion point for members of the public, i.e. - risk of an accident causing the death of 50 people or more is taken to be broadly acceptable if the estimated frequency is less than one in 500,000 per annum; and

- each individual point is plotted on a graph and criterion lines extrapolated through them, to give the Cumulative Frequency (F) – Number of Fatality (N) criteria lines shown in *Figure 5.1*.

*Figure 5.1* *Cumulative F-N Criteria Lines*



## 5.3 ENVIRONMENT IMPACT CRITERIA

The HSA Policy and approach for COMAH risk-based LUP makes reference to EPA's 'Guidance Note on the Storage and Transfer of Scheduled Activities' (available from EPA website http://www.epa.ie/) that provides a detailed approach for conducting an environmental risk assessment.

The major concern at Great Island generally relates to whether a distillate spill (or contaminated firewater) could escape and pollute the surrounding land and the damage the marine environment.

The assessment criteria are based on using water hazard classes (WHCs), which are:

- Non hazardous;
- WHC 1 – low hazard;
- WHC 2 – hazardous; and
- WHC 3 – severe hazard

The risk category table presented as *Table 5.3* is based on four levels of risk classification. Generally, category A equates to low risk, B to medium risk, while categories C and D equate to higher risk. It should be noted that the nature of dangerous substances and their associated volumes stored at petroleum bulk stores is likely to classify such sites as category C or D inasmuch that there is a high potential for pollution in the event of a major release.

*Table 5.3 Risk Category Matrix*

| Vol. (m3) or mass (tonnes) | Risk Category | | |
|---|---|---|---|
| | **WHC 1** | **WHC 2** | **WHC 3** |
| <0.10 | A | A | A |
| 0.10 – 1.0 | A | A | B |
| 1.0 -10 | A | B | C |
| 10 - 100 | A | C | D |
| 100 – 1000 | B | D | D |
| >1000 | C | D | D |

Based on the quantity of distillate that would be present at the Great Island combined cycle power plant, and assuming WHC 1 it would be classified a category C site as a minimum.

# 6 RISK CALCULATION

Individual and societal risk calculations have been performed using ERM's *ViewRisk* software, combining the frequency and consequence information. The development of *ViewRisk* was funded under contract to the UK Health and Safety Executive (HSE) and is regularly used for calculating risks from major accident hazard installations.

## 6.1 RISK TO HYPOTHETICAL HOUSE RESIDENTS

Since, in the event of a major accident, the likelihood of harm to a person indoors differs from that for a person outdoors (see *Section 3.3*) it is necessary to consider the proportion of time individuals may spend indoors and outdoors. To account for time spent indoors and outdoors, the HSA employs the concept of a 'hypothetical house resident'. The hypothetical house resident is present all of the time at their dwelling, spending 90% of their time indoors. The calculation of individual risk has therefore used these 'hypothetical house resident' assumptions.

## 6.2 POPULATION DATA

For the purposes of calculating societal risk, it is necessary to define the population distribution around the proposed facility. However, since the hazard distances predicted for potential major accidents at the Great Island site do not extend to areas where people would normally be present, it has therefore not been necessary to include the population data in the analysis.

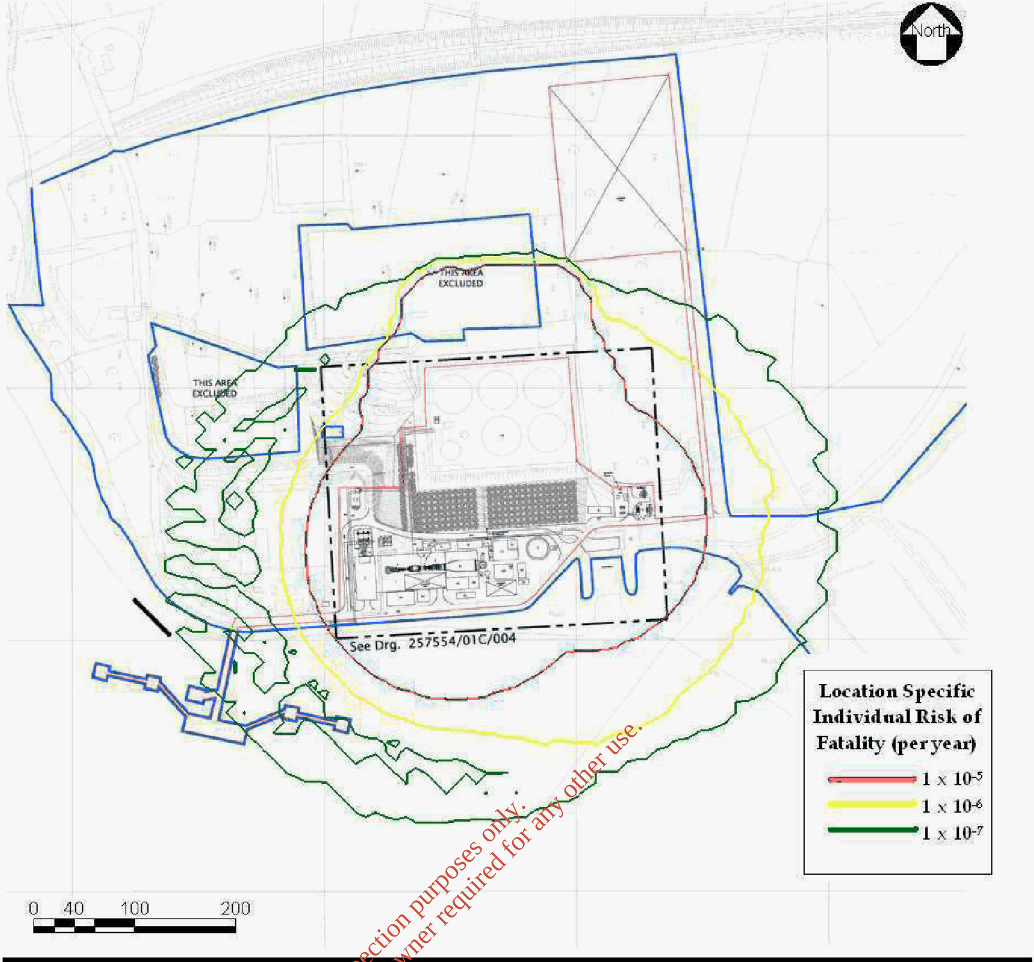
## 6.3 INDIVIDUAL RISK RESULTS

The individual risk of fatality contours displayed in *Figure 6.1* are based on an individual being present outdoors for 10% of the time and indoors for 90% of the time.

The inner zone (1 x $10^{-5}$ /yr risk contour) covers virtually all of the Great Island power plant facilities and extends beyond the site boundary over the coastal area to the south.

Whilst each of the zones extends outside the site boundary, with the outer zone (1 x $10^{-7}$ /yr risk contour) extending to the eastern unloading berths at the jetty area, they only cover a small area beyond the coastline, where no people would be present. The middle and outer zones also cover a small offsite area of vegetation to the east, but do not encompass any developments where people would normally be present.

*Figure 6.1 Individual Risk of Fatality Contours for People Outdoors*



## 6.4 SOCIETAL RISK RESULTS

Only the 1 x $10^{-7}$ /yr risk contour extends to locations offsite where people could be present, which would be at the eastern berths at the jetty. However, the societal risk can be deemed to be negligible if the probability of people being present at this location is taken into account. No member of the general public would normally be encompassed by any of the zones. The jetty is used for unloading oil, and although there is no scheduled use of the jetty for passengers, it is sometimes used by cruise liners as a contingency arrangement and occurs with a frequency of less than once per year since the early 1990's.

On site, the distribution of personnel is assumed to be similar to that presented in the assessment of major accident hazards for the Toomes Power Station(17) and summarised in *Table 6.1*.

### *Table 6.1 Occupancy Levels*

| Building | Normal | |
|---|---|---|
| | Day | Night |
| Turbine Hall | 1 | 1 |
| Canteen | 3 | 1 |
| Admin building | 8 | 0 |
| Gatehouse | 1 | 1 |
| Central Control Room | 3 | 3 |

The F-N data obtained for personnel on site is summarised in *Table 6.2* and so the societal risks are interpreted as being in the broadly acceptable region (see *Figure 5.1*).

### *Table 6.2 F-N Data*

| **N** | **F** |
|---|---|
| 1 | $6.38 \times 10^{-5}$ |
| 2 | $6.34 \times 10^{-5}$ |
| 4 | $4.29 \times 10^{-5}$ |

# 7 *RISK OF MAJOR ACCIDENTS TO THE ENVIRONMENT*

## 7.1 *BUND OVERTOPPING*

### 7.1.1 *Methods for reducing overtopping risks*

Methods for reducing the volume of material overtopping the bund and entering the environment following catastrophic tank failure considered for the Great Island establishment are listed below.

1. Construction of a double-walled tank;
2. Maintaining the height of the bunding, but increasing the angle of the embankment to $90^0$;
3. Maintaining the slope of the embankment, but increasing the height of wall by 2m;
4. Installation of tertiary containment and drainage system outside the bund;
5. Increasing the height of the existing bund wall to ensure complete containment;
6. Construction of a baffle wall within the existing bunded area at the toe of the dyke; and
7. Construction of a 2.5m baffle wall within the existing bunded area at the base of the dyke, increase height of bund by 2m, same slope.

The overtopping risks have considered for one tank only. The distillate will be stored in the tank located in the middle of the three tanks to the north. This tank will have its own dedicated filling pipe from the jetty and no piping will be installed that would make it possible for distillate to be transferred to any of the other tanks.

The fraction of liquid overtopping the bunded area following catastrophic failure of the distillate tank will depend on the direction in which the liquid is released, which in turn will be governed by the section of the tank which fails.

The land rises steeply by about 5.5m from the floor of the bund to the level of the surrounding ground at the northern side of the Great Island storage tank bund. For the purpose of estimating the overtopping fraction at the northern boundary, the bund is considered to be a 5.5m embankment at an angle of $60^0$. The amount of distillate overtopping the bund was calculated to be $2683m^3$, which corresponds to 24.4% of the tank inventory. However, there would be some ground contamination beyond the 2.5m concrete section of bunding.

If the release were directed to the south, the overtopping volume over the southern embankment is estimated to be $2608m^3$ (23.7%), which is similar to the fraction that would overtop the bund on the northern side. Any impact from the presence of the tanks on the south side of the storage area have not been taken into account in the analysis.

Therefore, various bund containment options need to be considered around the entire perimeter of the tank storage area.

### 7.1.2 *Analysis of Measures*

The effectiveness of the proposed measures in terms of the volume and fraction of distillate that would overtop the bund on the north and south side of the storage is given in *Table 7.1.*

***Table 7.1 Effectiveness of Measures to Control Bund Overtopping – Catastrophic Tank Failures***

| **Measure** | **Potential Overtopping** | | | |
|---|---|---|---|---|
| | **North side of Bund** | | **South side of Bund** | |
| | **%** | **Volume (m3)** | **%** | **Volume (m3)** |
| 1. Double walled tank | 24.4 | 2683 | 23.7 | 2608 |
| 2. Increased embankment angle to $90^0$ but maintain bund wall height | 8.9 | 976 | 18.3 | 2014 |
| 3. Maintaining the slope of the embankment, but increasing the height of wall by 2m | 17.3 | 1902 | 10.2 | 1128 |
| 4. Tertiary containment (beyond existing bunded area) | 0 | 0 | 0 | 0 |
| 5. Increase embankment angle to $90^0$ and increase bund wall height to 7.7m (north) and 5m (south), which ensures containment | 0 | 0 | 0 | 0 |
| 6. Construction of a 1.5m baffle wall within the existing bunded area at the base of the dyke, maintain height of bund | 22.3 | 2495 | 26.2 | 2879 |
| 7. Construction of a 2.5m baffle wall within the existing bunded area at the base of the dyke, increase height of bund by 2m, same slope. | 6 | 673 | 7.6 | 837 |

The figures in *Table 7.1* show that there are clear differences in the effectiveness of the measures considered for reducing the risk of bund overtopping from a catastrophic failure of a distillate storage tank. Furthermore, there are differences in the effectiveness of the measures on the north and south sides of the bunded storage area. Therefore, it may be appropriate to incorporate different measures on different sides of the bund.

One approach to assess the reasonableness of these proposed measures is to compare the cost of implementing the measure with the reduction in environmental spill liability across the lifetime of the plant, referred to as the threshold cost.

The threshold cost is calculated by:

Total liability cost x spill frequency (per year) x 30 years x disproportionate factor (5).

The threshold costs for a single tank containing 11,000$m^3$ distillate are reported in *Table 7.2*.

***Table 7.2 Cost Benefit Threshold Costs – Catastrophic Tank Failures***

| **Measure** | **North side** | | **South Side** | |
|---|---|---|---|---|
| | **Potential Residual Cost Liability (€)** | **Threshold Cost (€)** | **Potential Residual Cost Liability (€)** | **Threshold Cost (€)** |
| 1. Double walled tank | €198,456,648 | €267,916 | €192,909,034 | €260,427 |
| 2. Increased embankment angle to $90^0$ but maintain bund wall height | €72,192,951 | €189,396 | €148,971,931 | €74,227 |
| 3. Maintaining the slope of the embankment, but increasing the height of wall by 2m | €140,687,494 | €86,654 | €83,436,116 | €172,531 |
| 4. Tertiary containment (beyond existing bunded area) | 0 | €297,685 | 0 | €297,685 |
| 5. Increase embankment angle to $90^0$ and increase bund wall height to 7.7m (north) and 5m (south), which ensures containment | 0 | €297,685 | 0 | €297,685 |
| 6. Construction of a 1.5m baffle wall within the existing bunded area at the base of the dyke, maintain height of bund | €184,550,629 | €20,8549 | €212,954,413 | -€20,8549 |
| 7. Construction of a 2.5m baffle wall within the existing bunded area at the base of the dyke, increase height of bund by 2m, same slope. | €49,1780,591 | €223,014 | €61,911,373 | €204,818 |

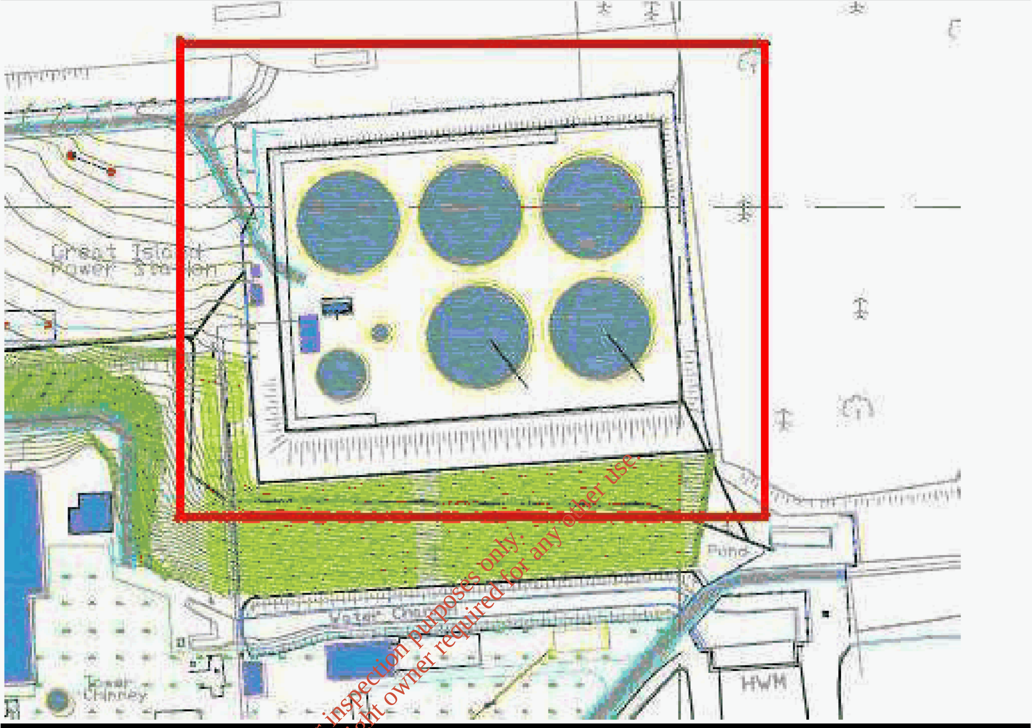
The threshold costs are based on a catastrophic tank failure of 1 x $10^{-5}$ per year. However, if the probability of the tank failing in a particular direction were taken into account, then the threshold costs would be lower. For instance if it were assumed that failure of the tank on the north and south sides were equally likely then the above threshold costs could be halved.

It can be deduced from a straightforward examination that some of the considered measures can be discounted from the cost benefit analysis.

The construction of a double walled tank (No. 1) would not reduce the overtopping fraction if it were to fail, but the likelihood of its failure would be reduced. Since the estimated cost for a double-walled tank would be in the region of €3.34 million, it is more than an order of magnitude higher than the threshold cost. Therefore, this measure is deemed not to be economically viable and was therefore dismissed as an option.

An indication of the extent of tertiary containment beyond the existing bunded storage area (No. 4), which would be designed to prevent any of the liquid released from reaching the marine environment is shown in *Figure 7.1*, However, this is perceived to be an impractical option and very costly incorporating measures to seal the area encompassed by the tertiary containment to prevent ground contamination.

***Figure 7.1*** ***Tertiary Containment***



In order to contain all 11,000$m^3$ of liquid released from a catastrophic tank failure, the bunding would need to comprise a 7.7m vertical wall along the northern boundary and a 5m vertical wall on the south side of the bund (No. 5). This is not considered to be a practical option and so was not examined further.

Increasing the embankment angle to $90^0$ but maintain bund wall height (No. 2) would reduce the overtopping fraction on the north side from 24.4% to 8.9%., but would be less effective on the south side when the overtopping fraction would be reduced to 18.3%.

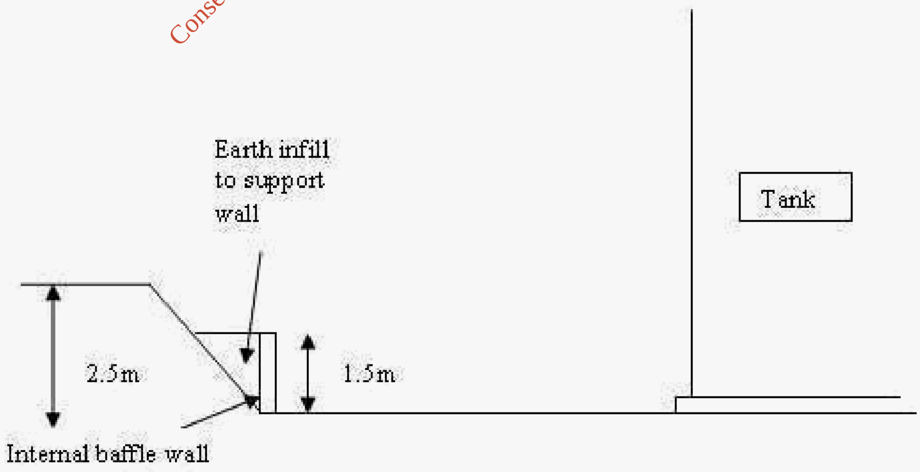
Installing a 1.5m vertical baffle wall at the base of the dyke, such as shown in *Figure 7.2* (No. 6) would not be effective. The construction of a 2.5m baffle wall within the existing bunded area at the base of the dyke and increasing the height of bund by 2m and maintaining the $60^0$ slope (No. 7) would reduce the overtopping fraction to 6% and 7.6% on the north and south sides respectively.

A less expensive, but less effective option would be to increase the height of bund by 2m and maintaining the $60^0$ slope (No. 3), which would decrease the overtopping fraction by 7.1% to 17.3% on the north side and by 13.5 % on the south side. The cost to implement this measure on the east west and south sides has been estimated to be €740,000, but is still considerable higher than the threshold costs. Furthermore, whilst credit has been taken for a 5.5m sloping bund on the northern side, only 2.5m has been concreted and so there would be a need to seal the bund to the full height, otherwise there would be ground contamination form the distillate.

In all the cases considered the expected cost of implementing the mitigation measures exceeds the calculated threshold cost.

The most cost effective way of controlling overtopping of the bund is to consider different measures on different sides of the bund. On the basis that the middle tank on the north side will be used to store the distillate, it is proposed that that the height of the dyke on the south, east and west sides is increased by 2m, maintaining the slope at 60°. On the north side, increasing the embankment angle to 90° but maintain bund wall height at 5.5m would be effective in reducing the overtopping fraction to 8.9%, but would be very costly to implement. It is expected that some of the overtopping on the northern side would flow back into the bund. As stated, if the frequency of the tank failing catastrophically on a particular side were taken into account, then the threshold figures would be lower than those presented in *Table 7.2* and it can be argued that the cost to implement measures on the northern side of the bunded area would be grossly disproportionate to the benefit gained.

***Figure 7.2*** ***Proposed Baffle Wall Arrangement***



## 7.2 JETTY RELEASES

The ACDS, Major Hazard Aspects of the Transport of Dangerous Substances(8) quotes an accident frequency figure of 1.8 x $10^{-4}$ per cargo transferred for low flash and high flash products, and so was considered appropriate for distillate. There will be a requirement to use the distillate for start up, but the quantities involved would only be low. Replenishment of the distillate used during start-up could therefore be supplied from road tanker deliveries. Large volumes of distillate would only be used in the event of the gas supply not being available and is assumed that such occurrences would arise once in 10 years. Therefore there would only be a requirement to transfer distillate from the jetty once every 10 years and the frequency of a release is therefore estimated to be 1.8 x $10^{-5}$ per year.

The spill sizes were calculated for release durations of 2, 5, 10 and 20 min and the probability and frequencies of the various spill volumes for full bore releases are set out in *Table 7.3* together with the potential cost liabilities and threshold costs. The total potential liability and threshold costs were estimated to be €40,615,193 and €2,287 respectively.

***Table 7.3*** ***Cost Benefit Threshold Costs - Jetty Releases (Full Bore)***

| **Release duration (mins)** | **Spill Volume (m3)** | **Probability** | **Frequency (/yr)** | **Potential Cost Liability (€)** | **Threshold Cost (€)** |
|---|---|---|---|---|---|
| 2 | 15.3 | 0.101 | 1.82 x $10^{-6}$ | €4,219,674 | €1,152 |
| 5 | 38 | 0.037 | 6.66 x $10^{-7}$ | €5,179,887 | €518 |
| 10 | 76 | 0.012 | 2.16 x $10^{-7}$ | €10,359,773 | €3,578 |
| 20 | 153 | 0.005 | 9.00 x $10^{-8}$ | €20,855,859 | €282 |
| **Total** | | | | **€40,615,193** | **€2,287** |

# 8 CONCLUSIONS AND RECOMMENDATIONS

A quantitative risk assessment (QRA) and environmental assessment of the proposed facilities at the Combined Cycle Gas Turbine (CCGT) power plant establishment at Great Island has been conducted. For the purposes of the QRA, the facilities were considered to be:

- the AGI;
- gas line between the AGI and the gas compressor;
- gas compression;
- gas line between the gas compressor and gas turbine;
- the jetty unloading arms; and
- distillate storage tank.

The jetty unloading lines (from jetty head to distillate storage); and transformer fires and explosions were also considered, but were not included in the quantified analysis as the associated risk levels were not deemed to be significant.

## 8.1 FATALITY RISKS

The inner, middle and outer zones, corresponding to individual risk levels of $1x10^{-5}$, $1 \times 10^{-6}$ and $1 \times 10^{-7}$ respectively were computed. None of these contours extended to areas offsite where members of the general public would normally be present. The inner zone covered most of the plant facilities and whilst the zones extended outside the site boundary, they only covered a small area beyond the coastline to the south and an area of vegetation to the east where members of the general public would not be expected to be present. The hazards distances do not extend other offsite buildings that could result in escalation. Although the flammability envelope and the effects from jet flames could extend to the jetty area, the risk of escalation to any ships refuelling would be negligible on the basis of the low risk of occurrence and the probability of a ship being present.

The HSA guidance document for COMAH based land use planning states that with respect to new establishments the individual risk of fatality should not be greater than $5 \times 10^{-6}$ (per year) to their current non-residential type neighbours or a risk of fatality greater than $1 \times 10^{-6}$ ( per year) to the nearest residential type property. Since the individual risk of fatality contours do not encompass any offsite developments, it can be demonstrated that the risks are acceptable.

No societal risks were calculated for offsite personnel because none of the risk zones encompassed areas where people would normally be present. The societal risks therefore only related to members of the workforce and these were determined to be broadly acceptable.

## 8.2 *Environmental Risk*

The environmental risks were considered to arise from spills of distillate being released into the marine environment from failures during unloading and catastrophic failure of a storage tank.

A number of proposed measures were assessed for reducing the environmental risks through containing and preventing distillate from reaching the marine environment following catastrophic failure of a storage tank. For a single distillate tank, the calculated threshold costs ranged from €74,227 for increasing the embankment angle (on the south side) so that it is vertical to €297,685 for tertiary containment or increasing the embankment angle to $90^0$ and increasing the bund wall height so that all the distillate released would be contained.

There was a considerable variation in the estimated costs for implementing the measures, which ranged from €300,000 for constructing a 1.5m baffle wall within the existing bunded area at the base of the dyke to around €3.34 million for the installation of a single doubled-walled tank. In all cases the estimated costs exceed the calculated threshold cost. The recommended measure for implementation is to increase the height of the bund wall by 2m, but maintain the slope of the embankment at 60 degrees, on the south, east and west sides of the storage area. This is estimated to cost €740,000.

Bearing in mind that some of the liquid overtopping the bund on the northern side is likely to flow back into the bund and that the cost to implement measures on the northern side would be significantly greater than the threshold cost, it can be argued that there is no need to implement measures in terms of increasing the bund angle or height on the northern side. The upper 3m of the dyke should be sealed to prevent any ground contamination in the event of a spillage. This is estimated to cost €45,000.

# 9 *REFERENCES*

1. Policy and Approach of the Health and Safety Authority to COMAH Risk-based Land Use Planning, HSA (2009)
2. HSE (2000). Risk Assessment Methodology for Storage of Refrigerate Flammable Liquids. Planning Case Assessment Guide Chapter 6K.
3. Council Directive, 96/82/EC on the control of major accident hazards involving dangerous substances.
4. G. Weiss, Hazardous Chemicals Data Book, Second Edition (1986).
5. National Authority for Occupational Safety and Health (2002). Code of Practice for the Safety, Health and Welfare at Work (Chemical Agents) Regulations (2001).
6. NTIS Publication No. PB-94-195047: Documentation for Immediately Dangerous to Life or Health Concentrations (IDLH): NIOSH Chemical Listing and Documentation of Revised IDLH Values
7. The Buncefield Incident 11 December 2005: The Final Report of the Major Incident Investigation Board (2008). Available at: http://www.buncefieldinvestigation.gov.uk/reports/volume1.pdf [Accessed 27 August 2009]
8. ACDS, Major Hazard Aspects of the Transport of Dangerous Substances, (1991).
9. The Oil Industry International Exploration and Production (E&P) Forum, 1992, Hydrocarbon Leak and Ignition Data Base. Report No. 11.4/180.
10. A W Cox, F P Lees and M L Ang, Classification of Hazardous Locations, IChemE, (1990).
11. Eisenberg, N.A., Lynch, C.J. and Breeding, R.J., 'Vulnerability Model. A Simulation System for Assessing Damage Resulting from Marine Spills', NTIS report AD-A015-245, 1975.
12. Hurst, N.W., Nussey, C. and Pape, R.P., 'Development and Application of a Risk Assessment Tool (RISKAT) in the Health and Safety Executive', Chem. Eng. Res. Des., Vol. 67, (July 1989).
13. Chemical Industries Association, 'Guidance for the Location and Design of Occupied Buildings on Chemical Manufacturing Sites', Second Edition, (2003).
14. UK HSE PCAS Chapter 5A
15. Modelling Oil Spill Response and Damage Costs Dagmar Schmidt Etkin, 2004. Environment Research Consulting Cortlandt Manor, NY, USA
16. HSE (2001). Reducing Risks, Protecting People. HSE Books, C100

17. Mott McDonald, Toomes CCGT Power Station, Major Accident Hazards, February 2008

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