ExxonMobil Canada Properties

Concept Safety Analysis for the Hebron Installation

RMRI Ref. EXM/0256
Report No. 001
Rev: 3

Submitted by

RMRI (Canada) Inc.

36 Quidi Vidi Road
St. John's, Newfoundland
A1A 1C1

March 2011

Report Approval Cover Sheet

Report Title Concept Safety Analysis for the Hebron Installation

RMRI Ref. No. EXM/0256

Report Ref. No. 001

Client ExxonMobil Canada Properties

Approval Record

Rev. No.	Date	Prepared	Reviewed	Approved
Rev. 0	4th December 2009	L. Fairbairn	A. Baxter	A. Pegram
Rev. 1	13th September 2010	A. Baxter	A. Pegram	A. Pegram
Rev. 2	17th September 2010	A. Baxter	A. Pegram	A. Pegram
Rev. 3	23rd March 2011	23rd Mar 2011 A. Baxter	23rd March 2011 A. Pegram	23rd March 2011 A. Pegram

Report Record of Revision

Report Title Concept Safety Analysis for the Hebron Installation

RMRI Ref. No. EXM/0256

Report Ref. No. 001

Client ExxonMobil Canada Properties

Record of Revision

Rev No	Date	Revision
0	4th December 2009	Original, issued for client comment.*
1	13th September 2010	Updated to account for changes to process equipment, module layout, manning distribution etc. and to reflect recently published historical data.
2	17th September 2010	Updated to incorporate client comments.
3	23rd March 2011	Updated to reflect changes to process equipment, module layout, manning distribution etc. and to account for the presence of H_2S in later years.
		* This report updates RMRI Report No. CCR/0161-001, Rev 0, produced for Chevron Canada Resources in February 2006.

Summary

This report identifies and assesses quantitatively the following Major Hazards associated with the proposed development of the Hebron oil field:

- Loss of hydrocarbon containment (resulting in fire, explosion or unignited, potentially toxic, release).
- Blowout (resulting in fire, explosion or unignited, potentially toxic, release).
- Iceberg collision.
- Ship collision.
- Helicopter transportation.
- Seismic activity.

Dropped object events are also considered. The risk arising from such events is, however, not quantified in this Concept Safety Analysis. This is because sufficiently detailed information on lifting activities is not available at this stage and because it is assumed that appropriate procedures will be put in place to reduce this risk where possible. It is recommended that a Dropped Object Study be carried out at detailed design stage, to either confirm the assumptions made or identify dropped object events that should be considered in the design stage QRA.

Occupational accidents are considered in this assessment, but the risk from such accidents is not quantified. Whilst it is clearly necessary to recognize occupational hazards, and to reduce the frequency and mitigate the consequences of such events, it is not, in general, appropriate to assess these hazards using QRA techniques. Fatal Accident Rates for occupational accidents are generally derived from historical accident data. Measures will be put in place for the monitoring, control and mitigation of occupational hazards and accidental events.

For each of the Major Hazards listed above, this report quantifies the following measures of risk:

Theoretical Annual Loss of Life (TALL). The average number of fatalities per year on the installation. For each hazard identified, TALL is calculated as:

$$\text{TALL} = \text{Hazard Frequency (per year)} \times \text{Potential Fatalities.}$$

Individual Risk per Annum (IRPA). A measure of the annual risk to an individual on the installation. This is calculated as:

$$\text{IR} = \frac{\text{TALL}}{\text{POB}} \times \text{Exposure}$$

The report presents an average IRPA for platform personnel as well as individual risk figures for representative worker groups, which are calculated taking into account:

- The proportion of time individuals within each worker group spend in each location, based on personnel distributions.
- The predicted frequency of hazardous events to which individuals are exposed in each location.
- The impact of those hazardous events, in terms of predicted fatality rates.

Two risk estimates are made, one for the drilling and production phase of the project (assumed to be the years up to and including 2025), and the second representative of the production only phase of the project (after 2025) when all drilling activities have ceased. This is because:

- The risk from blowouts depends on the drilling and well activities being carried out and on the number of wells in production.
- The risk from process loss of containment depends on the number of wells in production.
- There is potential for H_2S in certain streams in later years.

For each of the Major Hazards identified above, the risk assessed in terms of average IRPA, for each phase of operation, is shown in Tables 1 and 2. Risk figures for each worker group are given in Tables 3 and 4.

The Hebron Project is currently in the early FEED stage. There are, therefore, significant uncertainties in some of the risk assessment data used in this assessment, which mean that the risk values predicted are indicative only. Where uncertainties exist in the risk analysis, conservative assumptions (that is, assumptions that over-estimate the risk, rather than under-estimate the risk) are made.

Hazard	Average IRPA – Fatality Classification				Total
	Immediate	Escape/ Escalation	Precautionary Evacuation	TSR Impairment	
Loss of Containment (Fire/Explosion)	2.0×10^{-5}	4.1×10^{-7}	1.1×10^{-6}	4.1×10^{-8}	**2.2×10^{-5}**
Blowouts	2.4×10^{-6}	-	4.9×10^{-5}	1.7×10^{-7}	**5.2×10^{-5}**
Iceberg Collision	-	-	-	3.0×10^{-7}	**3.0×10^{-7}**
Passing Vessel Collision	-	-	-	7.5×10^{-8}	**7.5×10^{-8}**
Helicopter Crash	5.0×10^{-5}	-	-	-	**5.0×10^{-5}**
Seismic Activity	-	-	3.8×10^{-7}	7.5×10^{-7}	**1.1×10^{-6}**
TOTAL	**7.2×10^{-5}**	**4.1×10^{-7}**	**5.0×10^{-5}**	**1.3×10^{-6}**	**1.3×10^{-4}**

Table 1: Average IRPA (Drilling and Production Phase)

Hazard	Average IRPA – Fatality Classification				Total
	Immediate	Escape/ Escalation	Precautionary Evacuation	TSR Impairment	
Loss of Containment (Fire/Explosion/Toxic Gas)	2.8×10^{-5}	2.9×10^{-7}	1.6×10^{-6}	4.8×10^{-8}	**3.0×10^{-5}**
Blowouts	8.4×10^{-7}	-	1.1×10^{-5}	4.8×10^{-8}	**1.2×10^{-5}**
Iceberg Collision	-	-	-	3.0×10^{-7}	**3.0×10^{-7}**
Passing Vessel Collision	-	-	-	7.5×10^{-8}	**7.5×10^{-8}**
Helicopter Crash	5.0×10^{-5}	-	-	-	**5.0×10^{-5}**
Seismic Activity	-	-	3.8×10^{-7}	7.6×10^{-7}	**1.1×10^{-6}**
TOTAL	**7.9×10^{-5}**	**2.9×10^{-7}**	**1.3×10^{-5}**	**1.2×10^{-6}**	**9.3×10^{-5}**

Table 2: Average IRPA (Production Only Phase)

Hazard	**Worker Group**			
	Management/ Admin/ Catering	**Operations & Maintenance**	**Drilling/ Intervention**	**Construction**
Loss of Containment (Fire/Explosion)	2.2×10^{-6}	3.5×10^{-5}	2.4×10^{-5}	4.1×10^{-5}
Blowouts	5.0×10^{-5}	5.0×10^{-5}	5.5×10^{-5}	5.0×10^{-5}
Iceberg Collision	3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}
Passing Vessel Collision	7.5×10^{-8}	7.5×10^{-8}	7.5×10^{-8}	7.5×10^{-8}
Helicopter Crash	5.0×10^{-5}	5.0×10^{-5}	5.0×10^{-5}	5.0×10^{-5}
Seismic Activity	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
TOTAL	$\mathbf{1.0 \times 10^{-4}}$	$\mathbf{1.4 \times 10^{-4}}$	$\mathbf{1.3 \times 10^{-4}}$	$\mathbf{1.4 \times 10^{-4}}$

Table 3: IRPA by Worker Group (Drilling and Production Phase)

Hazard	**Worker Group**			
	Management/ Admin/ Catering	**Operations & Maintenance**	**Drilling/ Intervention**	**Construction**
Loss of Containment (Fire/Explosion/Toxic Gas)	2.9×10^{-6}	3.8×10^{-5}	5.8×10^{-5}	4.3×10^{-5}
Blowouts	1.1×10^{-5}	1.1×10^{-5}	1.4×10^{-5}	1.1×10^{-5}
Iceberg Collision	3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}
Passing Vessel Collision	7.5×10^{-8}	7.5×10^{-8}	7.5×10^{-8}	7.5×10^{-8}
Helicopter Crash	5.0×10^{-5}	5.0×10^{-5}	5.0×10^{-5}	5.0×10^{-5}
Seismic Activity	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
TOTAL	$\mathbf{6.5 \times 10^{-5}}$	$\mathbf{1.0 \times 10^{-4}}$	$\mathbf{1.2 \times 10^{-4}}$	$\mathbf{1.1 \times 10^{-4}}$

Table 4: IRPA by Worker Group (Production Only Phase)

Comparison of the predicted risks with the Hebron Target Levels of Safety (presented in Section 4) concludes that they are below the intolerable IR criterion threshold of 1×10^{-3} per year, and within the 'ALARP' region defined by the criteria. To comply with the Target Levels of Safety, it will also be necessary to show, for hazards that are assessed as being in the ALARP region, that all practicable means of risk reduction have been employed to ensure that the risk is demonstrably ALARP. To achieve this, cost benefit studies may be required at detailed design stage to ensure that appropriate measures of risk reduction are incorporated into the final design.

It is however concluded that there are no significant areas for concern that could prevent demonstration that risks have been reduced to a level that is ALARP at the detailed design stage. Further studies will, however, be required at detailed design stage, to confirm or refine some of the assumptions that have been made in this Concept Safety Analysis and to reflect the design of the installation as it is developed by ExxonMobil.

Contents

Report Approval Cover Sheet i
Report Record of Revision ii
Summary iii
Contents viii
Glossary of Terms xii

1. INTRODUCTION 1

1.1 Study Objectives and Methodology 1

1.2 Presentation and Ongoing Use of Risk Model 2

2. OUTLINE PROJECT DESCRIPTION 4

2.1 Outline Description of the Concept Platform 6
2.1.1 Topsides Facilities 7
2.1.2 Gravity Base Structure (GBS) 10
2.1.3 Offshore Loading System (OLS) 11

3. PREVENTION, CONTROL AND MITIGATION OF MAJOR HAZARDS 12

3.1 Facility Layout 12

3.2 Classification of Hazardous Areas 13

3.3 Ventilation of Hazardous Areas 13

3.4 Ventilation of Non-Hazardous Areas 13

3.5 Emergency Power 14

3.6 Offshore Drainage Systems 15

3.7 Fire and Gas Detection 15

3.8 Emergency Shutdown and Blowdown System 16

3.9 Telecommunication and Alarm Systems 17

3.10 Active Fire Protection 17

3.11 Passive Fire and Blast Protection 19

3.12 Escape Routes 20

3.13 Temporary Safe Refuge 21

3.14 Evacuation and Rescue Systems 21

3.15 Operating and Maintenance Procedures 22

3.16 Contingency Plans 22

4. TARGET LEVELS OF SAFETY 23

4.1 Risk to Personnel 23

4.2 Environmental Risk 24

4.3 Impairment Criteria 24

5. IDENTIFICATION OF MAJOR HAZARDS 25

5.1 Potential Major Hazards Identified and Assessed 26

6. BASIS OF HAZARD ASSESSMENT AND RISK ASSESSMENT 28

6.1 Personnel Distribution 28

6.2 Platform Layout 31

7. PROCESS LOSS OF CONTAINMENT EVENTS 32

7.1 Hydrocarbon Release Frequencies 33
7.1.1 Event Leak Frequencies 33
7.1.2 Selection of Representative Hole Sizes 38

7.2 Ignition Probability 39

7.3 Fire and Gas Detection Probability 40

7.4 Inventory Isolation and Blowdown Probability 41

7.5 Deluge Probability 42

7.6 Explosion Overpressure Probability 42

7.7 Consequence Assessment 43
7.7.1 Immediate Fatalities due to Non-Explosive Ignition (Fires) 44

7.7.2 Immediate Fatalities due to Explosions....45
7.7.3 Immediate Fatalities due to Toxic Gas....47
7.7.4 Escalation Fatalities due to Impairment of Fire and Blast Walls....48
7.7.5 Escape Fatalities....49
7.7.6 Precautionary Evacuation and TSR Impairment Fatalities....50

8. BLOWOUTS....57

8.1 Blowout Location and Frequency....57

8.2 Ignition Probability....59

8.3 Fire and Gas Detection Probability....60

8.4 Isolation Probability....60

8.5 Deluge Probability....60

8.6 Explosion Overpressure Probability....60

8.7 Consequence Assessment....61
8.7.1 Immediate Fatalities for Blowouts in the Wellhead Area....61
8.7.2 Immediate Fatalities for Blowouts at the Drill Floor....62
8.7.3 Escalation Fatalities due to Impairment of Fire and Blast Walls....63
8.7.4 Escape Fatalities....63
8.7.5 Precautionary Evacuation and TSR Impairment Fatalities....63

9. OTHER HYDROCARBON HAZARDS....66

9.1 Releases in the Shaft....66

9.2 Release from OLS Export Pipeline/OLS....67

10. OTHER HAZARDS....68

10.1 Iceberg Collision and Scouring, Sea Ice, Topsides Icing....68
10.1.1 Iceberg Collision....68
10.1.2 Iceberg Scour....69
10.1.3 Sea Ice....69
10.1.4 Ice Loading....69

10.2 Ship Collision....70
10.2.1 Passing Vessels....70

10.3 Helicopter Transportation....71
10.3.1 Hebron Helicopter Operations....71
10.3.2 Helicopter Transport Risk, In-Flight....72
10.3.3 Helicopter Crash Frequency, Take-Off and Landing....73

10.3.4 Helicopter Transport Risk Summary 73

10.4 Seismic Activity....73

10.5 Structural Failure due to Extreme Weather....74

11. RISK SUMMARY AND CONCLUSIONS....75

11.1 Theoretical Annual Loss of Life....75

11.2 Individual Risk per Annum....77

11.3 Environmental Risks....79

11.4 Conclusions....80

12. SENSITIVITY ANALYSIS....82

12.1 Isolation Probabilities....82

12.2 Precautionary Evacuation....83

12.3 Pool 3 Subsea Development....84
12.3.1 Process Loss of Containment....85
12.3.2 Blowouts....86
12.3.3 Risk Results....87

12.4 Produced Water Re-injection....87

13. RECOMMENDATIONS....89

14. REFERENCES....91

APPENDIX 1: REPRESENTATIVE LOSS OF CONTAINMENT EVENT TREE
APPENDIX 2: IMMEDIATE FATALITIES DUE TO FIRES
APPENDIX 3: EXPLOSION FATALITIES
APPENDIX 4: ICEBERG COLLISION EVENT TREE
APPENDIX 5: PASSING VESSEL COLLISION EVENT TREE
APPENDIX 6: REPRESENTATIVE HELICOPTER CRASH EVENT TREE
APPENDIX 7: SEISMIC ACTIVITY EVENT TREE
APPENDIX 8: REPRESENTATIVE SMOKE INGRESS EVENT TREE
APPENDIX 9: GAS INGRESS EVENT TREE
APPENDIX 10: SMOKE AND GAS IMPAIRMENT OF TSR/EVACUATION SYSTEMS
APPENDIX 11: PHAST JET FIRE MODELLING
APPENDIX 12: TOXIC GAS - PHAST MODELLING AND FATALITY ESTIMATES

Glossary of Terms

AFFF	Aqueous Film-Forming Foam
ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
BOP	Blowout Preventer
CCR	Central Control Room
CEC	Canadian Electrical Code
CEAA	Canadian Environmental Assessment Act
CSA	Concept Safety Analysis
DCR	Drilling Control Room
DDMT	Data and Decision Management Tool
DES	Drilling Equipment Set
DNV	Det Norske Veritas
DSM	Drilling Support Module
EDC	Excavated Drill Centre
EERA	Escape, Evacuation and Rescue Assessment
ESD	Emergency Shutdown
ESV	Emergency Shutdown Valve
FEED	Front-End Engineering and Design
GBS	Gravity Base Structure
H_2S	Hydrogen Sulphide
HP	High Pressure
HPHT	High Pressure, High Temperature
HSE	Health and Safety Executive
HVAC	Heating Ventilation and Air Conditioning
IEEE	Institute of Electrical and Electronics Engineers
IOP	Interconnecting Offshore Pipeline
IR	Individual Risk
KO	Knock-Out
LFL	Lower Flammable Limit
LG	Lift Gas
LP	Low Pressure
LQ	Living Quarters
MODU	Mobile Offshore Drilling Unit
MP	Medium Pressure
OIM	Offshore Installation Manager
OLS	Offshore Loading System
PA	Public Address
PABX	Private Automatic Branch Exchange
PDQ	Production, Drilling and Quarters
PFP	Passive Fire Protection

POB	Persons on Board
QRA	Quantified Risk Assessment
RF	Radio Frequency
RP	Recommended Practice
SDL	Significant Discovery Licence
TALL	Theoretical Annual Loss of Life
TEMPSC	Totally Enclosed Motor Propelled Survival Craft
TIF	Test Independent Failure
TLS	Target Levels of Safety
TSR	Temporary Safe Refuge
UPM	Utility and Process Module
VEC	Valued Environmental Component

1. Introduction

ExxonMobil Canada Properties (ExxonMobil) is proposing to develop the Hebron oil field using a Gravity Base Structure (GBS). The GBS will be located approximately 350 km East-Southeast of St. John's, Newfoundland, 6 km North of Terra Nova, and 35 km Southeast of the Hibernia field. The Hebron Project is currently at the conceptual design stage.

According to Section 43 of the Newfoundland Offshore Petroleum Installations Regulations, an operator is required to submit to the Chief Safety Officer a concept safety analysis of an installation that considers all components and activities associated with each phase in the life of the production installation. The concept safety analysis must include a determination of the frequency of occurrence and potential consequences of potential accidents identified, and details of safety measures designed to protect personnel and the environment from such accidents.

This report, therefore, identifies major hazards associated with the Hebron facility, taking into account the basic design concepts, layout and intended operations, and assesses the risks to personnel and the environment resulting from these hazards.

Section 2 provides an outline description of the Hebron project and Section 3 describes the key safety design features and systems proposed for the prevention, detection and control of potential major hazards. Sections 6 to 10 present the basis of the assessment of risk to personnel due to the identified major hazards (listed in Section 5). Section 11 presents the results of the assessment, and compares them to the Target Levels of Safety set for the Project (Section 4). Section 12 details sensitivity studies that have been performed.

1.1 Study Objectives and Methodology

The objectives of this Concept Safety Analysis (CSA) are to:

- Identify the potential Major Hazards associated with the development concept.
- Evaluate the identified Major Hazards in terms of risk to personnel, through event tree-based Quantified Risk Assessment (QRA).
- Compare predicted risks with the Hebron Target Levels of Safety (TLS).
- Document results, findings, conclusions and recommendations.
- Fulfil the CSA requirements stipulated in Section 43 of the Offshore Petroleum Installations Regulations.

As required by the Offshore Petroleum Installations Regulations, this CSA considers all components and activities associated with each phase in the life of the Hebron GBS, including the construction, installation, operational and removal phases of the installation.

The hazard identification carried out was based on a detailed review of standard Major Hazards that have been identified as a result of many years of similar operations experience, and in particular experience on the Hibernia, Terra Nova and White Rose projects. Reference was also made to previous hazard identification exercises carried out for the Project.

As required, the risk assessment is quantitative where it can be demonstrated that input data is available in the quantity and quality necessary to demonstrate confidence in results. Where quantitative assessment methods are inappropriate, qualitative methods are employed.

Quantitative estimates of risk to personnel are based on event tree modelling of the following Major Hazards identified for the proposed installation:

- Loss of hydrocarbon containment (resulting in fire, explosion or unignited, potentially toxic, release).
- Blowout (resulting in fire, explosion or unignited, potentially toxic, release).
- Iceberg collision.
- Ship collision.
- Helicopter crash.
- Seismic activity.

The estimated risks are compared with ExxonMobil's TLS in order to determine whether risks are acceptable.

The level of detail in this assessment reflects the information available at the early FEED stage. It has been necessary to make a number of assumptions in the development of the risk model, because of the inevitable lack of detailed information at this stage of the Project.

Sensitivity studies have therefore been undertaken on a number of these assumptions to ensure that the information used is robust and appropriate at this stage. These sensitivity studies:

- Estimate the effect on risk levels of varying input data.
- Identify areas where particular consideration should be given to reducing uncertainty through further study or data acquisition.

1.2 Presentation and Ongoing Use of Risk Model

The quantified risk assessment carried out for this CSA has been developed in a risk model that can be refined and updated throughout the life of the Project. To facilitate the tracking and updating of the data, the risk model is represented in RMRI's Data and Decision Management Tool (DDMT). This software tool allows quick and efficient interrogation of the risk model, ensuring that the best available data is used in ongoing decision-making on issues relating to personnel safety, the environment and the integrity of the installation.

This tool may be used during the Hebron Project development in order to fulfil commitments to:

- Protecting the health and safety of all individuals affected by their work, as well as the environment in which they live and operate.
- Communicating health, safety and environmental matters in an open and timely manner with all affected parties.
- Developing the culture and providing the training and resources necessary to support their commitments.
- Taking health, safety and environmental matters into account when making business decisions.

2. Outline Project Description

The Hebron Offshore Project Area is located approximately 350 km East-Southeast of St. John's, Newfoundland, 6 km North of Terra Nova, and 35 km Southeast of the Hibernia field (as shown in Figure 2.1).

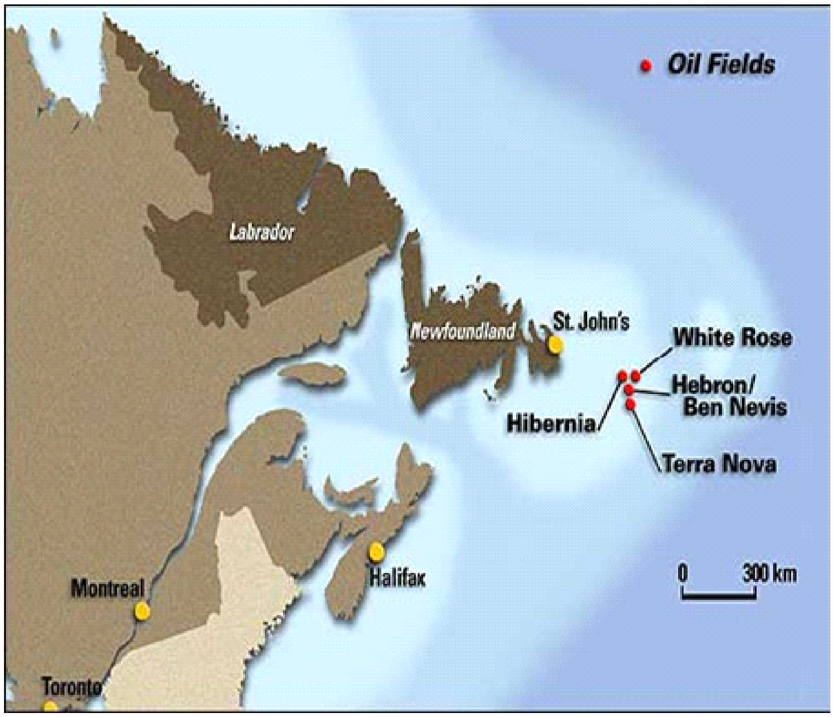

Figure 2.1: Location of Hebron Project Area

The Hebron Unit (as shown in Figure 2.2) contains three discovered fields (the Hebron Field, the West Ben Nevis Field and the Ben Nevis Field) and incorporates four Significant Discovery Licences (Hebron SDL 1006, Hebron SDL 1007, Ben Nevis SDL 1009 and West Ben Nevis SDL 1010).

The Unit contains separate oil pools in at least four stratigraphic intervals: the Lower Cretaceous Ben Nevis Reservoir, the Lower Cretaceous Avalon Reservoir, the Lower Cretaceous Hibernia Reservoir and the Upper Jurassic Jeanne d'Arc Reservoir. The Ben Nevis Pool within the Hebron Field is the core of the Hebron Project and it is anticipated that about 80% of the Project's crude oil will be produced from this pool. This oil is heavy (~20^{o}API) and difficult to separate from water. Therefore, a specially designed oil/water separation system with sufficient residence times and heating will be implemented, and gas lift will also be necessary for production wells.

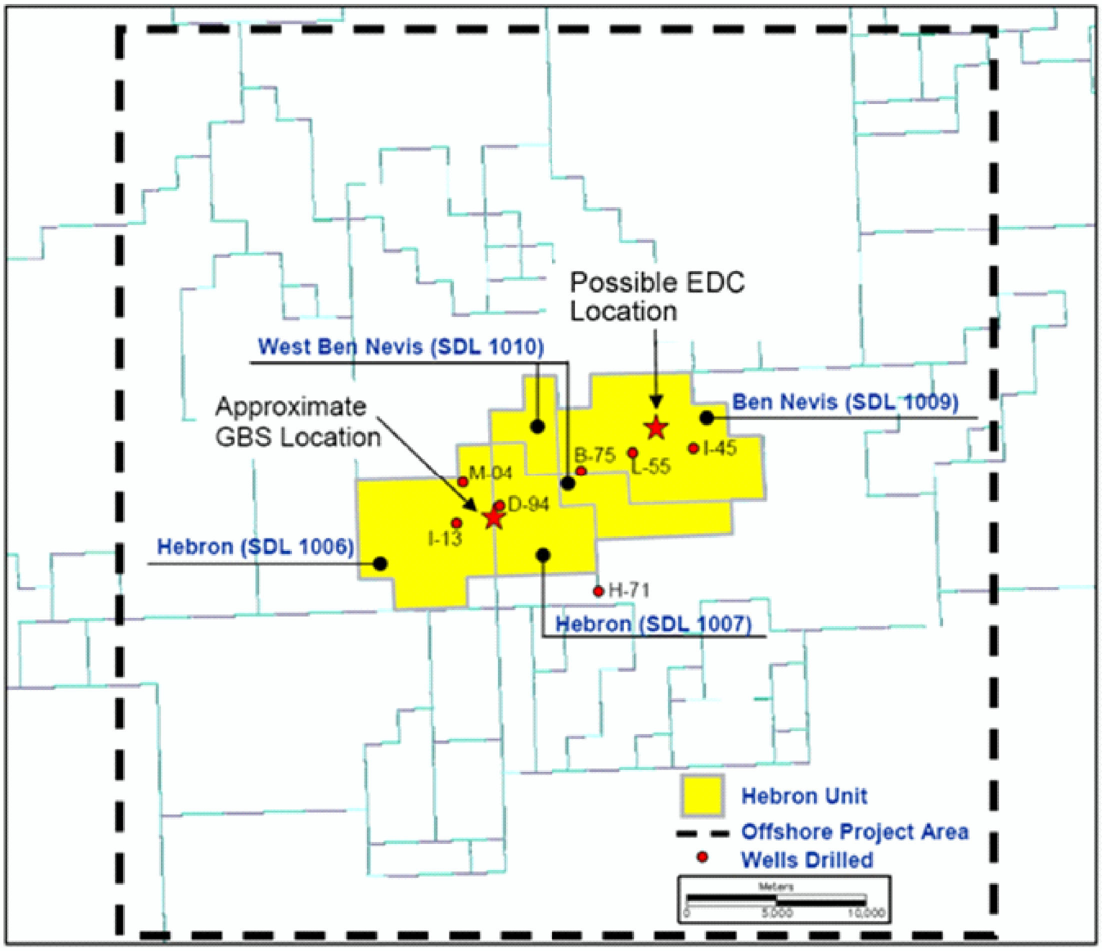

Figure 2.2: Hebron Offshore Project Area for Environmental Assessment

The main process, designed to separate the oil for storage in the GBS cells, the gas for gas lift, fuel gas and gas re-injection, and the water for treatment and disposal to sea or potentially reinjection, will include:

- A four stage separation train with heating.
- A two stage Low Pressure (LP) compression system.
- Two 60% compression trains, each including a Medium Pressure (MP) compressor, a High Pressure (HP) compressor and a Lift Gas (LG) compressor.
- Gas dehydration facilities.
- A gas re-injection compressor.
- Produced water treatment.

The produced oil will be stored in the cells in the GBS substructure until pumped, via submerged loading stations, to a shuttle tanker.

The processing facility will be designed to produce approximately 150,000 barrels of oil per day.

Wells are to be drilled from the installation, using the platform's drilling rig, during the early years of production. The first well drilled will be used for cuttings reinjection. In addition, it is anticipated, based on the current development plan, that there will be:

- 19 MP production wells.
- 6 HP production wells.
- 10 water injection wells.
- 2 gas injection wells.

A subsea tieback development of Pool 3 is also planned, but this is considered within this CSA as a sensitivity case (see Section 12.3), rather than as part of the 'base case' development.

The GBS has a total of 52 well slots and it is therefore possible that further wells will be drilled at some stage. However, this CSA is based on the 'most probable' well count considered in the current development plan, as outlined above.

2.1 Outline Description of the Concept Platform

The platform description provided here is based on conceptual design studies carried out to date. The components described herein will be subject to change as the design develops during Front End Engineering and Design (FEED) and detailed design. The conceptual design of the facility is illustrated in Figure 2.3.

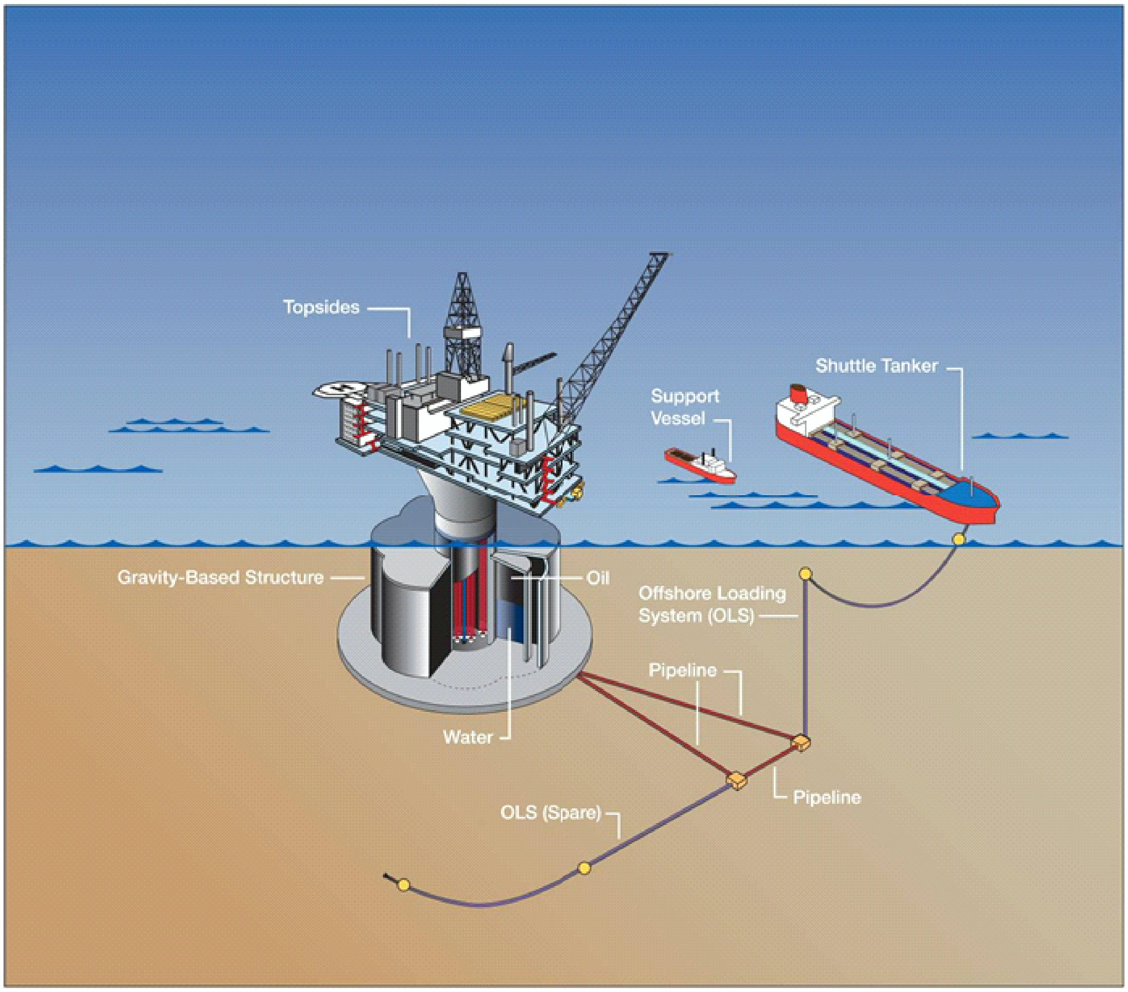

Figure 2.3: Conceptual Hebron Facilities Layout

The platform will consist of three main components:

- A Production, Drilling and Quarters (PDQ) topsides.
- A concrete GBS. The GBS supports the topsides and provides an oil storage facility.
- An Offshore Loading System (OLS).

Brief descriptions of each of these components are provided in the following subsections.

2.1.1 Topsides Facilities

The conceptual design of the topsides is illustrated in Figure 2.4. The length of the topsides will provide the maximum separation between the hazardous and non-hazardous areas, with the Process Area at the East end of the platform and the Living Quarters at the West end of the platform.

From East to West, the platform areas will be arranged as follows:

- Process Area, with Drilling Support Module (DSM) above.
- Wellhead/Manifold Area, with Drilling Equipment Sets (DES) above.
- Utility Area, with Gravel Pack Area, drilling offices and Power Generation Area above.
- Living Quarters (LQ).

Each area is briefly described in the following sections.

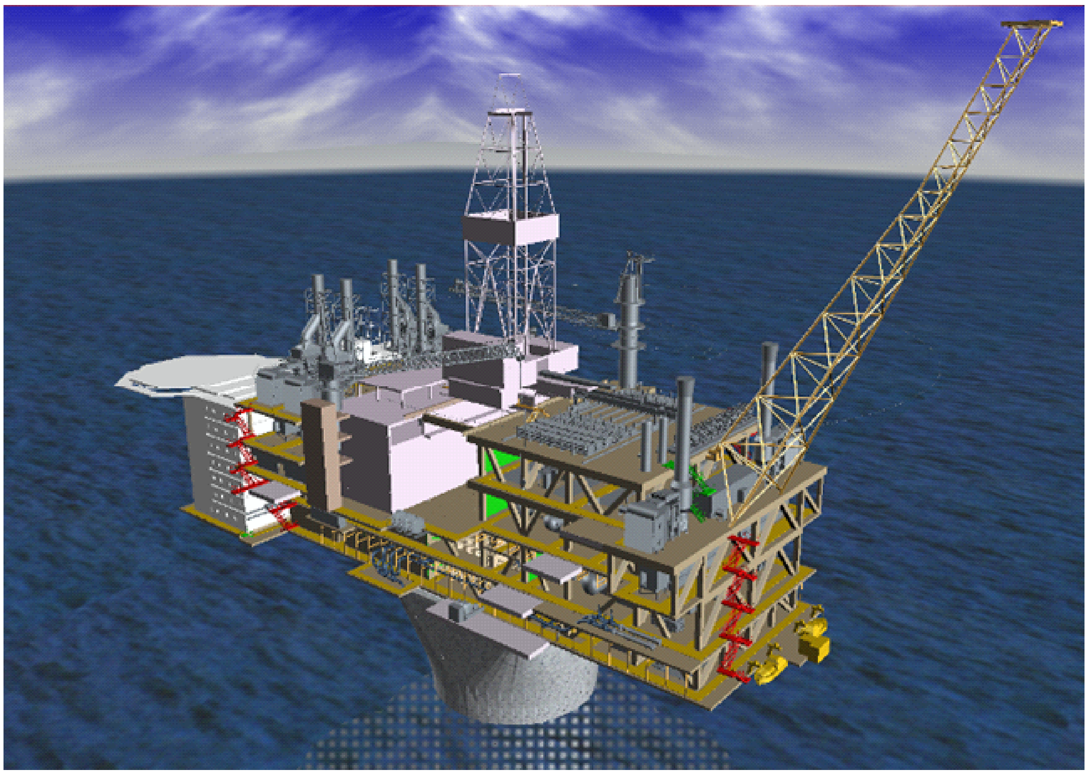

Figure 2.4: Conceptual Hebron Platform Design

2.1.1.1 Process Area

The Process Area has four main levels, Cellar Deck, Lower Deck, Main Deck and Upper Deck. There are also mezzanine platforms located within these Process Area deck levels.

The layout of the equipment on the four decks has been arranged with the intent of:

- Ensuring adequate egress for escape, evacuation and rescue.
- Hazard segregation.
- Minimizing blast overpressure.

- Ensuring adequate access for maintenance.
- Optimizing material handling access.
- Optimizing pipe and cable routings.

The secondary muster area with lifeboats and liferafts, protected from Process Area hazards, will be provided at the East end of the Process Area at Cellar Deck level.

2.1.1.2 Drilling Support Module (DSM)

The DSM will contain drilling related liquid/pump systems and utility systems, including mud treatment and mixing systems, storage tanks, transfer pumps, electrical distribution equipment and HVAC rooms. The Drillers' Pipe Deck will be located to the East of the DES, above the DSM. A special pipe handling crane will be located at the East side of the Pipe Deck.

2.1.1.3 Wellhead/Manifold Area

The Wellhead Area will be split into three main levels: Cellar Deck, Lower Deck and Main Deck. There will be a recess towards the Process Area at Cellar Deck level to accommodate the export booster pumps discharge piping, risers and j-tube terminations and at Lower Deck level for the Manifold Area.

The wellbay area will be designed to accommodate a maximum of 52 wells.

The area above the Main Deck will be the Intervention Area. The Intervention Area will be constructed to provide dropped object protection to minimize potential hazard to the wellheads. The area has been designed with the intention of providing intervention access to wells, such as for coil tubing operations. There will be removable hatches for access to the wellheads, and two laydown areas, one on the North side and one on the South side, that will be designed to facilitate intervention material handling requirements.

2.1.1.4 Drilling Rig/Drilling Equipment Set (DES)

The Drilling Rig/DES will be supported by the skid base, which, in turn, will be supported by the Utility and Process Module (UPM). The Gravel Pack Area and drilling offices will be located in the Utility Area, adjacent to the Intervention Area.

The DES will mainly contain the mechanical drilling systems. The blowout preventer (BOP) will also be located within the DES and securely mounted to the DES such that travel from well to well may be accomplished with minimized dropped objects risk.

Drilling operations will be controlled from the Drilling Control Room (DCR), located on the drill floor. The DCR will have all necessary facilities for the driller and the assistant driller to control and monitor all drilling and pipe handling operations.

2.1.1.5 Utility Area, Power Generation Area and Gravel Pack Area

The Utility Area and Power Generation Area have been designed to group areas with similar hazards such that workshops, stores and switchgear are separated from power generation facilities, and so emergency and essential functions are separated from hazards.

Utilities will be located primarily on the Cellar Deck and Lower Deck, with gravel pack facilities located on the Main Deck, Process Deck and Weather Deck levels above the water injection area. The main Power Generation Area will be located above the Utility Area on the Upper Deck, adjacent to the Living Quarters. Workshops, stores, labs and switchgear are located on the Main Deck between the Gravel Pack Area and the LQ.

2.1.1.6 Living Quarters

The Living Quarters will be designed to accommodate the maximum POB and will be laid out over seven floors.

There will be a lift and internal staircase up to Level 7, providing a sheltered route to the Arrivals/Departures Lounge. From there, stairs lead up to the Weather Deck (where there is a vestibule and an electrical/telecommunications room) and to the helideck above.

The Living Quarters is the designated Temporary Safe Refuge (TSR) and as such is provided with appropriate lifesaving equipment.

Access to the Primary Lifeboat Station from the muster area in the LQ is protected from hazardous events. Additional access will be provided by walkways from the West staircases.

2.1.2 Gravity Base Structure (GBS)

The GBS will be a concrete structure consisting of a central column and a cylindrical underwater caisson.

The underwater caisson is expected to be 73 metres high and will contain the crude oil storage cells. The caisson will have an appropriately-strengthened icebelt and roof structure to provide protection against iceberg impact.

The central column of the GBS will support the topsides approximately 33 metres above mean sea level and will be designed to protect against iceberg or ship impact.

2.1.3 Offshore Loading System (OLS)

Oil for export will be transported through two sub-sea offshore pipelines. Each sub-sea offshore pipeline will run approximately 2km from the GBS to a loading station. Each loading station will enable oil to be loaded to shuttle tankers, and will consist of an OLS base with vertical OLS riser, sub-surface buoy, catenary riser and shuttle tanker connection.

An interconnecting offshore pipeline (IOP) about 1km long will connect the two OLS bases.

The subsea pipelines can be flushed to protect against the possibility of oil spillage in the event of iceberg scour.

3. Prevention, Control and Mitigation of Major Hazards

This section describes the safety design features and safety systems proposed for the prevention, detection and control of potentially Major Hazards. An overview of the escape and evacuation systems is also presented.

In all cases the systems will be designed to meet or exceed appropriate codes and standards.

3.1 Facility Layout

The proposed development will comprise a central production, drilling, quarters (PDQ) structure that utilizes a concrete gravity base structure (GBS).

The topsides configuration ensures that the Process Area is as far from the Living Quarters as possible. The Process Area and Living Quarters will also be separated by the Gravel Pack Area and utilities.

Safety considerations of the facility layout will include the provision of:

- Separation between flammable hydrocarbons and ignition sources.
- Separation between hydrocarbon handling areas and emergency services, main safety equipment, accommodation, temporary safe refuge areas, means of evacuation and escape, muster points and control centres.
- Sufficient structural protection in the form of passive fire and blast protection to ensure structural integrity for the time required for orderly evacuation or escape.
- Dropped object protection above the Wellhead Area.
- Sufficient means of escape to enable efficient and protected evacuation from all areas designated as muster and evacuation stations under foreseeable hazard conditions.
- Availability of essential services and the main safety equipment under foreseeable hazard conditions, including protecting critical systems and equipment required to function in a fire and explosion emergency.
- Safe access to systems and equipment for operational and maintenance purposes.

Specific considerations for the offshore facilities will include:

- Providing in the design for helicopter approach and take-off flight sectors that conform to Transport Canada requirements and are free of interference. This will have an influence on helideck location and platform orientation with respect to prevailing winds.
- Positioning and arranging cranes and laydown areas to facilitate safe lifts from supply boats and eliminating or reducing the potential for vessel collisions and dropped objects contacting subsea pipelines.

- Locating and orienting survival craft, launch gear and other sea evacuation or escape systems to provide the maximum practicable clearance from any part of the platform during deployment, and to avoid adverse effects of wind, waves and currents.

3.2 Classification of Hazardous Areas

Due to the nature of the hydrocarbon processing to be carried out on the offshore installation, the potential exists for release of hydrocarbons.

Hazardous platform areas in which hydrocarbon gas or vapours are, or may be, present will be classified in accordance with Section 18 of the Canadian Electrical Code (CEC) Part 1 C22.1 and API RP 505 "*Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class 1, Zone 0, Zone 1, and Zone 2*".

In classified hazardous areas, various measures will be taken to minimize the occurrence of hazards to personnel, including:

- Assurance of adequate natural ventilation or the provision of ventilation to prevent the accumulation of flammable gases or vapours.
- The control of potential ignition points, by selection of appropriate equipment.

Electrical equipment for use in hazardous areas will be selected in compliance with API RP 14FZ "*Recommended Practice for Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class I, Zone 0, Zone 1 and Zone 2 Locations*". In addition to API RP 14FZ, Standard 45 of the IEEE and relevant ExxonMobil design specifications will be used.

3.3 Ventilation of Hazardous Areas

Hazardous areas will be ventilated to prevent the accumulation of flammable or toxic gases and vapours, to reduce the likelihood of ignition, and thereby minimize the risk from fire and explosion.

In hazardous areas where natural ventilation is not adequate, mechanically-assisted ventilation will be provided. Ventilation for hazardous areas will be in compliance with API RP 505 "Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class 1, Zone 0, Zone 1, and Zone 2" and the Installations Regulations.

3.4 Ventilation of Non-Hazardous Areas

HVAC applications for non-hazardous areas will include pressurization systems to prevent the migration of fumes or vapours from hazardous areas to closed non-hazardous areas.

The HVAC systems will incorporate safety features designed to prevent the spread of flammable gas, fire and smoke. These will include:

- Fire dampers in ventilation ducts.
- Fire dampers in all main fresh air intakes.
- Fire dampers in penetrations to fire-rated assemblies.
- Location of air intakes away from potential sources of hazardous gases or vapours.
- Gas and smoke detectors protecting air intakes, all of which will generate an alarm in the control room and close intake dampers to prevent the ingress of hazardous gases or vapours.

Air handling systems will have automatic detection of system failure, with appropriate alarms to the control room.

3.5 Emergency Power

The offshore installation will have emergency electrical power systems to allow platform personnel to maintain control in the event of loss of main power, and to maintain systems necessary for evacuation and meet regulatory requirements.

Emergency electrical power will be supplied to emergency systems, including:

- Fire and gas detection and shutdown systems.
- Emergency alarm system.
- Distributed control system.
- Instrument, auxiliary supply switchgear, escape lighting.
- Power management systems.
- Public address systems.
- Radio link.
- PABX system.
- Drillers' intercom.
- Mud logging unit.
- BOP/diverter interface panel.
- Drillers' control and data acquisition systems.
- Navaids.
- Safety-related HVAC systems.

To ensure that the power system will be operable during major gas releases and fires on the platform, the emergency generators and emergency power distribution system will be protected by at least A-60 partitions.

3.6 Offshore Drainage Systems

Open and closed drain systems will be provided on the Hebron installation.

The main purpose of the open drain systems will be to collect rainwater, firewater, deck wash water and liquid spillage from all systems open to atmosphere, from both process and utility areas. The collected liquids will be treated to avoid pollution of the environment and meet overboard disposal requirements.

Drain water and liquid spillage will be collected in drain boxes and drain gullies, and will be directed to drain tanks via sloped gravity flow collection headers containing seal pots for area segregation. Drainage from utility and process areas will be separately routed to the Utility Open Drain Tank and Process Open Drain Tank, respectively. Liquid from the Process Open Drain Tank will be pumped by the Process Open Drain Pump to the Drain Centrifuge for removal of contaminates. The treated water will be disposed to sea, whilst the rejected oil will be routed to the Closed Drain Drums.

The closed drain system is designed to collect drain fluid containing hydrocarbons from piping, tanks and other platform/processing equipment.

The fluids will be directed to the Closed Drain Drums via sloped gravity flow collection headers. The Closed Drain Drums will be provided with heating to prevent freezing and wax formation, and will be constantly purged with nitrogen. Flash gas will be routed to a flare system. Liquid will be pumped to the LP Separator, or may, during shutdowns, be pumped to the GBS oil storage cells.

3.7 Fire and Gas Detection

All areas of the facility will be monitored by automatic fire and gas detection systems appropriate to the fire or explosion risk. Toxic gas detection facilities may also be installed in future as required due to increasing H_2S concentrations (discussed in Section 7.7.3). The systems will provide warnings to control points and, in situations hazardous to personnel, automatically initiate visual and audible alarms. In specific cases, confirmed fire or gas detection will also automatically initiate executive actions, to control and mitigate the consequences of a fire or gas release.

Fire detectors will be installed on the offshore facilities to continuously monitor spaces where the potential for fire exists. Fires will be detected and confirmed by smoke detection, flame detection or heat detection, depending on the nature of the area and the risk.

The fire detection system will automatically alert all personnel in the event of a fire, and relay information about the location and extent of the fire to the designated control point. In designated cases, the fire detection system will initiate executive actions such as:

- Shutdown of process, utility and non-critical electrical systems.
- Activation of protection and mitigation systems, such as blowdown and firewater deluge.

Flammable gas detectors will be installed in locations such as: process areas, ventilation air intakes, barriers between process areas and potential ignition sources in utility areas, gas turbine enclosures, air compressor intakes, gas turbine combustion air intakes and inlets to accommodation and breathing air compressors.

The flammable gas detection system will indicate in the control room the location of the detector and the concentration of gas. Flammable gas detection warns of a build-up of an explosive atmosphere and, therefore, confirmed detection will initiate executive actions involving process shutdown and removal of ignition sources (electrical isolation).

The fire and gas detection systems will be provided with adequate redundancy and protection to ensure, as far as is reasonably practicable, their availability in the event of a major accident.

3.8 Emergency Shutdown and Blowdown System

Emergency shutdown systems will be provided to maintain safe operating conditions compatible with production requirements.

Blowdown of process equipment will be considered for pressurized hydrocarbon systems, to dispose of the gaseous inventory under emergency conditions in order to reduce the duration of an event and the intensity of the fire.

The principal functions of the emergency shutdown (ESD) system will be:

- The protection of personnel and overall safety of the platform.
- The minimization of environmental pollution.

The ESD system will be designed to comply with the relevant statutory requirements, codes and standards, and to, as far as reasonably practicable, remain operational in an emergency. It will also be designed so that it can be initiated both manually and automatically.

The shutdown levels and detailed logic for the ESD system will be defined during FEED.

3.9 Telecommunication and Alarm Systems

The telecommunications system will be designed so that the performance of the systems/subsystems essential to the safety of the platform and personnel will remain operational during an emergency situation.

Radio systems will be designed so as to limit the radio frequency (RF) radiation to an acceptable safe level. This is to ensure that personnel are not exposed to harmful radiation and that under gas escape conditions RF power radiated in hazardous areas is kept well below the threshold to avoid any possibility of sparks and ignition.

Where required by the availability criteria, systems will be duplicated such that failure of any one area will not render the system inoperable. The systems will be designed to allow maintenance activity on any one of the redundant units whilst the system remains in service, without endangering service personnel or the safe operation of the equipment.

Essential control equipment for communications systems will be located in designated safe areas. This will enable communications to be maintained in the event of a hazard. As appropriate, non-essential equipment and supplies may be isolated to eliminate ignition sources during certain ESD situations. All equipment not certified for use in a hazardous area, that is required to continue to operate, will be protected by a gas detection system so that it is shut down before an explosive concentration of gas is reached in the vicinity of the equipment.

A Public Address and Alarm (PA) system will provide audible speech for the broadcast of routine or emergency messages. Routine use of the PA system will consist mainly of paging messages. In an emergency, the PA system will be used to broadcast one of a selection of alarm tones to indicate the nature of the emergency, and to issue instructions to all areas where personnel may be located. Alarm signals will be attenuated during the transmission of emergency speech messages.

Alarms will be generated by the fire and gas system and by manual call points. Fire and gas alarms will be audible and will have a distinct tone. Alarm beacons will give visual indication throughout all areas with high noise levels.

Additionally, upon detection of fire or gas, an audible and visual signal will automatically be activated on the fire and gas indicator panel in the CCR along with an indication of the location and extent of the fire or gas.

3.10 Active Fire Protection

The facility will be provided with a combination of active fire protection and passive fire protection selected to meet regulatory requirements and appropriate for the fire hazards that exist.

The firewater system is the primary active fire protection system. It will be designed to provide an adequate supply of firewater to user points to meet the largest credible demand for fire control and mitigation.

This will be achieved by:

- Ensuring firewater pumps are not subject to a single point failure.
- Ensuring the firewater system will deliver sufficient quantities of water at a suitable pressure.
- Ensuring that firewater drivers, firewater pumps, piping and deluge control points are adequately protected from fire and explosion damage.
- Having diverse firewater supply routes to systems and equipment.

Firewater pumps and drivers will be provided, located within A-60 enclosures to avoid fire in one fire pump system escalating to the other. There will be sufficient redundancy in the provision of pumps and drivers to ensure that firewater can be maintained in the event that a pump or driver is out of service. The fire pump units will be protected by fixed fire extinguishing systems suitable for machinery spaces.

The firewater pumps will be connected to distribution systems in such a way that damage in one area will not cause loss of all the firewater supply to that area. Firewater distribution piping will be routed outside areas where it could be exposed to damage, and will be protected to the extent practicable against external forces, such as environment, falling loads, fire and explosion. Shut-off valves and cross connections will be included to enable isolation of parts of the firewater ring main and to ensure supply to consumers from two different sections.

The deluge systems will deliver sufficient quantities of water to designated hazardous areas to:

- Cool equipment in the event of a fire.
- Control burning rate of fires.
- Limit the potential of fires escalating to adjacent areas.
- Reduce the effect of radiation and smoke movement, in order to protect personnel during escape and evacuation.

The deluge systems will be automatically activated on confirmed fire detection in designated protected areas.

In areas where liquid hydrocarbon fires are identified as a potential hazard, a solution containing Aqueous Film Forming Foam (AFFF) will be supplied on a fire zone basis via fixed deluge systems or manually by hydrants or hose reels.

Details of fire hydrants, hose cabinets, monitors and portable fire extinguishers will be defined during detailed design.

3.11 Passive Fire and Blast Protection

Passive Fire Protection (PFP) will be provided for offshore topsides primary structures and hydrocarbon vessels that contain significant quantities of hydrocarbons, to prevent fires escalating through structural collapse or vessel failure.

The selection of PFP will account for the:

- Required period of protection.
- Characteristics of the type of fire that may occur.
- Limiting temperature for the integrity of the structural elements or equipment.

Fire-rated and, where necessary, blast-rated divisions will be installed to:

- Segregate hazardous and non-hazardous areas.
- Subdivide areas to prevent the spread of fire, to reduce the overall area that might be subjected to a fire.

PFP may also be used to protect piping, emergency shutdown valves and enclosures. This possibility will be investigated at a later stage of the project.

Fire and blast ratings to be provided for partitions will be confirmed during detailed design, but they will, as a minimum, meet all regulatory requirements and will be specified and constructed in order to minimize the potential for escalation of events and in particular for impairment of the TSR. The proposed configuration is presented in Figure 3.1.

As shown in Figure 3.1, appropriately-rated fire and blast walls will be provided to separate the main process areas from the drilling and wellhead areas (including manifolds), and the drilling and wellhead areas from the utility and drilling support areas. A fire and blast wall will also extend vertically upwards from the Cellar Deck to cover the entire Eastern side of the Living Quarters, providing protection against potential hazards originating in the Power Generation and Utility Areas, as well as in the main process and drilling areas. A fire/blast rated wall will also be provided to the East of the Process Area, at Cellar Deck level, to provide protection to the alternative muster area at the East end of the platform.

All decks in the Process, Wellhead/Intervention, DSM, Power Generation and Utility Areas will be plated. In addition, the Upper Deck below the Power Generation Area will be fire/blast rated, and the Main Deck in all areas to the East of the Power Generation Area will be fire rated. The Cellar Deck in the area immediately above the GBS is also envisaged to be blast rated, with two hours' fire integrity.

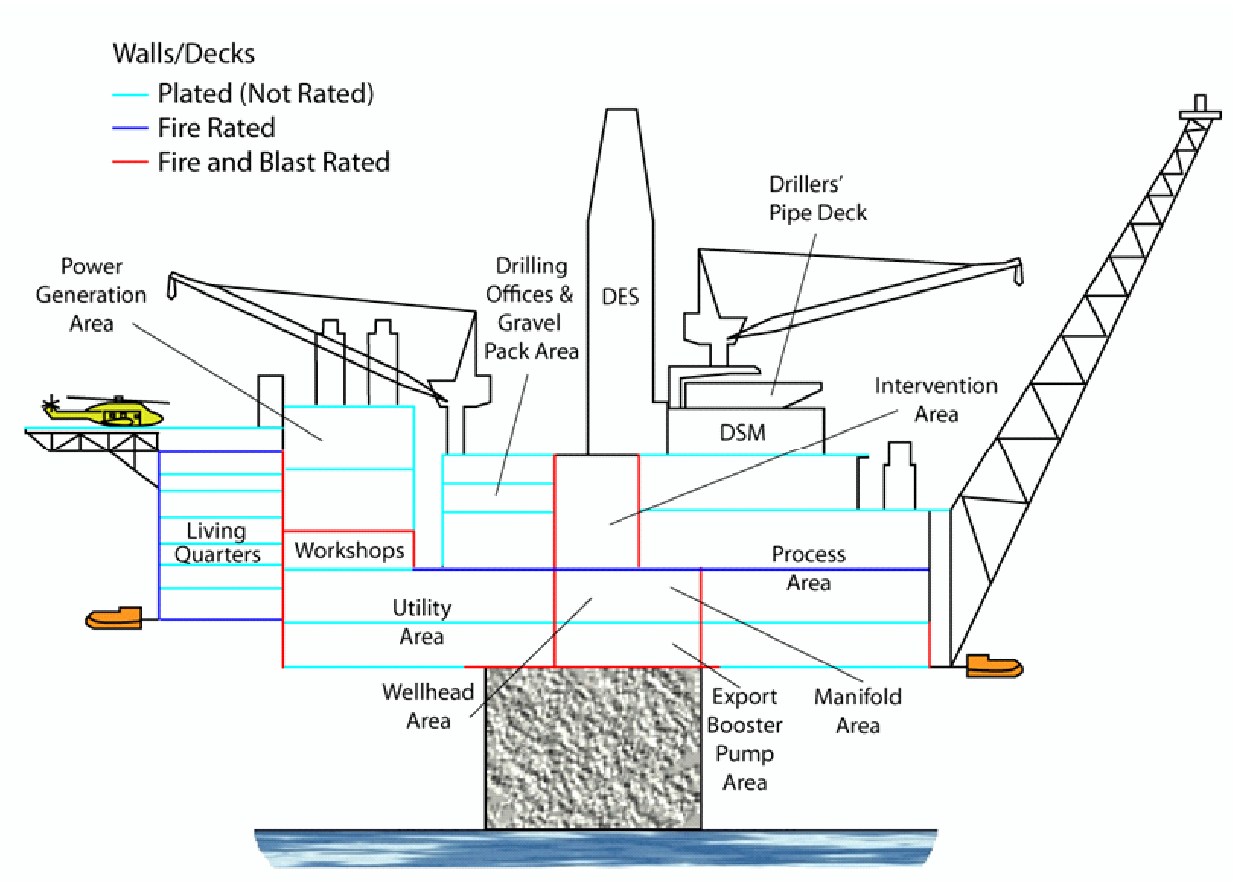

Figure 3.1: Hebron GBS Wall/Deck Configuration

3.12 Escape Routes

Safe means of escape will be provided from all parts of the facility that are regularly manned. Escape routes will direct personnel to the Temporary Safe Refuge and to the means of evacuation or escape from the platform. Escape routes will take as direct a route as possible, from the immediate hazard to an area of shelter.

Main escape routes will be:

- Of sufficient height and width, meeting or exceeding regulatory requirements and in line with industry best practices.
- Readily accessible and permanently unobstructed.
- Clearly marked and rapidly identifiable by everyone at the facility.
- Adequately illuminated by escape lighting independent of the normal power supply.

Where the results of hazard and risk assessment indicate that it is necessary, escape routes will be protected against predicted hazard effects for the duration required to effect escape.

Where practicable, escape routes will be routed at the perimeter of the platform decks to achieve separation from the main hazards and to provide the maximum separation between redundant escape routes.

3.13 Temporary Safe Refuge

The prime function of the Temporary Safe Refuge (TSR) is to protect all personnel for a pre-determined time during an emergency. The TSR will be designed to protect and shelter personnel from accidental events for sufficient time to organize and effect a safe evacuation.

The TSR will contain facilities that allow the incident to be investigated, emergency response procedures to be initiated and pre-evacuation planning to be undertaken.

It will therefore provide:

- Shelter for personnel and control points, particularly from fire, smoke, unburned and toxic gases, explosion and thermal radiation.
- Sufficient control facilities to facilitate the evaluation of an incident and, where possible, allow personnel to bring it under control.
- Sufficient means of communication between individuals at the installation and those at other installations, on vessels, aircraft and on shore.

The TSR will be positively pressurized to prevent ingress of smoke and gas.

3.14 Evacuation and Rescue Systems

The following means of evacuation and escape are provided (listed in descending order of preference):

- Helicopter.
- Lifeboats (Totally-Enclosed Motor-Propelled Survival Craft, or TEMPSC).
- Escape to sea via escape chutes and inflatable rafts.

There will be sufficient provision of lifeboats to provide for 200% of the maximum POB during normal operations. Lifeboats will be distributed between the primary muster station and a secondary muster station at the processing end of the platform according to the results of an evacuation study and according to the Installations Regulations. The preliminary arrangement locates four craft in the vicinity of the TSR and two at the alternative muster station at the processing end. The need for enhanced evacuation systems will be investigated during FEED. If there is a requirement for a temporary upmanning of the facility (for example during offshore commissioning) the arrangement will meet the regulatory requirements and will be subject to a separate risk assessment.

In addition, escape chutes and inflatable life rafts will be provided, with a total capacity sufficient for 100% of the maximum platform POB. The final quantity and arrangement will be determined based on the outcome of an Escape, Evacuation and Rescue Assessment (EERA) carried out during FEED or detailed design.

3.15 Operating and Maintenance Procedures

Operating and maintenance procedures will be developed to include the following activities amongst others:

- Loss Prevention Procedures.
- Environmental Monitoring Plans and Procedures.
- Ice Management Plan and Procedures.
- Drilling and Work-over Procedures.
- Production Operations Procedures.
- Offloading Procedures.
- Maintenance Procedures.
- Emergency Management Procedures and Response Plans.

3.16 Contingency Plans

ExxonMobil Canada has existing contingency plans for exploration activities on the Grand Banks plus other operating assets and these plans will be further developed and expanded to include the permanent GBS-based production, drilling and export facilities. The process for developing the Contingency Plan is outlined in the Comprehensive Study Report. More detail concerning contingency plans will be provided in the Operational Safety Plan.

4. Target Levels of Safety

The selection of clear design goals aimed at protecting personnel and the environment is fundamental to the design of offshore facilities. These design goals are known as Target Levels of Safety (TLS).

For the Hebron Project, TLS are specified with regard to risk to personnel and risk to the environment.

TLS provide a benchmark against which the results of the QRA can be assessed. Tolerability of risk to personnel is generally judged based on three risk 'regions', the boundaries of which are defined by the TLS:

- An upper region (intolerable region), which defines risk levels that are unacceptable, so that further safety measures must be taken.
- A lower region (broadly acceptable or 'negligible' region), which defines risk levels that are generally tolerable and there is no need for consideration of further safety measures.
- Between these upper and lower regions, an intermediate (ALARP) region where the risk may be tolerable, but it must be demonstrated that risk is 'As Low As Reasonably Practicable' (ALARP), that is, that no further credible risk reduction measures could be implemented cost-effectively.

4.1 Risk to Personnel

Risks to personnel will be measured in terms of Individual Risk (IR), which is a measure of the annual risk to an individual.

The target levels for risks to individuals on the installation will be:

- **Intolerable** IR > 1 x 10^{-3} per year.
- **ALARP** IR < 1 x 10^{-3} per year, but > 1 x 10^{-6} per year.
- **Negligible** IR < 1 x 10^{-6} per year.

If risks can be shown to be below the 'negligible' level, no further action is required.

If risks are not negligible, it will first be necessary to show that risks are below the intolerable level, and then to demonstrate that risks have been reduced to a level that is ALARP.

4.2 Environmental Risk

The design of the installation will comply with all corporate environmental policies and principles, and all applicable environmental regulations.

Environmental risks are subject to evaluation by regulatory authorities through the project registration and approval process in the Canadian Environmental Assessment Act (CEAA). These reviews include an evaluation of accidental events and operational discharges into the environment.

A Target Level of Safety in terms of risk to the environment will be defined quantitatively, for design purposes only, by development of a trigger to identify when further examination is required to determine whether additional steps should be taken to reduce the risks associated with a pollution incident.

The trigger value adopted for Hebron will be based on determination of whether an accident, malfunction or unplanned event is either "Significant" or "Not Significant" from an environmental perspective. The overall environmental impacts associated with the Hebron Project will be discussed in detail in the Hebron Project Comprehensive Study Report. The approach used by ExxonMobil is to identify Valued Environmental Components (VECs) and to evaluate the impact on such components against a number of subject variables, which include, for example, the frequency and size of a spill and the ability of the VEC to recover.

4.3 Impairment Criteria

In addition to the TLS outlined above, impairment criteria are specified, which will be used during the design phase to distinguish between possible accidental events that have the potential to escalate and affect personnel outside the immediate area of the accident and those that do not.

Provided that the impairment criteria are complied with during an accident, the accident is considered to have no potential to:

- Prevent personnel escaping from the event and mustering in the TSR.
- Threaten the structural integrity of the installation.
- Threaten the integrity of the TSR.
- Threaten the integrity of the means of evacuation within the time period required to safely evacuate personnel.

These impairment criteria will be developed and assessed in more detail, early in the FEED phase, in line with ExxonMobil corporate expectations, regulatory requirements and industry best practice.

5. Identification of Major Hazards

Hazard identification forms the basis of any risk assessment. If the hazards are not adequately identified, the risk assessment will be incomplete. To identify possible causes of accidents or precursors that may lead to accidental events, it is necessary to use information derived from industry experience. It is also necessary to ensure that small hazards are not overlooked. Only after due consideration of the consequences of the hazard and its potential for escalation should small hazards be discounted.

Whilst all potential accidents should be considered, the focus, in terms of identifying those hazards that it is appropriate to assess quantitatively, is on identifying Major Hazards. In this context, Major Hazards are commonly accepted as being fire and explosion events, and other accidental events that have the potential to result in multiple fatalities, either in the immediate area of the event or because they have the potential to escalate and result in fatalities outside the immediate area. Other accidental events are categorized as occupational hazards. These hazards affect one or a small number of personnel, for example trips, falls or electrocution.

It is clearly necessary to recognize occupational hazards, and to reduce the frequency and mitigate the consequences of such events. However it is not, in general, appropriate to assess these hazards quantitatively, particularly at the concept stage of a project, when information is inevitably limited. Measures in place for the monitoring, control and mitigation of occupational hazards and accidental events include:

- A comprehensive, auditable Safety Management System.
- Hazard identification and assessment studies, to be undertaken prior to commencing short-term work or introducing modifications to procedures or processes.
- Rigorous tracking procedures, to ensure that recommendations from such hazard identification and assessment studies are implemented as required.
- Provision of appropriate training to all personnel.
- Comprehensive incident reporting procedures and monitoring of incident records, providing feedback to update procedures, as required.

The hazard identification carried out for this risk assessment was based on a detailed review of standard Major Hazards that have been identified as a result of many years of similar operations experience. Reference was also made to previous hazard identification exercises carried out for the Project.

All stages of the Project were covered by the hazard identification. In particular, accidents during construction onshore, marine installation, hook-up and commissioning, pipe-laying, and drilling and production were considered. The intention is to achieve maximum onshore commissioning and to minimize the offshore hook-up workscope. Hazards identified that are specific to the construction and installation stages of the Project are, in general, categorized as occupational hazards but there is also the potential for Major Hazards associated with installation and integration activities such as GBS construction in drydock, GBS floatout, and GBS/topsides floatover mating. However, due to the infrequent (if not unique) nature of these activities, industry data is sparse and therefore insufficiently complete to allow an adequate and meaningful assessment of the associated risks until planning for these events is at a more defined stage. These activities will be of limited duration, will have clearly defined scope and will be the subject of thorough consideration and assessment prior to commencement to ensure identification and appropriate mitigation of all risks. Risks associated with these stages of the project are therefore not considered further here.

At the end of the production life of the Project, ExxonMobil will decommission and reclaim the site in accordance with the regulatory requirements. The GBS infrastructure will be decommissioned and the wells will be plugged and abandoned. The GBS structure will be designed for removal at the end of its useful life, although the decision as to whether this is required and justified will be made at that time. The OLS loading points will be removed and a decision will be made as to whether removal of the pipeline is required and justified in accordance with the regulations in place at that time. Again, these activities will be of limited duration, will have clearly defined scope and will be the subject of thorough consideration and assessment prior to commencement to ensure identification and appropriate mitigation of all risks. Hazards specific to these decommissioning activities are, therefore, not considered further here.

5.1 Potential Major Hazards Identified and Assessed

Hazards identified for the drilling and production phases of the Project are recorded in a Register of Identified Hazards (Ref. 1), which identifies the following Major Hazards as requiring consideration in the quantified risk assessment:

- Loss of Hydrocarbon Containment, resulting in:
  - Fire and smoke.
  - Explosion.
  - Unignited, potentially toxic, release.
- Blowout.
- Iceberg collision.
- Passing ship collision.
- Helicopter crash.
- Seismic activity.

Descriptions of each of these Major Hazards are given in Sections 7 to 10. Each hazard is described in terms of:

- Potential causes.
- Safeguards to prevent occurrence.
- Consequences and potential for escalation.
- Mitigating measures in place to minimize consequences.
- Impairment of main safety systems.

Dropped Objects (leading to loss of hydrocarbon containment) has not been quantitatively assessed in this Concept Safety Analysis, because it is assumed that the following measures will be taken to prevent a dropped object event resulting in a hydrocarbon release:

- Procedures to ensure that lifting devices are appropriately operated and maintained.
- Procedures to restrict lifts over equipment containing hydrocarbons.
- Decks over which lifting will occur designed to withstand most dropped loads.
- Appropriate procedures to restrict lifting heights where necessary.

In addition, the BOP will be within the DES and securely mounted to the DES such that travel from well to well may be accomplished in a manner that minimizes the risk associated with a dropped BOP, which is often one of the more significant dropped object hazards.

Note that dropped object events leading to loss of hydrocarbon containment are implicitly accounted for, as historical leak frequency data includes information on release events resulting from causes such as dropped objects and human error.

It is recommended that a dropped object study be carried out at detailed design stage, as sufficiently detailed information on lifting activities is not available at this stage of the Project, in order to ensure that proposed procedures are adequate and:

- Either confirm the above assumption that the risk due to dropped objects need not be explicitly quantified.
- Or identify events that should be considered in the design-stage QRA.

6. Basis of Hazard Assessment and Risk Assessment

The major hazards identified for the installation are listed in Section 5.1. The risk assessment for each of these major hazards is summarized in the following sections.

In the risk assessment outlined in the following sections, judgements have been made to estimate the likely number of statistical fatalities arising from each of the hazards considered. To ensure a conservative analysis, pessimistic judgements have been made where there is uncertainty in the data used, ensuring that worst case scenarios are considered in the assessment. In each case, the basis of the risk analysis is stated.

Fatalities are classified as:

- **Immediate Fatalities.** These are fatalities local to an event. For example, for ignited loss of containment events, immediate fatalities are those caused by the immediate thermal or overpressure effects of the ignited release in the area in which the release occurs.
- **Escape and Escalation Fatalities.** These are fatalities that occur outside the immediate area of an event either because an event escalates to affect personnel in adjacent areas or whilst personnel are escaping to the TSR.
- **Precautionary Evacuation Fatalities.** It is recognized in the risk assessment that the Offshore Installation Manager (OIM) would not necessarily wait for the TSR to be impaired before ordering an evacuation of the installation. Under certain circumstances, the OIM may order an evacuation by lifeboat as a precautionary measure. Precautionary evacuation fatalities include fatalities due to failure of the evacuation systems and fatalities whilst rescuing personnel from lifeboats or survivors from the sea.
- **TSR Impairment Fatalities.** These are fatalities that occur as a result of impairment of the installation's TSR. They also include any fatalities that occur during an evacuation of the installation in the event that the TSR is impaired.

6.1 Personnel Distribution

The anticipated personnel levels for the installation, during both the drilling and production and the (post-drilling) production phases, are shown in Table 6.1.

Platform Area/Level	Drilling and Production			Post Drilling (Production)		
	Day	Night	Average	Day	Night	Average
Process Area						
Cellar Deck	3	0	1.5	3	0	1.5
Lower Deck	3	0	1.5	3	0	1.5
Main Deck	3	2	2.5	3	2	2.5
Upper Deck	3	2	2.5	3	2	2.5
Process Area Total	**12**	**4**	**8**	**12**	**4**	**8**
Manifold/Export Pump Area						
Cellar Deck	1	1	1	1	1	1
Lower Deck	1	1	1	1	1	1
Manifold/ Export Pump Area Total	**2**	**2**	**2**	**2**	**2**	**2**
Wellhead/Intervention Area						
Cellar Deck	0	0	0	0	0	0
Lower Deck	7	7	7	3	3	3
Main Deck	7	7	7	4	4	4
Wellhead/Intervention Area Total	**14**	**14**	**14**	**7**	**7**	**7**
Mud Module/Drilling Support Module (DSM)	**15**	**15**	**15**	**0**	**0**	**0**
Gravel Pack Area and Drilling Offices	**35**	**15**	**25**	**0**	**0**	**0**
Drilling Equipment Set (DES)	**8**	**8**	**8**	**4**	**4**	**4**
Drillers' Pipe Deck	**2**	**2**	**2**	**0**	**0**	**0**
Power Generation Area	**2**	**1**	**1.5**	**2**	**1**	**1.5**
Utility Area (including Workshops)	**6**	**1**	**3.5**	**6**	**1**	**3.5**
Living Quarters/CCR	**138**	**172**	**155**	**92**	**106**	**99**
GBS Shaft	**0**	**0**	**0**	**0**	**0**	**0**
INSTALLATION TOTAL	**234**	**234**	**234**	**125**	**125**	**125**

Table 6.1: Personnel Distribution

The risks to which individuals are exposed during the time they spend on the platform vary according to the types of areas in which they work. In order to reflect this, the following worker groups have been defined:

- Management, admin, catering crew, who spend the majority of their time in the Living Quarters and very little (if any) time in areas where there are hydrocarbons present. Vendors/visitors who spend the majority of their time on the installation in the Living Quarters are also included in this worker group.
- Operations and maintenance crew, who spend a significant proportion of their working time in the Process Area, Utility Area or Power Generation Area. Vendors/visitors who spend a significant amount of time in these areas are also included in this worker group.
- Drilling/intervention crew, who spend the majority of their working time in areas of the installation associated with drilling and well operations, including the Wellbay/Intervention Area and DES.
- Construction crew, who undertake ad hoc engineering/construction projects, and may work in any area of the installation.

Based on the personnel distribution given in Table 6.1, Table 6.2 and Table 6.3 give the personnel distribution, by worker group, for the Hebron installation.

Location	**Management/ Admin/ Catering**	**Operations & Maintenance**	**Drilling/ Intervention**	**Construction**
Process Area	0.5	4.5	0	3
Wellbay/ Intervention Area	0	2.5	13	0.5
DSM	0	0	15	0
Gravel Pack Area/Drilling Offices	0	0	25	0
DES	0	0	8	0
Drillers’ Pipe Deck	0	0	2	0
Power Generation	0	1.5	0	0
Utility Areas	0	2.5	0	1
Living Quarters/CCR	57.5	27	63	7.5
Total POB	**58**	**38**	**126**	**12**

Table 6.2: Personnel Distribution by Worker Group (Drilling and Production Phase)

Location	Management/ Admin/ Catering	Operations & Maintenance	Drilling/ Intervention	Construction
Process Areas	0.5	4.5	0	3
Wellbay/ Intervention	0	2.5	6	0.5
DES	0	0	4	0
Power Generation	0	1.5	0	0
Utility Areas	0	2.5	0	1
Living Quarters/CCR	47.5	27	17	7.5
Total POB	**48**	**38**	**27**	**12**

Table 6.3: Personnel Distribution by Worker Group (Production Only Phase)

6.2 Platform Layout

Because of the stage of the Project, some key aspects of the design, including the rating of fire and blast divisions, have not yet been finalized. This assessment is therefore based on an assumed concept layout, as described in Section 3.11, which is considered sufficiently representative but the details of which may still be refined.

For the purposes of this assessment, it is assumed that the ratings of fire walls are sufficient to prevent escalation of a fire to an adjacent area within the time required for personnel to escape that area. It is also assumed that blast walls will be designed to withstand predicted worst case overpressures and prevent escalation to adjacent areas.

Further analysis will be required at detailed design stage, when more information is available on other aspects of the Project, in order to ensure that the final design is practicable and affords a high level of protection for personnel.

The selected design will, of course, as a minimum, meet prescriptive regulatory requirements and be such that risks can be demonstrated to be As Low As Reasonably Practicable (ALARP).

7. Process Loss of Containment Events

Loss of hydrocarbon containment can result in several possible outcomes (for example, a fire, an explosion or an unignited, potentially toxic, release). This is because the actual outcome depends on other events that may or may not occur following the initial release. Event Tree Analysis is therefore used to identify the potential outcomes of a hydrocarbon release and to quantify the risk associated with the outcomes. A representative loss of hydrocarbon containment event tree is shown in Appendix 1. In the event trees, the following branch events are considered:

- Non-explosive ignition.
- Fire or gas detection.
- Inventory isolation/blowdown.
- Deluge.
- Explosive ignition.
- Explosion overpressure.

The event tree branches enable the following factors to be taken into account:

- Whether ignition occurs and the timing of an ignition (relative to the time of release).
- Any benefit provided by the facility's safety systems.

If a release ignites rapidly, a jet fire is likely to result. Alternatively, a gas cloud may accumulate before ignition, resulting in an explosion or flash fire.

The risk to personnel, in terms of Theoretical Annual Loss of Life (TALL), from each event tree outcome is the product of the frequency of that outcome and its consequence (in terms of statistical fatalities). The risk from a particular release event is the total risk from its identified outcomes.

Each outcome frequency is derived by estimating:

- The frequency of the initiating event (the release event).
- The probability of each of the events represented by the event tree branches leading to that outcome.

The consequence of an outcome is determined by:

- Modelling the physical conditions produced by the fire event, explosion or unignited release.
- Assessing the impact of those conditions on personnel, in terms of potential statistical fatalities.

7.1 Hydrocarbon Release Frequencies

7.1.1 Event Leak Frequencies

Wells are to be drilled from the installation, using the platform's drilling rig, during the early years of production. Since the frequency of loss of hydrocarbon containment from the production manifolds and gas lift manifold, for example, will depend on the number of wells in production, two risk estimates are made to account for this. The first is representative of the drilling and production phase (assumed to be the years up to and including 2025) and the second representative of the subsequent production only phase of the project when all drilling activities have ceased.

Ref. 1 identifies 66 process hydrocarbon release events. The leak frequencies for these events, during the drilling and production phase, are summarized in Tables 7.1a, 7.1b, 7.1c and 7.1d.

Release Event	Type of Equipment	Frequency Per Year
Cellar Deck – Process Area Release From:		
Crude Oil Pumps	Pump, Centrifugal	3.06×10^{-2}
Export Pumps	Pump, Centrifugal	4.59×10^{-2}
Fiscal Metering Skid	Metering, oil	3.69×10^{-2}
Flare KO Drum (Gas)	KO Drum	1.09×10^{-2}
Flare KO Drum and Pumps (Liq)	KO Drum + Pump, Reciprocating	2.62×10^{-2}
	Total	$\mathbf{1.51 \times 10^{-1}}$
Lower Deck – Process Area Release From:		
Oil/Water Separator	Separator	1.12×10^{-3}
LP Inlet Heater	Heat Exchanger, Shell & Tube HC in Shell	7.97×10^{-3}
Compact Electrostatic Coalescer	Pressure Vessel, Vertical	7.47×10^{-3}
Crude Oil Cooler	Heat Exchanger, Plate Type	1.77×10^{-2}
Oil/Oil Exchanger – Downstream from MP Separator	Heat Exchanger, Plate Type	1.77×10^{-2}
Oil/Oil Exchanger – Downstream from Crude Oil Pumps	Heat Exchanger, Plate Type	1.77×10^{-2}
MP Inlet Heater	Heat Exchanger, Shell & Tube HC in Shell	7.97×10^{-3}
Fuel Gas Scrubber	Scrubber	1.79×10^{-3}
Fuel Gas Heater	Heat Exchanger, Plate Type	1.77×10^{-2}
Fuel Gas Calorimeter	Metering, Gas	2.89×10^{-2}
Power Generator Turbine and Compressor Turbine Fuel Gas Filter/Scrubber Packages	Filter	1.17×10^{-2}
TEG Flash Drum (Gas)	KO Drum	1.09×10^{-2}
Stripping Gas Column (Gas), Still Column (Gas) and Vent Cooler	2 x Pressure Vessel, Vertical, Heat Exchanger, Plate Type	3.26×10^{-2}
TEG Vent Scrubber	Scrubber	1.79×10^{-3}
TEG Vent Blower	Compressor, Centrifugal	1.88×10^{-2}
OLS Pig Launchers/Receivers	Pig Launcher/Receiver	2.34×10^{-2}
	Total	$\mathbf{2.25 \times 10^{-1}}$

Table 7.1a: Release Events on the Cellar Deck and Lower Deck of the Process Areas

Release Event	Type of Equipment	Frequency Per Year
Main Deck – Process Area Release From:		
LP Separator (Gas)	Separator	1.12×10^{-3}
LP Separator (Liquid)	Separator	1.12×10^{-3}
MP Separator (Gas)	Separator	1.12×10^{-3}
MP Separator (Liquid)	Separator	1.12×10^{-3}
LP Compression 1st Stage Suction Scrubber	Scrubber	1.79×10^{-3}
LP Gas Compressor (1st Stage)	Compressor	1.88×10^{-2}
LP Compression 2nd Stage Suction Scrubber	Scrubber	1.79×10^{-3}
LP Gas Compressor (2nd Stage)	Compressor	1.88×10^{-2}
MP Compression Suction Scrubber	Scrubber	3.57×10^{-3}
MP Gas Compressor	Compressor	3.75×10^{-2}
HP Compression Suction Scrubber	Scrubber	3.57×10^{-3}
HP Gas Compressor	Compressor	3.75×10^{-2}
Gas Lift Compression Suction Scrubber	Scrubber	3.57×10^{-3}
Gas Lift Gas Compressor	Compressor	3.75×10^{-2}
Gas Injection Compression Suction Scrubber	Scrubber	1.79×10^{-3}
Gas Injection Compressor	Compressor	1.88×10^{-2}
Dehydration Contactor	Pressure Vessel, Vertical	7.47×10^{-3}
Dehydration Scrubber	Scrubber	1.79×10^{-3}
Dehydration Filter Coalescer	Filter	5.85×10^{-3}
Produced Water Degassing Drum (Gas)	Pressure Vessel, Horizontal	1.12×10^{-3}
TEG Vent and Flash Gas to LP Suction Cooler	Piping	6.85×10^{-3}
	Total	$\mathbf{2.13 \times 10^{-1}}$

Table 7.1b: Release Events on the Main Deck of the Process Area

Release Event	Type of Equipment	Frequency Per Year
Upper Deck – Process Area Release From:		
HP Separator (Gas)	Separator	1.12×10^{-3}
HP Separator (Liquid)	Separator	1.12×10^{-3}
MP Test Separator (Gas)	Separator	1.12×10^{-3}
MP Test Separator (Liquid)	Separator	1.12×10^{-3}
MP Test Separator Inlet Heater	Heat Exchanger, Shell & Tube HC in Shell	7.97×10^{-3}
HP Test Separator (Gas)	Separator	1.12×10^{-3}
HP Test Separator (Liquid)	Separator	1.12×10^{-3}
HP Test Separator Inlet Heater	Heat Exchanger, Shell & Tube HC in Shell	7.97×10^{-3}
LP Compression 1st Stage Suction Cooler	Heat Exchanger, Plate Type	1.77×10^{-2}
LP Compression 2nd Stage Suction Cooler	Heat Exchanger, Plate Type	1.77×10^{-2}
MP Compression Suction Cooler	Heat Exchanger, Plate Type	3.54×10^{-2}
HP Compression Suction Cooler	Heat Exchanger, Shell & Tube HC in Shell	1.59×10^{-2}
Gas Lift Compression Recycle Cooler	Heat Exchanger, Shell & Tube HC in Shell	1.59×10^{-2}
Gas Injection Compression Suction Cooler	Heat Exchanger, Shell & Tube HC in Shell	7.97×10^{-3}
Dehydration Inlet Cooler	Heat Exchanger, Shell & Tube HC in Shell	7.97×10^{-3}
Gas/Glycol Heat Exchanger	Heat Exchanger, Shell & Tube HC in Tube	4.94×10^{-3}
Gas Lift Cooler	Heat Exchanger, Shell & Tube HC in Shell	7.97×10^{-3}
	Total	$\mathbf{1.54 \times 10^{-1}}$
Cellar Deck – Wellhead/Manifold Area Release From:		
Crude Recirculation Heater	Heat Exchanger, Plate Type	1.77×10^{-2}
	Total	$\mathbf{1.77 \times 10^{-2}}$
Upper Deck – Power Generation Area Release From:		
Main Power Generators	Turbine	1.73×10^{-1}
	Total	$\mathbf{1.73 \times 10^{-1}}$

Table 7.1c: Release Events on the Upper Deck of the Process Area, on the Cellar Deck of the Wellhead/Manifold Area and in the Power Generation Area

Release Event	**Type of Equipment**	**Frequency Per Year**
Lower Deck – Wellhead/Manifold Area Release From:		
HP Production/Test Manifolds	Flowlines, Manifold, Flanges and Valves	6.05×10^{-2} **(1)**
MP Production/Test Manifolds	Flowlines, Manifold, Flanges and Valves	1.51×10^{-1} **(1)**
Gas Lift Manifold	Flowlines, Manifold, Flanges and Valves	1.26×10^{-1} **(1)**
Distribution Manifold	Manifold	1.55×10^{-2}
Recirculation/Offloading Manifold	Manifold	1.55×10^{-2}
	Total	$\mathbf{3.69 \times 10^{-1}}$
	Platform Total	**1.30**

(1) The leak frequencies for these events vary depending on the phase of operation, see text in Section 7.1.1 and Table 7.1e.

Table 7.1d: Release Events on the Lower Deck of the Wellhead/Manifold Area

The release frequency for each event in Tables 7.1a, 7.1b, 7.1c and 7.1d is estimated based on hydrocarbon leak frequency data provided in Ref. 2 for various individual items of equipment (e.g. pressure vessels, pumps). To account for piping, flanges, valves and instrument tappings, the equipment frequencies were increased, where appropriate, by 50% for use in the risk assessment.

It is recommended that consideration be given to undertaking a parts count, based on piping and instrumentation drawings, at detailed design stage in order to refine the leak frequency estimates and more accurately reflect the equipment associated with each inventory.

The leak frequencies for the production/test manifolds and gas lift manifold will depend on the number of wells in production. The leak frequencies for these inventories, summarized in Table 7.1d and 7.1e, are based on the following assumptions:

- 1 gas injection well, up to 3 HP production wells and a representative 14 MP production wells are in operation during the drilling and production phase. (This well count is used to ensure an appropriately conservative, but not worst case, assessment of risks during this phase of the project.)
- 2 gas injection wells, up to 6 HP production wells and up to 19 MP production wells are in operation during the production only phase.
- Each of the production wells uses gas lift.

Consequently, the leak frequencies for the production/test manifolds and the gas lift manifold during the production only phase, given in Table 7.1e, are different to those given in Table 7.1d.

Release Event	Type of Equipment	Frequency Per Year
Lower Deck – Wellhead/Manifold Area Release From:		
HP Production/Test Manifolds	Flowlines, Manifold, Flanges and Valves	7.59×10^{-2}
MP Production/Test Manifolds	Flowlines, Manifold, Flanges and Valves	1.82×10^{-1}
Gas Lift Manifold	Flowlines, Manifold, Flanges and Valves	1.76×10^{-1}
Distribution Manifold	Manifold	1.55×10^{-2}
Recirculation/Offloading Manifold	Manifold	1.55×10^{-2}
	Total	$\mathbf{4.69 \times 10^{-1}}$

Table 7.1e: Production/Test Manifolds and Gas Lift Manifold Leak Frequencies During Production Only Phase

The platform leak frequency during the production only phase is 1.40 per year.

7.1.2 Selection of Representative Hole Sizes

A major factor influencing the characteristics of a release is the hole size. In conjunction with inventory conditions such as pressure, hole size determines the initial hydrocarbon mass release rate and hence, if the release is ignited, the size of the resulting fire. Hole size and release rate are also factors in determining the release duration.

In reality, a continuum of hole sizes is possible. In order to rationalize hydrocarbon risk assessment, it is industry practice to select three distinct hole sizes (described as ‘small’, ‘medium’ and ‘large’) to be representative of the range of possible hole sizes.

Based on an in-house study (Ref. 3) of historical hole size data (Ref. 4) and a representative offshore installation parts count, representative hole sizes and an associated hole size distribution were selected for this risk assessment, see Table 7.2.

Representative Hole Size		Range Represented	Percentage of Leaks Allocated
Small	7mm	0 – 14mm	91
Medium	33mm	14 - 52mm	6
Large	76mm	52mm +	3
		Total:	100

Table 7.2: Representative Hole Sizes and Distribution

Therefore, for each of the release events identified in Tables 7.1a, 7.1b, 7.1c and 7.1d, three event trees are actually used in the risk assessment, one for each of the Small, Medium and

Large hole sizes. A proportion of the total leak frequency for each release event is allocated to the event tree for each representative hole size according to the distribution shown in Table 7.2.

7.2 Ignition Probability

An ignition probability is calculated for each release event based on the initial mass release rate, using the UKOOA ignition model (Ref. 5). The UKOOA ignition model assesses the probability of ignition of hydrocarbon releases for use in QRAs by combining established data and methods on gas build up, gas dispersion, area and ignition source characteristics, etc. The model estimates the volume or area of flammable gas or liquid in a given plant area, and then combines this with suitable ignition source densities to calculate the overall ignition probability.

The model includes data on ignition of both gas and oil releases, as well as on the probability of explosion in the case of gas releases. Representative ignition and explosion probabilities are given in Tables 7.3 and 7.4, respectively.

Release Rate	**Ignition Probability**	
	Gas	**Oil**
Minor (<1kg/s)	0.0038	0.0021
Major (1-50kg/s)	0.0240	0.0070
Massive (>50kg/s)	0.0400	0.0175

Table 7.3: Representative Ignition Probabilities (Ref. 5)

Release Rate	**Explosion Probability**[1]
Minor (<1kg/s)	0.04
Major (1-50kg/s)	0.12
Massive (>50kg/s)	0.3

(1) For gas release, given that ignition occurs

Table 7.4: Representative Explosion Probabilities (Ref. 5)

Mass release rates are estimated for each release event using DNV's consequence modelling software package, PHAST, based on hole size and stream composition, temperature and pressure. Stream data used in the consequence modelling and results from PHAST are presented in Appendix 12.

In order to estimate the ignition probability for 2-phase releases, the process gas ignition model from Ref. 5 is conservatively used as, for a given mass release rate, the probability of ignition for a gas release is generally higher than that for an oil release. For gas and 2-phase streams that contain a significant proportion of water, the mass release rate assumed is calculated by deducting the water mass release rate from the total mass release rate.

If liquid inventories containing a significant proportion of lighter hydrocarbons at relatively high temperature and pressure are released to the atmosphere, these lighter hydrocarbons may flash off as gas, making an explosion a credible event. Therefore, for liquid releases from the HP Separator and the HP Test Separator, an 'equivalent' gas mass release rate is calculated, based on the liquid mass release rate and the proportion of lighter hydrocarbon fractions contained within the liquid released, and this is used as the basis for estimating explosion probabilities for these inventories. It is not considered that explosion is a credible event for other liquid inventories.

In the event trees (see Appendix 1), the first branch represents ‘non-explosive’ ignition. Non-explosive ignition events are represented as fire events, because sufficient time is unlikely to elapse to allow a gas/air mixture to accumulate and cause an explosion. The probability of non-explosive ignition is calculated as the total ignition probability minus the probability of an explosion (the product of the ‘explosion probability’ as in Table 7.4 and the total ignition probability).

The probability of explosive ignition required in the event trees (fifth branch) is the probability of explosive ignition given that non-explosive ignition did not occur.

7.3 Fire and Gas Detection Probability

Fire and gas detection probabilities are estimated based on historical failure data for fire and gas detectors (Ref. 6 and Ref. 7). These probabilities account for the probability that a gas release will be out of range of a detector or a fire will be obscured from a detector (the Test Independent Failure (TIF) probability), as well as the probability that the detector will fail to operate on demand.

The fire and gas detection probabilities calculated, based on the Ref. 6 and Ref. 7 data, for use in the event tree risk assessment are shown in Table 7.5. In each case, probabilities are calculated for small and large releases, and the probability for medium releases is assumed to be the average of these two.

Representative Hole Size	Detection Probability	
	Gas	Fire
Small (7mm)	0.9	0.75
Medium (33mm)	0.95	0.87
Large (76mm)	0.99	0.99

Table 7.5: Fire and Gas Detection Probabilities

Any attempt to link detection probability to release rate (rather than hole size) is considered spurious accuracy because of the quality of the historical data available on TIF probabilities, which is quoted only as a range between 0.0003 and 0.5 for fire detectors and between 0.0003 and 0.1 for gas detectors.

7.4 Inventory Isolation and Blowdown Probability

Each event tree represents a release from a specific isolatable section (inventory) of the process train. The probability of the inventory being isolated and de-pressurized (‘blown down’) on an Emergency Shutdown is determined by three factors:

- The number of Emergency Shutdown Valves (ESVs) that must close.
- The number of blowdown valves that must open.
- The probability that each valve will operate successfully on demand.

Ref. 7 gives failure rate data for ESVs. Although the regulations require monthly testing, a three month test interval is conservatively assumed in calculating a probability of failure on demand for an ESV of 0.04, based on the Ref. 7 data. This failure probability is also assumed here for blowdown valves. Therefore, the probability that a single valve operates on demand is 1 – 0.04 = 0.96.

For the purposes of this CSA, it is assumed that a process inventory (other than a manifold inventory) is successfully isolated and blown down if two ESVs and one blowdown valve operate successfully. Therefore, the probability of successful isolation and blowdown of a typical process inventory is $0.96^3 = 0.885$.

When calculating the isolation probability for manifold inventories, the number of flowlines is taken into account in determining the number of valves that must close to successfully isolate the inventory. In addition, credit is taken, in the case of production/test manifold inventories, for the fact that there are a number of valves associated with each well that can provide isolation and that failure to shut in the well requires failure of all of these valves.

It is expected that an assessment of the number of valves that would have to operate successfully to ensure isolation of each inventory would be undertaken for the detailed QRA to be performed at design stage, once Piping and Instrumentation Diagrams are available. A sensitivity study undertaken (outlined in Section 12) to investigate the impact on overall risk levels of varying the number of valves assumed, however, indicated that the assumptions outlined above are robust and appropriate at this stage.

7.5 Deluge Probability

The event tree risk assessment is based on the assumption that deluge will be initiated on successful fire detection, but not on gas detection.

The probability that the deluge system does not operate on demand is assumed, in the risk assessment to be 0.015. This is based on reliability data for modern deluge systems quoted in Ref. 4.

7.6 Explosion Overpressure Probability

The explosion overpressure branches provided in the process loss of containment event tree structure in Appendix 1 enable each explosive ignition event to be represented by four possible outcomes, where each outcome is representative of an explosion within a specific range of overpressure. This is necessary because the consequence of an explosion depends on the overpressure produced.

There are several explosion overpressure 'thresholds' of interest with respect to the risk assessment:

- Threshold 1 (T1): 0.2 bar. This is the explosion overpressure above which all personnel in the area in which the explosion occurs are considered, in the risk assessment, to be fatally injured by the explosion.
- Threshold 2 (T2): 1.0 bar. This is the overpressure above which it is considered that bulkheads and partitions (e.g. decks) may fail, resulting in escalation of the effects of the explosion to other platform areas.
- Threshold 3 (T3): 2 bar. This is the overpressure above which it is assumed that structural steel in the affected area may fail, leading to impairment of the platform structure in the vicinity of the explosion.

The four overpressure ranges defined by the three overpressure thresholds are therefore:

- Explosion overpressure is between 0 and 0.2 bar.
- Explosion overpressure is between 0.2 bar and 1 bar.
- Explosion overpressure is between 1 bar and 2 bar.
- Explosion overpressure is greater than 2 bar.

The probability that an explosion in an area exceeds each of the thresholds is determined from explosion overpressure exceedence 'curves'. These 'curves' are generated assuming a linear relationship between the exceedence probability and overpressure, and accounting for an assumed worst case overpressure. Based on explosion modelling performed using DNV's consequence modelling software package, PHAST, the worst case maximum overpressure is taken to be:

- 2.0 bar in the Process Area and Power Generation Area.
- 0.5 bar in the Wellhead/Manifold and Intervention Areas.

The explosion overpressure branch probabilities used in the event trees are estimated based on the exceedence probabilities and are given in Table 7.6.

Location	**Overpressure Range**	**Probability**
Process/Power Generation Areas	< 0.2 Bar	0.10
	0.2 Bar to 1.0 Bar	0.40
	1.0 Bar to 2.0 Bar	0.50
	> 2.0 Bar	0.00
Wellhead/Manifold Area	< 0.2 Bar	0.40
	0.2 Bar to 1.0 Bar	0.60
	1.0 Bar to 2.0 Bar	0.00
	> 2.0 Bar	0.00

Table 7.6: Overpressure Probabilities

7.7 Consequence Assessment

As discussed in Section 6, fatalities are classified as immediate fatalities, escape/escalation fatalities, precautionary evacuation fatalities and TSR impairment fatalities. For this assessment of loss of containment events, the following types of fatalities are discussed:

- Immediate fatalities due to non-explosive ignition (fires).
- Immediate fatalities due to explosions.
- Immediate fatalities due to toxic gas.
- Escape and escalation fatalities.
- Precautionary evacuation and TSR impairment fatalities.

7.7.1 Immediate Fatalities due to Non-Explosive Ignition (Fires)

A jet fire is likely to result if a gas release ignites rapidly. A flash fire occurs when a cloud of gas burns without generating any significant overpressure. The duration of the flash fire is likely to be relatively short, but it may stabilize as a continuing jet fire from the leak source. The size of the gas cloud may be calculated using gas dispersion models, but Ref. 4 indicates that, with the exception of passive releases in low wind speeds, the gas cloud size is smaller than the effect zone from a jet fire. As a result, many studies model only the ensuing jet fire. Since the impact area of the jet fire that may follow an initial flash fire is, in almost all cases, larger than the gas cloud size, this approach results in a conservative estimate of fatalities and is adopted in this assessment.

Thermal radiation from a hydrocarbon fire is a significant hazard to personnel. The degree of injury caused by thermal radiation is related to the intensity of the thermal radiation and the exposure time.

Ref. 4 discusses typical thermal radiation criteria for use in offshore risk assessment:

- 12.5kW/m^2 is taken as the limiting radiation intensity for escape actions lasting a few seconds. At this level, the pain threshold is reached in about 4 seconds, and second degree burns on exposed skin in about 40 seconds.
- 37.5kW/m^2 is taken as the criterion for immediate fatality. At this level, the pain threshold is virtually instantaneous and second degree burns occur on exposed skin in about 8 seconds.
- Between 12.5 and 37.5kW/m^2 personnel are assumed to be able to use escape routes, provided that this allows them to leave the area within a few seconds, but they may suffer second degree burn injuries.

Personnel exposed initially to heat radiation less than 37.5kW/m^2 may be seriously or even fatally injured if their escape from the effects of the radiation is not rapid. For radiation of 25kW/m^2, pain is virtually instantaneous, second degree burns occur within approximately 12 seconds, third degree burns after approximately 30 seconds and ‘50% lethality’ very soon after (Ref. 4).

It is considered, in this risk assessment, that all personnel within the 25kW/m^2 heat flux contour around a fire are fatally injured. The area bounded by this contour is referred to as the ‘Fatality Area’, and outside this contour it is assumed that personnel are able to escape the immediate vicinity of the fire.

The 25kW/m^2 heat flux contour represents a larger area than that corresponding to the 37.5kW/m^2 heat flux stated as the criterion for ‘immediate fatality’ above. The 25kW/m^2 heat flux contour is used to conservatively account for the fact that personnel outside the

37.5kW/m^2 heat flux may still be sufficiently injured that they cannot effectively escape within 'a few seconds', as stipulated above.

The consequences of event tree outcomes that represent non-explosive ignition events are therefore modelled, using DNV's consequence modelling software package, PHAST, as follows:

- A mass release rate is determined, based on representative inventory conditions identified for the release location.
- From the mass release rate, jet fire dimensions and the resulting 'Fatality Area' are determined.

Immediate fatalities from jet fires are calculated as:

$$\text{Fatalities} = \text{Fatality Area x Population Density}$$

If the Fatality Area for a release is greater than the area of the section of deck in which the release occurs, the number of personnel in the area is taken as an upper bound on the number of immediate fatalities.

Population Density is a characteristic of the area of the platform in which the release event occurs. It is calculated as:

$$\text{Population Density} = \frac{\text{Number of Personnel in Release Location}}{\text{Area of Release Location}}$$

The assumed number of personnel in each area of the platform is detailed in Table 6.1.

Details on the number of fatalities estimated for each identified release event are given in Appendix 2.

7.7.2 Immediate Fatalities due to Explosions

If ignition of a hydrocarbon release is delayed, a gas/air mixture may accumulate prior to ignition and an explosion could result.

Ref. 8 gives fatality probabilities, reproduced in Table 7.7, for the effects of explosion overpressure on personnel.

Explosion Overpressure (Bar)	Fatality Probability
0 to 0.07	0
0.07 to 0.21	0.1
0.21 to 0.34	0.25
0.34 to 0.48	0.7
> 0.48	0.95

Table 7.7: Effect of Overpressure on Fatality Probability

Ref. 4, however, suggests that, irrespective of the overpressure produced, personnel that are caught in a burning gas cloud are likely to be fatally injured from thermal effects. For a large gas cloud that ignites after filling an area, this suggests that all personnel in that area will be fatally injured.

However, not all explosions will result from a gas cloud that fills an area. In fact, for many small releases the gas cloud will occupy only a small proportion of the volume of an area at the time of ignition. Worst case overpressures generated by explosions resulting from small releases will also, in general, tend to be fairly low.

To take account of both the thermal effects and overpressure produced by an explosion, the rule set in Table 7.8 is, therefore, used to estimate immediate fatalities for explosion events.

Explosion Overpressure	Fatality Probability	
	Not Detected	Detected
<0.2 Bar	0.5	0.25
>0.2 Bar	1.0	0.5

Table 7.8: Explosion Immediate Fatality Rule-Set

For releases that are successfully detected, it is assumed that there is a probability of 0.5 that personnel escape from the area before ignition occurs.

The rule set gives the probability of fatality to be applied to each person in the platform area affected by the explosion.

Details on the number of explosion fatalities estimated for each identified release event are given in Appendix 3.

For the purposes of this concept study, the rule set detailed in this section is based on release size, rather than release rate. It may be necessary, at detailed design stage, to review the above qualitative assessment in a detailed explosion modelling analysis and revise the risk assessment accordingly.

7.7.3 Immediate Fatalities due to Toxic Gas

Although H_2S (a toxic gas) is not expected to be present in the initial years of production, some well souring is predicted in later years.

H_2S has an odour of rotten eggs at low concentrations, but the smell is not noticeable above 150ppm. At moderate concentrations it is irritating to the eyes and respiratory tract, whilst higher concentrations can cause respiratory paralysis and rapid death. Review of data available on the effects of H_2S, and in particular recent guidance produced by the UK Health and Safety Executive, indicates that exposure to H_2S concentrations of:

- Approximately 300ppm to 500ppm could lead to pulmonary edema with the possibility of death.
- Approximately 500ppm to 1000ppm causes strong stimulation of the central nervous system and rapid breathing, leading to loss of breathing and death over a period of several minutes.
- Over 1000ppm can lead to immediate collapse and loss of breathing, even after a single breath.

For the purposes of this assessment, it is therefore conservatively assumed that exposure to an H_2S concentration of 500ppm or above will result in fatality.

Once H_2S is released it disperses, mixing with the surrounding air and reducing in concentration. Therefore, it is not considered that a release has the potential to result in fatalities due to toxic gas if the concentration of H_2S in the stream is less than 600ppm.

Work done to date indicates that H_2S is unlikely to be encountered in produced well fluids on Hebron before 2034 and this assessment does not therefore consider the potential for fatalities due to toxic gas during the drilling and production phase of the project. However, analysis of potential acid gas concentrations during later years indicates that concentrations of up to 40,000ppm are possible in certain process streams (Ref. 9). Estimation of toxic gas fatalities for the production only phase is conservatively based on the worst case concentrations predicted in Ref. 9, those for the year 2045.

Events considered, during the production only phase, to have the potential to result in fatalities due to toxic gas are releases from the:

- LP separator (gas releases only).
- Fuel gas scrubber.
- Fuel gas heater.
- LP gas compression train (1^{st} and 2^{nd} stage).
- Dehydration filter coalescer.
- TEG flash drum (gas releases only).

- Stripping gas column.
- TEG still column.
- TEG vent cooler.
- TEG vent scrubber.
- TEG vent blower.
- TEG vent and flash gas to 1st stage LP suction cooler.
- Produced water degassing drum (gas releases only).

For each identified release event, a Fatality Area is determined based on dispersion modelling undertaken using PHAST to estimate the area occupied by the gas cloud with an H_2S concentration above 500ppm.

Immediate fatalities from toxic releases are then estimated, taking into account the Population Density calculated as described in Section 7.7.1, as:

Fatalities = Fatality Area x Population Density

Details of the dimensions of the toxic gas clouds for the release events considered and the corresponding fatality estimates are given in Appendix 12.

7.7.4 Escalation Fatalities due to Impairment of Fire and Blast Walls

Fatalities may also occur, outside the immediate area of an event, if the event rapidly escalates due to impairment of walls or decks.

The length of the topsides will provide the maximum separation between the hazardous and non-hazardous areas, with the process module at the East end of the platform and the Living Quarters at the West end of the platform. It is assumed that appropriate fire and blast-rated divisions will also be provided in order to minimize escalation and to ensure sufficient protection for personnel in the TSR.

As a result, no escalation fatalities are accounted for in fire (non-explosive ignition) scenarios resulting from process loss of containment events.

Explosion events may, however, have the potential to escalate to adjacent areas, if the blast overpressure is sufficient to breach boundaries (module walls and/or decks).

The rule set in Table 7.9 is used to estimate escalation fatalities resulting from explosions. For releases that are successfully detected, it is assumed that there is a probability of 0.5 that personnel leave the area before ignition occurs.

Overpressure Range	**Fatality Probability in Adjacent Areas (not Protected by Blast Rated Wall/Deck)**	
	Not Detected	**Detected**
< 0.2 Bar	0	0
0.2 Bar to 1.0 Bar	0	0
1.0 Bar to 2.0 Bar	0.5	0.25
> 2.0 Bar	1.0	0.5

Table 7.9: Explosion Escalation Fatality Rule Set

It is assumed, for the purposes of this CSA, that blast walls will be designed to withstand the predicted worst case overpressures. The rule set in Table 7.9 gives the probability of fatality to be applied to any personnel in adjacent platform areas not protected by blast rated boundaries, which could be affected by the explosion.

Details of the number of explosion fatalities estimated for each identified release event are given in Appendix 3.

The assumption that blast walls will be designed to withstand predicted worst-case overpressures should be reviewed at design stage and detailed studies performed if necessary.

7.7.5 Escape Fatalities

The risk assessment accounts for escape fatalities in a scenario for which it is considered that both routes from an area may become impassable. For example, a sufficiently large fire in an area could impair the escape routes at the side of the platform adjacent to the event by heat/flames. Then, if the wind direction is towards the other side of the platform, escape routes at that side could be affected by smoke.

On the Cellar Deck, Lower Deck and Main Deck of the platform, there will be two continuous escape routes running from the Process Area to the Living Quarters. Personnel escaping from the Upper Deck and Drillers' Pipe Deck will have to escape to the lower decks to proceed to the Living Quarters or use the escape routes across the DES and/or the Intervention Area roof to gain access to the Utility Area. On all levels, there will be escape routes in the North-South direction, connecting the escape routes on the periphery of the platform. There will also be two sheltered continuous escape routes below the Cellar Deck running from the East of the platform to the Living Quarters at the West of the platform.

There will be one open and one closed stair tower at the East end of the installation, as well as one open stair tower on the North and one open stair tower on the South side of the Drilling Module. These stair towers will provide access from the Upper Deck to the sheltered escape routes below the Cellar Deck.

The muster area is located on Level 1 of the Living Quarters, within the TSR. The Living Quarters can be accessed from the Cellar Deck, Lower Deck or Main Deck. There are two fully enclosed stair towers at either end of the Utility Area and three stair towers within the Living Quarters that provide access from all levels below the helideck to the TSR.

Taking into account the location of and redundancy in escape routes, it is considered unlikely that both escape routes from any area will be impaired by a fire, explosion or toxic gas release event. Main escape routes are plated, covered in non-skid yellow paint and will be heat traced to prevent build up of ice. There will also be at least one lifeboat provided at the East side of the Process Area, to enable personnel unable to reach the TSR to evacuate, if necessary.

Based on the above discussion, this risk assessment does not account for any escape fatalities. However, as the design of the Hebron facility is still at a relatively early stage, details of escape routes have not yet been finalized. It will be necessary, at detailed design stage, to review the above qualitative assessment in a detailed escape, evacuation and rescue study, and to revise the risk assessment accordingly.

7.7.6 Precautionary Evacuation and TSR Impairment Fatalities

In most hazardous loss of containment scenarios, personnel who muster will remain in the TSR until the event is under control. In extreme scenarios, however, the integrity of the TSR may be threatened. In some cases, the TSR and/or lifeboat evacuation systems may become impaired.

This section considers risk to personnel from TSR/evacuation system impairment due to the following mechanisms:

- Smoke ingress.
- Gas ingress (either toxic gas or flammable gas leading to potential for an explosion within the TSR).
- High temperature.
- External explosions.
- Structural impairment.

For each mechanism, events that could cause impairment (if they occur coincident with other unfavourable conditions) are identified.

Event tree analysis is then used to identify the hazardous TSR conditions that could result from the impairment mechanism. For example:

- A threat to TSR integrity, leading to a precautionary lifeboat evacuation.
- Impairment of TSR and/or evacuation systems, leading to an emergency evacuation.

An estimate is made of the potential fatalities for each hazardous TSR condition identified. Statistical fatality rates are then determined for each identified potential TSR impairment event. The fatality rates are determined from the event trees, accounting for the likelihood of a potential impairment event resulting in a hazardous TSR condition and the fatality estimate made for that condition.

This analysis provides only an indication of the risk to personnel from TSR impairment conditions. In the absence of details of the final TSR design and detailed smoke, gas and flame modelling studies, simplifying assumptions have been made. It is recommended that detailed studies be performed at detailed design stage.

7.7.6.1 Smoke Ingress

Smoke is generated by any burning hydrocarbon but, in general, significant quantities of smoke are only generated by long duration liquid fires. Therefore, it is assumed that any unisolated ignited large oil or 2-phase release will result in a large long duration fire, which, if coincident with unfavourable conditions, could impair the TSR.

For the TSR to be affected by smoke, the following conditions would have to occur, coincident with a long duration fire:

- Wind blows smoke from the fire towards the TSR.
- Smoke reaches TSR at high concentration.
- Smoke enters the TSR (for example, via the HVAC inlet or any other penetrations such as doors).

Any decision to evacuate the platform will be at the discretion of the OIM. If smoke enters the TSR, the OIM will not necessarily wait until the concentration reaches impairment levels before considering an evacuation of the platform.

It is assumed therefore that if smoke begins to ingress into the TSR and the lifeboat evacuation systems are <u>not</u> impaired by smoke, the OIM will order a ‘precautionary’ evacuation. That is, the OIM will tactically decide to evacuate by lifeboat whilst they are available, to protect personnel from the possibility of further smoke ingress and the possibility of subsequent coincident impairment of both TSR and evacuation systems.

However, if the evacuation systems are impaired by smoke when smoke begins to ingress into the TSR, it is assumed that personnel remain in the TSR. That is, to wait either for the event to be brought under control or for wind conditions to improve. Should impairment conditions subsequently be reached in the TSR, however, the OIM would have to order an ‘emergency evacuation’ of the installation under smoke impairment conditions.

Event trees (see Appendix 8) are used to account for the likelihood of the coincident conditions that must occur for the TSR to be affected by smoke from a long duration fire. Details of the event tree analysis are given in Appendix 10. The statistical fatalities assigned to each of the scenarios detailed above, in the event tree analysis, are shown in Table 7.10.

The smoke impairment event trees (Appendix 8) are used to determine statistical fatality rates for a potential impairment event. Statistical fatality rates are determined for:

- Precautionary evacuation of the TSR, as a result of smoke ingress.
- Smoke impairment of the TSR.

The fatality rates, which depend on fire location, are summarized in Table 7.11. These rates account for the full complement of platform personnel mustering and evacuating from the TSR.

Scenario	**Drilling and Production Phase**		**Production Only Phase**	
	Lifeboat Evacuation Fatalities	**Smoke Impairment Fatalities**	**Lifeboat Evacuation Fatalities**	**Smoke Impairment Fatalities**
No smoke hazard in the vicinity of the TSR	-	-	-	-
Smoke ingress into the TSR, but does not impair the lifeboats	7.02	-	3.75	-
Smoke ingress into the TSR and lifeboat impairment. Personnel remain in TSR.	-	-	-	-
Smoke impairment conditions are also reached in the TSR	-	117	-	62.5

Table 7.10: Smoke Impairment Event Tree Statistical Fatalities

Release Location	Drilling and Production Phase		Production Only Phase	
	Precautionary Evacuation Fatality Rate	TSR Impairment Fatality Rate	Precautionary Evacuation Fatality Rate	TSR Impairment Fatality Rate
Process Area	0.168	0.351	0.090	0.188
Manifold and Wellhead/ Intervention Areas	0.337	0.702	0.180	0.375
Drilling Equipment Sets	0.084	0.176	0.045	0.094
Power Generation Area	0.842	1.755	0.450	0.938

Table 7.11: Statistical Fatality Rates for Potential Smoke Impairment Events

7.7.6.2 Gas Ingress

Based on the predicted H_2S concentrations (Ref. 9) and resulting toxic gas cloud sizes, it is not considered that sufficiently high concentrations of H_2S could be experienced at the TSR to threaten its integrity. However, if gas from a large long duration release reaches the TSR at a flammable concentration, it could ingress into the TSR and result in the potential for an explosion within the TSR.

In general, gas releases from the process systems will be transient events, even in the case of an ESV failure. This is particularly true in the case of large gas releases.

However, if a large release occurs from the production or gas lift flowlines or manifolds in the Manifold Area or Wellhead/Intervention Area and, upon ESD, a well fails to shut in, a long duration gas or 2-phase release could occur.

Therefore, it is considered that any non-ignited unisolated large release from the production or gas lift flowlines or manifolds, coincident with unfavourable conditions, could impair the TSR.

For the TSR to be affected by gas, the following coincident conditions would have to occur:

- Wind blows gas from the release towards the TSR.
- Gas reaches the TSR at high concentration.
- Gas enters the TSR (for example, via the HVAC inlet or any other penetrations such as doors).

Any decision to evacuate the platform will be at the discretion of the OIM. If gas enters the TSR, the OIM will not wait until the concentration reaches LFL levels before considering an evacuation of the platform.

Because the potential impairment event involves failure of a well to shut-in, and is therefore unlikely to be transient, it is assumed that the OIM will order a 'precautionary' evacuation. That is, the OIM will tactically decide to evacuate by lifeboat, to protect personnel from the possibility of further gas ingress and the possibility of a subsequent explosion within the TSR. In this situation a precautionary evacuation fatality rate of 3% is considered.

Event trees (see Appendix 9) are used to account for the likelihood of the coincident conditions that must occur for the TSR to be affected by gas from a large long duration release. Details of the event tree analysis are given in Appendix 10. The statistical fatalities assigned to each of the scenarios detailed above, in the event tree analysis, are shown in Table 7.12.

Scenario	**Phase of Operations**	
	Drilling and Production	**Production Only**
No gas hazard at the TSR	-	-
Gas ingress to TSR	7.02	3.75

Table 7.12: Gas Impairment Event Tree Statistical Fatalities

The gas impairment event trees (Appendix 9) determine the statistical fatality rate for potential gas impairment events, accounting for the full complement of platform personnel mustering and evacuating from the TSR, as 0.421 for the drilling and production phase and 0.225 for the production only phase.

7.7.6.3 High Temperature

The TSR will be separated from the hazardous Process and Wellhead Areas by the Power Generation and Utility Areas. It is assumed that appropriate fire and blast-rated divisions will also be provided to ensure sufficient protection for personnel in the TSR. Therefore, the potential for heat impairment of the TSR, due to direct fire impingement, is not considered to be significant. The potential for TSR impairment from structural failure due to fires is considered in Section 7.7.6.5.

7.7.6.4 External Explosion

The TSR is separated from the hazardous Process and Wellhead Areas by the Utility Area. It is assumed that appropriate fire and blast divisions will also be provided to ensure sufficient protection for personnel in the TSR. Because of these fire/blast divisions, the layout of the platform and the location of the TSR, the potential for impairment of the TSR, due to external explosion, is not considered to be significant.

Consideration will be required, at detailed design stage, to ensure that protection provided is also sufficient to mitigate against potential explosions in the Power Generation Area, adjacent to the Living Quarters.

7.7.6.5 Structural Impairment

The PFP provided for the structural steel and bulkheads will protect the platform structure in the event of a large jet fire or pool fire.

In the case of a jet fire, the blowdown systems will reduce inventory pressure and terminate jet fires. Even if a blowdown ESV in an isolated inventory fails to open, a large jet fire would diminish rapidly due to the effect of the isolated inventory being released through the hole.

For a liquid release to persist, the release rate would have to be small and so the resultant fire should be able to be controlled and extinguished by the automatic or, if necessary, manual fire-fighting systems.

The protection provided by the PFP allows ample time for personnel to muster in the TSR and for both automatic and manual fire fighting action.

However, if a large release occurs from the production or gas lift flowlines or manifolds in the Manifold and Wellhead/Intervention Area and, upon ESD, a well fails to shut in, a long duration release could occur. If the release ignites, the resulting fire could eventually impair the platform structure or bulkheads.

For the purposes of this concept stage assessment, it is considered that any ignited unisolated large release from the production or gas lift flowlines or manifolds could potentially impair the platform structure and, therefore, the TSR. This is a conservative assumption, in particular during later stages of the field life when the well fluid will have a low gas content and production will be likely to cease if water injection stops, in which case a long duration release, even in the event that a wells fails to shut in, is unlikely. It may be appropriate to update the risk model at a later stage to reflect this decrease in risk.

In such a situation, it is considered that an OIM will not wait for structural impairment to occur before considering an evacuation of the platform. Rather, when an assessment of the situation indicates that a well has failed to shut-in and could possibly continue to fuel a fire for many hours, the OIM will initiate a precautionary evacuation.

For this situation, ‘precautionary evacuation fatalities’ are accounted for. It is assumed that a lifeboat evacuation will be undertaken, and a weather-averaged fatality rate of 3% is applied. Detailed asset-specific evacuation modelling will be required at design stage, but the 3% fatality rate, which is based on experience of assessing evacuation risk for other installations, assuming a lifeboat evacuation under controlled conditions, is considered sufficiently conservative for this assessment. The fatality rate, accounting for the full complement of platform personnel mustering and evacuating from the TSR, is 7.02 for the drilling and production phase and 3.75 for the production only phase.

8. Blowouts

HP and MP production, gas injection and water injection wells will be drilled using the platform's drilling rig during the 'drilling and production' phase of the project. Well activities, such as interventions, will continue to be performed during the 'post-drilling' period of operation.

Blowout frequency depends on the drilling and well activities being carried out and on the number of wells in production. Therefore, two estimates are made of blowout frequency. The first is representative of the drilling and production phase. The second is representative of the production only phase of the project when all drilling activities have ceased.

The risk to personnel from blowouts is assessed using the same event tree structure as is used to assess the risk due to loss of containment events (see Appendix 1). The basis of the blowout risk assessment is outlined below.

8.1 Blowout Location and Frequency

Ref. 10 provides historical data on the frequency of blowout events for 'offshore operations of North Sea standard'. Table 8.1 provides blowout frequency by 'phase of operation' based on data from Ref. 10.

Phase of Operation	Blowout Frequency	
Development Drilling:		
Non-HPHT Oil Wells	*4.8×10^{-5}*	per well drilled
Shallow Gas	*4.7×10^{-4}*	per well drilled
Total	**5.2×10^{-4}**	per well drilled
Completion	5.4×10^{-5}	per well completed
Producing Well (Oil)	2.6×10^{-6}	per well year
Gas Injection Well	1.8×10^{-5}	per well year
Workover	1.8×10^{-4}	per workover
Wirelining	3.6×10^{-6}	per wireline job

Table 8.1: Blowout Frequency Data

The 'most probable' well count for the development is outlined in Section 2 and is used as the basis for this assessment. However, in order to estimate blowout frequencies for the drilling and production phase of the project, it is considered more appropriate to use a representative, rather than worst case, well count. It is therefore assumed that 18 (1 gas injection well, up to 3 HP production wells and up to 14 MP production wells) of the anticipated total of 27 production and gas injection wells are in operation during the drilling and production phase.

In estimating blowout frequencies for the Hebron project, summarized in Table 8.2, it is further assumed that:

- Up to 27 wells (2 gas injection wells, up to 6 HP production wells and up to 19 MP production wells) will be in operation during the production phase of the project.
- 5 wells will be drilled per year during the drilling/production phase of the project.
- Heavy interventions will be carried out on each well once every nine years.
- Wells will undergo 3 light interventions every 4 years.

There will also be up to 10 water injection wells and a cuttings reinjection well. However, there is considered to be negligible risk to personnel associated with these wells and they are therefore not accounted for in the blowout risk assessment.

For the purposes of this analysis, it is considered that the blowout data for workover and wirelining activities given in Ref. 10 is sufficiently representative of blowout frequencies associated with heavy and light interventions, respectively.

It is also noted that the Ref. 10 data on blowouts during development drilling (non-high pressure, high temperature (HPHT) wells) indicates that the majority of blowouts are shallow gas blowouts. Some surveys of the Hebron site have indicated the possibility of shallow gas, however, if the GBS is located where there is no danger of shallow gas, a reduced development drilling frequency could be used for the risk assessment.

Phase of Operation and Activity	Blowout Frequency (per well-year)	Number of Wells	Blowout Frequency (per year of operation)
Drilling and Production			
Development Drilling	5.2×10^{-4}	5	2.59×10^{-3}
Completion	5.4×10^{-5}	5	2.70×10^{-4}
Producing Well (Oil)	2.6×10^{-6}	17	4.42×10^{-5}
Gas Injection Well	1.8×10^{-5}	1	1.80×10^{-5}
Heavy Intervention	1.8×10^{-4}	2	3.60×10^{-4}
Light Intervention	3.6×10^{-6}	13.5	4.86×10^{-5}
		Total	$\mathbf{3.33 \times 10^{-3}}$
Production Only			
Producing Well (Oil)	2.6×10^{-6}	25	6.50×10^{-5}
Gas Injection Well	1.8×10^{-5}	2	3.60×10^{-5}
Heavy Intervention	1.8×10^{-4}	3	5.40×10^{-4}
Light Intervention	3.6×10^{-6}	20.25	7.29×10^{-5}
		Total	$\mathbf{7.14 \times 10^{-4}}$

Table 8.2: Estimated Blowout Frequencies for Hebron

Historical data indicates that:

- The majority of blowouts during production, wirelining and completion occur at the wellhead.
- The majority of blowouts during workovers and drilling occur at the drill floor.
- A minority of blowouts occur sub-sea.

For this risk assessment, the combined total frequency of all production, light intervention and completion blowouts is taken as representative of the blowout frequency in the Wellhead Area. Similarly, the combined total frequency of all heavy intervention and drilling blowouts is taken as representative of the blowout frequency at the drill floor, in the DES.

A sub-sea blowout could result in hydrocarbons entering the shaft, which could result in a rapid accumulation of gas in the area (see Section 9.1). Although the potential for ignition in the normally unmanned shaft is low, it is recommended that the potential of explosions in the GBS should be evaluated further during detailed design to ensure that risk is tolerable.

Based on the above discussion, the blowout frequencies, by location, calculated for use in the blowout risk assessment are as shown in Table 8.3.

Phase and Location	Blowout Frequency (per year)
Drilling/Production	
Wellhead	3.81×10^{-4}
Drill Floor	2.95×10^{-3}
Total	$\mathbf{3.33 \times 10^{-3}}$
Production	
Wellhead	1.74×10^{-4}
Drill Floor	5.40×10^{-4}
Total	$\mathbf{7.14 \times 10^{-4}}$

Table 8.3: Blowout Frequencies by Location

8.2 Ignition Probability

Ignition probabilities are calculated using the UKOOA ignition model (Ref. 5), as described in Section 7.2.

The model calculates ignition probabilities based on mass release rate, with a maximum ignition probability for a blowout of 0.1 and a maximum explosion probability, given ignition, of 0.3.

These maximum ignition probabilities are used for the purposes of this assessment.

8.3 Fire and Gas Detection Probability

For blowouts, the detection probability is assumed to be similar to that for a large process release (i.e. 0.99, see Table 7.5).

8.4 Isolation Probability

A blowout is, by definition, an uncontrolled release of fluids from a well. Therefore, the probability of isolating the release is 0.

8.5 Deluge Probability

The overall on-demand failure probability for deluge is 0.015, see Section 7.5.

8.6 Explosion Overpressure Probability

As discussed in Section 7.6, four overpressure ranges are considered in the risk assessment:

- Explosion overpressure between 0 and 0.2 bar.
- Explosion overpressure between 0.2 bar and 1 bar.
- Explosion overpressure between 1 bar and 2 bar.
- Explosion overpressure greater than 2 bar.

Also from Section 7.6, based on explosion modelling performed using DNV's consequence modelling software package, PHAST, the worst case maximum overpressure in the Wellhead/Manifold Area is taken to be 0.5 bar. Based on the discussion in Section 7.6, the explosion overpressure branch probabilities used in the assessment of blowouts in the Wellhead Area are given in Table 8.4.

Location	Overpressure Range	Probability (Deluge)	Probability (No Deluge)
Wellhead/Manifold Area	< 0.2 Bar	0.80	0.40
	0.2 Bar to 1.0 Bar	0.20	0.60
	1.0 Bar to 2.0 Bar	0.00	0.00
	> 2.0 Bar	0.00	0.00

Table 8.4: Overpressure Probabilities

Due to the open elevated position of the DES (above the Weather Deck) there is limited potential for a delayed ignition at the drill floor to generate significant overpressure. Therefore the event trees for drill floor blowouts do not distinguish between explosions of different overpressure in the event of a delayed ignition.

8.7 Consequence Assessment

The approach to estimation of consequences for blowout events is similar to that applied for process loss of hydrocarbon containment events (in Section 7.7).

8.7.1 Immediate Fatalities for Blowouts in the Wellhead Area

8.7.1.1 Non-Explosive Ignition (Fires)

The Lower Deck in the Wellhead Area is plated and the Main Deck (separating the Wellhead Area and the Intervention Area) is fire rated. In addition, the wall between the Wellhead Area and Utility Area is blast rated. However, there is no barrier between the Wellhead Area and Manifold Area.

Therefore, in addition to personnel on the Lower Deck of the Wellhead Area, there is potential for immediate fatalities in the Manifold Area in the event of early ignition following a blowout. However, the walls and plated decks would prevent immediate fatalities in other areas of the installation.

There are, on average, 7 people on the Lower Deck of the Wellhead Area during the drilling and production phase of the project and 3 people during the production only phase. There is also 1 person, on average, in the Manifold Area.

Due to the nature of the event, this risk assessment assumes that in the event of a wellhead blowout that ignites 100% of the personnel in the Wellhead/Manifold area will be fatally injured. Therefore 8 immediate fatalities are accounted for in the assessment of the drilling and production phase and 4 in the assessment of the production only phase of the project.

8.7.1.2 Explosions

Based on the rule set presented in Section 7.7.2, it is assumed that, in the event of an explosion of overpressure less than 0.2 bar, 50% of personnel in the area when ignition occurs are fatally injured. For overpressures of 0.2 bar or greater, 100% of personnel in the area when ignition occurs are assumed to be fatally injured.

However, in the event of a delayed ignition following a blowout in the Wellhead Area, it is assumed that personnel will be aware of the incident and that there is a 50% chance that they will escape from the area before the ignition occurs.

8.7.1.3 Toxic Gas

Based on data presented in Ref. 9, the concentration of H_2S in the well streams is not considered sufficient to result in toxic concentrations in air in the event of a release. Therefore, it is not considered that a blowout would result in fatalities due to toxic gas.

8.7.2 Immediate Fatalities for Blowouts at the Drill Floor

8.7.2.1 Non-Explosive Ignition (Fires)

It is assumed that there are, on average, 8 personnel in the DES during the drilling and production phase of the project.

The risk assessment considers that during well activities (such as drilling into a reservoir) a ‘well kick’ will, in general, occur, which gives forewarning of the potential blowout situation. This gives time for precautionary downmanning of the immediate area, with only essential personnel remaining to attempt to control the situation.

Therefore, during the drilling and production phase, for blowouts at the drill floor that ignite early, the number of fatalities is reduced from the total number of personnel in the DES (8) to 4, to account for any personnel remaining in the area to attempt to control the well.

For the production only phase, the number of personnel in the DES is reduced to 4. In the event of a ‘well kick’, these personnel are assumed to remain in the area to attempt to control the well.

8.7.2.2 Explosions

The DES is a very open area, with low congestion and low confinement. Therefore, it is not considered that there is potential for a significant explosion overpressure to be generated.

In addition, for delayed ignition events, the risk assessment assumes that any personnel remaining in the area after a ‘well kick’ has occurred in an attempt to control the well are able to escape the area before ignition, so no immediate fatalities are accounted for.

8.7.2.3 Toxic Gas

As discussed in Section 8.7.1.3, blowouts are not considered to have the potential to result in toxic gas fatalities.

8.7.3 Escalation Fatalities due to Impairment of Fire and Blast Walls

As discussed in Section 7.7.4, no escalation fatalities are accounted for in fire (non-explosive ignition) scenarios. In addition, based on the predicted overpressures and the overpressures at which it is considered that bulkheads and partitions (e.g. decks) may fail (see Section 7.6), it is not considered that delayed ignition events in the DES and Wellhead Area have the potential to escalate to adjacent areas and no escalation fatalities are therefore accounted for.

8.7.4 Escape Fatalities

As discussed in Section 7.7.5, the risk assessment does not account for any escape fatalities.

8.7.5 Precautionary Evacuation and TSR Impairment Fatalities

8.7.5.1 Precautionary Evacuation

Section 7.7.6.5 identifies process release events that are considered to have the potential for a long duration fire with potential to eventually impair the platform structure. The identified events are ignited unisolated releases from the production or gas lift flowlines or manifolds in the Wellhead/Manifold Area. This accounts for the possibility of a well failing to shut-in on ESD and then continuing to fuel a fire for several hours. Because a blowout is an uncontrolled release of wellfluids, ignited blowouts (either at the wellhead or at the drill floor) are similarly considered here to be events that could result in long duration fires that could eventually impair the platform structure. This is a conservative assumption that takes no credit for the fact that production is likely to cease if water injection is halted.

In fact, because of the severity of the consequences of a blowout, it is assumed that the OIM will initiate a precautionary evacuation, irrespective of whether the blowout ignites. For all blowouts, ‘precautionary evacuation’ fatalities are accounted for. It is assumed that a lifeboat evacuation will be undertaken, and a weather-averaged fatality rate of 3% is applied. Detailed asset-specific evacuation modelling will be required at design stage, but the 3% fatality rate, which is based on experience of assessing evacuation risk for other installations, assuming a lifeboat evacuation under controlled conditions, is considered sufficiently conservative for this assessment. The fatality rate, accounting for the full complement of platform personnel mustering and evacuating from the TSR, is 7.02 for the drilling and production phase and 3.75 for the production only phase.

8.7.5.2 Smoke Ingress

From Section 8.7.5.1, the basis of the risk assessment for all blowouts is that personnel will muster in the TSR and the OIM will initiate a precautionary evacuation. If however, smoke from an ignited blowout impairs the evacuation systems, it is assumed that personnel will remain in the TSR. That is, to wait either for the event to be brought under control or for wind conditions to improve. Should impairment conditions subsequently be reached in the TSR, however, the OIM would have to order an 'emergency evacuation' of the installation under smoke impairment conditions. These conditions are accounted for in the TSR impairment event tree analysis (Section 7.7.6.1 and Appendix 10) and statistical fatality rates are determined for smoke impairment of the TSR. The statistical fatality rates for smoke impairment of the TSR and evacuation systems as a result of a fire in the Wellhead/Intervention Area or DES are 0.702 and 0.176 respectively for the drilling and production phase and 0.375 and 0.094 for the production only phase, see Table 7.11.

8.7.5.3 Gas Ingress

The likelihood of rapid ingress of gas into the TSR due to the HVAC system failing to shutdown is not considered in the risk assessment (Section 7.7.6.2). It is assumed, however, that gas could enter slowly through various other TSR penetrations, such as doors.

From Section 8.7.5.1, the basis of the risk assessment for blowouts is that when a blowout occurs, the OIM will initiate a precautionary evacuation.

Therefore, because the risk assessment considers only slow ingress of gas into the TSR, personnel will have evacuated the platform before gas ingress and explosion impair the integrity of the TSR. No TSR impairment fatalities as a result of gas ingress from unignited blowouts are accounted for in this assessment.

8.7.5.4 High Temperature

The TSR will be separated from the hazardous Process and Wellhead Areas by the Power Generation and Utility Areas. It is assumed that appropriate fire and blast-rated divisions will also be provided to ensure sufficient protection for personnel in the TSR. Therefore, the potential for heat impairment of the TSR, due to direct fire impingement, is not considered to be significant.

8.7.5.5 External Explosion

The TSR is separated from the hazardous Process and Wellhead Areas by the Utility Area. It is assumed that appropriate fire and blast divisions will also be provided to ensure sufficient protection for personnel in the TSR. Because of these fire/blast divisions, the layout of the platform and the location of the TSR, the potential for impairment of the TSR due to external explosion is not considered to be significant.

9. Other Hydrocarbon Hazards

In addition to process loss of containment events identified in Section 7 and blowouts, which are discussed in Section 8, Ref. 1 identifies the following hydrocarbon hazards, each of which is discussed in the following sections:

- Releases in the shaft from well conductors, storage cell loading/offloading pipework or from gas migrating from topsides.
- Releases from the oil export pipeline in the vicinity of the installation.

9.1 Releases in the Shaft

The central column of the GBS consists of a shaft, which contains the well conductors and oil export risers. Oil storage cells are located in the underwater caisson around the central column.

The Cellar Deck above the central column will be fire-rated and will be sealed in order to prevent the migration of gas from topsides into, and subsequent explosion within, the central column. It will also prevent escalation of topsides fires, explosions or blowouts into the shaft.

The central column will be ventilated, and gas detectors will be provided.

There is potential for hydrocarbon release into the shaft from the well conductors, the oil storage cell loading/offloading pipework or the oil export risers.

A release of well fluid from the conductors could result in a rapid accumulation of gas in the shaft. The conductors consist of several concentric casings and production tubing, and the annuli between the casings are regularly monitored for pressure. The likelihood of a release from the conductors is therefore likely to be small.

Oil released from the oil storage cell loading/offloading pipework, the oil lift (booster) pumps caisson or the oil export risers will be of stabilized crude. The ventilation and detection systems provided will reduce the potential for any gas that evolves off the crude, following a release, to accumulate to flammable concentrations.

Although the potential for ignition in the normally unmanned shaft is low, it is recommended that the potential for explosions in the GBS should be evaluated further during detailed design to ensure that the associated risk is tolerable.

9.2 Release from OLS Export Pipeline/OLS

The GBS will be connected to each OLS by two 24 inch 2 km long crude oil transfer lines. Crude oil will be pumped from the storage system in the GBS through the OLS to the tankers. A release from the transfer lines during export will result in a large pool of oil forming on the sea surface. The oil will become very viscous as it is cooled by sea and is therefore unlikely to spread very quickly on the sea unless it is broken up and dispersed by wave action. The ignition probability of stabilized crude is also low, therefore the risk to personnel from a release from the oil export lines is not considered to be significant.

10. Other Hazards

Ref. 1 also identifies the following non-hydrocarbon hazards, which are discussed in the following sections:

- Iceberg collision with the installation, sea ice and ice loading.
- Ship collision with the installation.
- Helicopter accidents, during transportation of platform personnel to and from the installation.
- Seismic activity, leading to structural damage and/or damage to equipment.
- Extreme weather leading to structural failure.

10.1 Iceberg Collision and Scouring, Sea Ice, Topsides Icing

10.1.1 Iceberg Collision

The design of the GBS is still under consideration. However, standards are in place to ensure that risks associated with iceberg impact are appropriately controlled (Ref. 11) and design studies to ensure that the project fully complies with all requirements are underway.

Design criteria state that the GBS should be capable of withstanding an impact from a 10,000 year iceberg and 100 year wave simultaneously. Ref. 11 gives the probability of loads exceeding platform design as between 10^{-4} and 10^{-6} per year. Therefore, based on this data, the risk assessment assumes that the design of the GBS will be such that the statistical annual frequency of structural failure as a result of iceberg collision is 10^{-5} per year.

The risk to personnel is estimated in the event tree risk assessment (Appendix 4) on the basis that, following structural failure of the platform due to iceberg collision, the integrity of the TSR will be impaired and an emergency evacuation required. An evacuation fatality rate of 6% is assigned, twice the precautionary evacuation fatality rate, to account for the fact that the evacuation may take place under TSR impairment conditions and that the evacuation may be impaired by the proximity of the iceberg.

It is recommended that consideration be given at detailed design stage, to developing a more complex model to assess the risk due to iceberg impact. Such a model may take account, for example, of:

- The design criterion of a return period for the Safety Level Iceberg of 10,000 years.
- The average number of icebergs that enter a critical zone surrounding the platform.
- The effectiveness of iceberg management, including iceberg detection and physical management (for example, towing) of icebergs.

- The fact that the OIM may initiate a precautionary evacuation of the personnel on the platform prior to iceberg impact, if the preventative measures fail.
- The potential for iceberg collision with the topsides, and the consequences of such an impact.

10.1.2 Iceberg Scour

Produced oil will be delivered to the tankers through an offshore loading system (OLS). The OLS oil loading lines could be exposed to iceberg scour, resulting in a hydrocarbon release. It is assumed that a significant percentage of icebergs would pass over the top of the OLS subsurface buoy if they were on a collision course with the buoy. If, however, the icebergs did breach an OLS pipeline, it is assumed that a release from the oil loading lines would not present a significant risk to personnel on the installation (Section 9.2). Potential environmental impact will be minimized by isolating and flushing the lines with seawater in the event of threat of approaching iceberg.

10.1.3 Sea Ice

Sea ice can occur in the Hebron area, particularly during the spring months. Sea ice can create loads on the GBS (see Section 10.1.4). Heavy sea ice can also affect the movement of standby vessels, shuttle tankers and supply vessels, and, in an emergency, the launching of lifeboats and liferafts.

It is assumed that support and standby vessels and shuttle tankers will be suitably ice-strengthened to permit their use in most sea ice conditions. This assumption should be reviewed at design stage to ensure that the possibility of sea ice is considered when selecting evacuation systems.

In the risk assessment, it is assumed that the OLS will not be affected by sea ice as the major working parts will be significantly below the sea surface.

10.1.4 Ice Loading

Hebron is located in an area where ice accretion may occur. Ice will accumulate on decks, superstructure and process equipment from freezing sea spray and atmospheric precipitation, resulting in ice loading.

Ref. 12 indicates that ice cannot result from freezing sea spray 25 metres above sea level. The topsides is located approximately 33m above sea level, therefore freezing sea spray is not considered to affect the Hebron topsides.

Ref. 13 suggests that the amount of ice formed from atmospheric precipitation can be decreased by reducing the topsides wind velocity within modules. It also indicates that this could be achieved by using 30% porous wind shields with a height of 3 metres. The open decks will be designed to withstand a density of 204kg/m^2 of snow (Ref. 14).

In addition, a winterisation plan, which may involve electrical, chemical or salt de-icing, will be established in order to ensure that ice loading does not exceed the design capability of the installation.

Based on this discussion, it is not considered that ice loading leading to structural damage is a significant risk to personnel.

10.2 Ship Collision

Risk from ship collision falls into two categories: risk due to impact from passing vessel and risk due to impact from authorized vessels. Authorized vessels are those that have a specific function associated with the platform, such as shuttle tankers, supply and standby vessels.

The main causes of authorized vehicles colliding with the installation are likely to be loss of power, and therefore steering, or pilot error, neither of which should result in a high energy collision.

In the event of loss of power of a passing vessel leading to collision, the impact energy is also likely to be relatively low, however the energy associated with collision by an errant passing vessel under power will be higher.

It is assumed that the GBS column will be able to withstand low energy impact (e.g. from an authorized vessel or drifting passing vessel). Therefore, it is considered that only high energy collisions (from passing powered vessels) have the potential to result in significant damage to the installation.

The event tree assessment of risk to platform personnel from passing vessels is shown in Appendix 5.

10.2.1 Passing Vessels

Ref. 15 gives the frequency, per platform year, of passing ship collisions with fixed installations as 2.5×10^{-4} per platform year (based on installations worldwide). This frequency is considered to be conservative compared to that estimated for Hibernia (6.3×10^{-6} per platform year, Ref. 16), which was justified because the main shipping routes are well away from the Hibernia area.

The Ref. 15 frequency is therefore reduced by a factor of 10, to 2.5 x 10^{-5} per platform year, for the purposes of this assessment.

It is assumed that 10% of passing vessel impacts with the installation will be high energy, exceeding the design capacity of the facility, or will have the potential to impact the topsides, causing significant damage.

In such situations, it is assumed in the risk assessment that an emergency evacuation by lifeboat would be initiated. An emergency evacuation fatality rate of 6%, twice the weather averaged precautionary evacuation fatality rate, is assigned. This takes account of the fact that the evacuation is not being undertaken in normal circumstances. In addition, damage to the platform may adversely affect the launch capability of the TEMPSCs.

10.3 Helicopter Transportation

The event tree assessment of risk to platform personnel for helicopter transportation is shown in Appendix 6.

Helicopter accidents during take-off and landing and in-flight are considered, and the risk assessment takes account of:

- The likelihood of a helicopter accident (per flying hour and per take-off/landing).
- The probability that an accident is a 'fatality accident'.
- The probability of each individual onboard being fatally injured in the event of a fatality accident.

Helicopter accident data is provided in Ref. 17 for three regions:

- North Sea.
- Gulf of Mexico
- Rest of the world

Data based on North Sea operations is used in this assessment, as it is considered most representative of operations in Atlantic Canada, in terms of helicopter type/age, helicopter maintenance, pilot training, travel distance and weather conditions.

10.3.1 Hebron Helicopter Operations

During operations, personnel will work a shift pattern of 3 weeks on/3 weeks off. It is assumed that S-92 helicopters will be used, and that each flight transfers 17 Hebron personnel to, or from, the installation. Therefore, for a POB of 234 during the drilling and production phase, there will be 239 return flights per year between the heliport and the Hebron installation. In this risk assessment, the number of flights is increased by 30% to account for the helicopter not always carrying the full capacity of personnel and for additional personnel visiting the installation. It is therefore conservatively assumed that there will be 311 return flights per year during the drilling and production phase.

On a similar basis, it is conservatively assumed that there will be 166 return flights per year during the production only phase, when the POB is assumed to be 125.

It is also assumed that:

- Each flight to, or from, the installation will take 1.5 hours.
- In addition to platform personnel, there will be two flight crew onboard the helicopter.

10.3.2 Helicopter Transport Risk, In-Flight

Ref. 17 indicates an in-flight ('cruise') helicopter accident frequency of 8.50×10^{-6} per flying hour. During the drilling and production phase, based on 311 return flights to/from the installation, the in-flight accident rate is, therefore:

$$8.50 \times 10^{-6} \times 311 \times 2 \times 1.5 = 7.93 \times 10^{-3} \text{ per year.}$$

During the production only phase, assuming 166 return flights to/from the installation, the in-flight accident rate is:

$$8.50 \times 10^{-6} \times 166 \times 2 \times 1.5 = 4.23 \times 10^{-3} \text{ per year.}$$

For in-flight accidents, it is assumed, based on Ref. 17, that the probability that any accident is a fatality accident is 0.2 and that the probability of fatal injury for each individual in the accident is 0.85. Accounting for the 17 personnel being transferred to or from the installation, the TALL due to in-flight helicopter accidents is, therefore:

- $7.93 \times 10^{-3} \times 0.2 \times 0.85 \times 17 = 2.29 \times 10^{-2}$ per year during the drilling and production phase.
- $4.23 \times 10^{-3} \times 0.2 \times 0.85 \times 17 = 1.22 \times 10^{-2}$ per year during the production only phase.

With respect to the helicopter crew, the TALL is 2.70×10^{-3} and 1.44×10^{-3} per year, respectively.

10.3.3 Helicopter Crash Frequency, Take-Off and Landing

Ref. 17 indicates a departure/arrival helicopter accident rate of 4.30 x 10^{-7} per flight stage. For 311 return flights to/from the installation during the drilling and production phase, the take-off/landing accident rate is, therefore:

$$4.30 \times 10^{-7} \times 311 \times 2 = 2.67 \times 10^{-4} \text{ per year.}$$

For 166 return flights to/from the installation, during the production only phase, the take-off/landing accident rate is:

$$4.30 \times 10^{-7} \times 166 \times 2 = 3.70 \times 10^{-4} \text{ per year.}$$

For accidents during take-off and landing, it is assumed, based on Ref. 17, that the probability that any accident is a fatality accident is 0.17 and that the probability of fatal injury for each individual in the accident is 0.48. Accounting for the 17 personnel being transferred to or from the installation, the TALL due to in-flight helicopter accidents is, therefore:

- 2.67 x 10^{-4} x 0.17 x 0.48 x 17 = 3.70 x 10^{-4} per year during the drilling and production phase.
- 1.43 x 10^{-4} x 0.17 x 0.48 x 17 = 1.98 x 10^{-4} per year during the production only phase.

With respect to the helicopter crew, the TALL is 4.36 x 10^{-5} and 2.33 x 10^{-5} per year, respectively.

10.3.4 Helicopter Transport Risk Summary

The total TALL due to helicopter transportation of Hebron personnel is 2.33 x 10^{-2} per year during the drilling and production phase and 1.24 x 10^{-2} per year during the production only phase.

The risk to helicopter crew is not included in the overall platform risk Tables 11.1 and 11.2, because flight crew are not part of the installation POB. Also, helicopter crew work patterns are different to those of the platform crew, so the calculations used to determine risk to individuals for platform crew do not apply.

10.4 Seismic Activity

The design criterion for the installation is that the return period for the Safety Level Earthquake is 2000 years. This is equivalent to an expected frequency of 0.0005 per year.

At lower frequencies there is the potential for earthquakes that may cause structural damage and damage to equipment. This type of major seismic event may result in a release of hydrocarbons. The size and construction of the Hebron GBS makes it unlikely that the entire topsides would experience immediate collapse. However, the safety and mitigation equipment may be damaged, increasing the potential for ignited hydrocarbon events to escalate.

The basis of the event tree risk assessment (see Appendix 7) is that the frequency of such a severe earthquake is only one order of magnitude less than that of the Safety Level Earthquake. To ensure that the risk assessment is conservative, it is assumed that Safety Function impairment may occur due to ignited hydrocarbon events. This is accounted for in the risk assessment by assuming that:

- In 50% of severe earthquakes, the integrity of the TSR is threatened. In such a scenario, it is considered that the OIM will not wait for TSR impairment conditions to arise but will initiate an evacuation as a precautionary measure, to safeguard personnel against sudden escalation of a potentially severe event. A weather-averaged precautionary evacuation fatality rate of 3% is assumed. Detailed asset-specific evacuation modelling will be required at design stage, but the 3% fatality rate, which is based on experience of assessing evacuation risk for other installations, assuming a lifeboat evacuation under controlled conditions, is considered sufficiently conservative for this assessment.
- In the remaining 50% of severe earthquakes, the integrity of the TSR is impaired and an emergency evacuation is required. An evacuation fatality rate of 6% is assigned, twice the precautionary evacuation fatality rate, to account for the fact that the evacuation may take place under TSR impairment conditions and that the evacuation systems may also have been impaired.

10.5 Structural Failure due to Extreme Weather

It is assumed that the platform will be designed to withstand appropriate wind/wave forces, as discussed in Ref. 12. The platform will also have extreme weather warning/contingency plans. For example, given advanced warning, if extraordinarily severe weather is anticipated the platform could be shutdown and personnel transferred to a place of safety.

In accident situations requiring evacuation, severe weather can have a detrimental effect on evacuation and rescue operations. However, the influence of weather conditions has already been accounted for in the previous risk assessment of hazardous events that may require evacuation.

11. Risk Summary and Conclusions

11.1 Theoretical Annual Loss of Life

The Theoretical Annual Loss of Life (TALL) for a hazard is the average number of fatalities per year on the installation resulting from that hazard. For each hazard identified, TALL is calculated as:

TALL = Hazard Frequency (per year) x Potential Fatalities

Risk estimates are provided here for two phases of the Project:

- The drilling and production phase (assumed to be the years up to and including 2025).
- The post-drilling production phase (the years after 2025).

This is because:

- The risk from blowouts depends on the drilling and well activities being carried out and on the number of wells in production.
- The risk from process loss of containment depends on the number of wells in production.

Tables 11.1 and 11.2 summarize the risk assessment by presenting the TALL for each major hazard, assessed as described in the previous sections, for each of the above phases.

Hazard	TALL Fatality Classification				Total
	Immediate	Escape/ Escalation	Precautionary Evacuation	TSR Impairment	
Loss of Containment (Fire/Explosion)	0.0093	0.00019	0.0005	0.000019	**0.01**
Blowouts	0.0011	-	0.023	0.000079	**0.024**
Iceberg Collision	-	-	-	0.00014	**0.00014**
Passing Vessel Collision	-	-	-	0.000035	**0.000035**
Helicopter Crash	0.023	-	-	-	**0.023**
Seismic Activity	-	-	0.00018	0.00035	**0.00053**
TOTAL	**0.033**	**0.00019**	**0.024**	**0.00062**	**0.058**

Table 11.1: Risk Summary, TALL (Drilling and Production Phase)

Hazard	TALL Fatality Classification				Total
	Immediate	Escape/ Escalation	Precautionary Evacuation	TSR Impairment	
Loss of Containment (Fire/Explosion/ Toxic Gas)	0.0069	0.000073	0.0004	0.000012	**0.0074**
Blowouts	0.00021	-	0.0027	0.000012	**0.0029**
Iceberg Collision	-	-	-	0.000075	**0.000075**
Passing Vessel Collision	-	-	-	0.000019	**0.000019**
Helicopter Crash	0.012	-	-	-	**0.012**
Seismic Activity	-	-	0.000094	0.00019	**0.00028**
TOTAL	**0.019**	**0.000073**	**0.0032**	**0.00031**	**0.023**

Table 11.2: Risk Summary, TALL (Production Only Phase)

11.2 Individual Risk per Annum

To assess the risk to each individual on the installation, it is necessary to normalize the TALL calculation to account for the distribution of risk over the entire population of the installation. This can be achieved by calculating an average individual risk per annum (IRPA), which is defined as the average annual risk to an individual on the installation. It can be calculated as:

$$\text{IRPA} = \frac{TALL}{POB} \text{ x Exposure}$$

where 'exposure' is the proportion of the year that an individual would spend at the installation. This is taken to be 0.5.

Tables 11.3 and 11.4 present the average IRPA for platform personnel calculated for each major hazard assessed, for the drilling and production and production only phases of operation.

Hazard	**Average IRPA**				Total
	Fatality Classification				
	Immediate	**Escape/ Escalation**	**Precautionary Evacuation**	**TSR Impairment**	
Loss of Containment (Fire/Explosion)	2.0×10^{-5}	4.1×10^{-7}	1.1×10^{-6}	4.1×10^{-8}	**2.2×10^{-5}**
Blowouts	2.4×10^{-6}	-	4.9×10^{-5}	1.7×10^{-7}	**5.2×10^{-5}**
Iceberg Collision	-	-	-	3.0×10^{-7}	**3.0×10^{-7}**
Passing Vessel Collision	-	-	-	7.5×10^{-8}	**7.5×10^{-8}**
Helicopter Crash	5.0×10^{-5}	-	-	-	**5.0×10^{-5}**
Seismic Activity	-	-	3.8×10^{-7}	7.5×10^{-7}	**1.1×10^{-6}**
TOTAL	**7.2×10^{-5}**	**4.1×10^{-7}**	**5.0×10^{-5}**	**1.3×10^{-6}**	**1.3×10^{-4}**

Table 11.3: Risk Summary, IRPA (Drilling and Production Phase)

Hazard	Average IRPA				Total
	Fatality Classification				
	Immediate	Escape/ Escalation	Precautionary Evacuation	TSR Impairment	
Loss of Containment (Fire/Explosion/ Toxic Gas)	2.8×10^{-5}	2.9×10^{-7}	1.6×10^{-6}	4.8×10^{-8}	**3.0×10^{-5}**
Blowouts	8.4×10^{-7}	-	1.1×10^{-5}	4.8×10^{-8}	**1.2×10^{-5}**
Iceberg Collision	-	-	-	3.0×10^{-7}	**3.0×10^{-7}**
Passing Vessel Collision	-	-	-	7.5×10^{-8}	**7.5×10^{-8}**
Helicopter Crash	5.0×10^{-5}	-	-	-	**5.0×10^{-5}**
Seismic Activity	-	-	3.8×10^{-7}	7.6×10^{-7}	**1.1×10^{-6}**
TOTAL	**7.9×10^{-5}**	**2.9×10^{-7}**	**1.3×10^{-5}**	**1.2×10^{-6}**	**9.3×10^{-5}**

Table 11.4: Risk Summary, IRPA (Production Only Phase)

Individual risk figures for the representative worker groups discussed in Section 6 are calculated taking into account:

- The proportion of time individuals within each worker group spend in each location, based on the personnel distributions given in Table 6.2 and Table 6.3.
- The predicted frequency of hazardous events to which individuals are exposed in each location.
- The impact of those hazardous events, in terms of predicted fatality rates.

Tables 11.5 and 11.6 present the IRPA for each worker group.

Hazard	Worker Group			
	Management/ Admin/ Catering	**Operations & Maintenance**	**Drilling/ Intervention**	**Construction**
Loss of Containment (Fire/Explosion)	2.2×10^{-6}	3.5×10^{-5}	2.4×10^{-5}	4.1×10^{-5}
Blowouts	5.0×10^{-5}	5.0×10^{-5}	5.5×10^{-5}	5.0×10^{-5}
Iceberg Collision	3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}
Passing Vessel Collision	7.5×10^{-8}	7.5×10^{-8}	7.5×10^{-8}	7.5×10^{-8}
Helicopter Crash	5.0×10^{-5}	5.0×10^{-5}	5.0×10^{-5}	5.0×10^{-5}
Seismic Activity	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
TOTAL	$\mathbf{1.0 \times 10^{-4}}$	$\mathbf{1.4 \times 10^{-4}}$	$\mathbf{1.3 \times 10^{-4}}$	$\mathbf{1.4 \times 10^{-4}}$

Table 11.5: IRPA (Drilling and Production Phase)

Hazard	Worker Group			
	Management/ Admin/ Catering	**Operations & Maintenance**	**Drilling/ Intervention**	**Construction**
Loss of Containment (Fire/Explosion/Toxic Gas)	2.9×10^{-6}	3.8×10^{-5}	5.8×10^{-5}	4.3×10^{-5}
Blowouts	1.1×10^{-5}	1.1×10^{-5}	1.4×10^{-5}	1.1×10^{-5}
Iceberg Collision	3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}
Passing Vessel Collision	7.5×10^{-8}	7.5×10^{-8}	7.5×10^{-8}	7.5×10^{-8}
Helicopter Crash	5.0×10^{-5}	5.0×10^{-5}	5.0×10^{-5}	5.0×10^{-5}
Seismic Activity	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
TOTAL	$\mathbf{6.5 \times 10^{-5}}$	$\mathbf{1.0 \times 10^{-4}}$	$\mathbf{1.2 \times 10^{-4}}$	$\mathbf{1.1 \times 10^{-4}}$

Table 11.6: IRPA (Production Only Phase)

11.3 Environmental Risks

The environmental effects from activities associated with the Hebron Project area are addressed in the Hebron Project Comprehensive Study Report, which identifies the following Valued Environmental Components (VECs):

- Fish and fish habitat.
- Marine mammals and sea turtles.
- Sensitive areas.
- Marine birds.
- Species at risk.
- Air quality.

- Commercial fisheries.

As discussed in Section 4.2, VECs identified are evaluated against a number of subject variables. These variables include:

- Likelihood of occurrence of the accident, malfunction or unplanned event.
- Size of the oil spill.
- Duration of spill.
- Geographical extent of spill.
- Consequences of the accident, malfunction or unplanned event.
- Ability of the VEC to return to pre-spill levels.

The final step in the environmental effects analysis is to determine the significance of the impact of the accidental event on the VECs.

11.4 Conclusions

From review of Tables 11.1 to 11.2, the largest contributors to risk to personnel on the Hebron installation are:

- Helicopter transportation (accounting for approximately 40% of overall platform risk during the drilling and production phase, and approximately 52% in the post-drilling phase).
- Blowout events resulting in evacuation fatalities (approximately 40% of overall platform risk during the drilling and production phase, and approximately 12% in the post-drilling phase).
- Process loss of containment events resulting in immediate fatalities (approximately 16% of overall platform risk during the drilling and production phase, and approximately 30% in the post-drilling phase).

A review of the adequacy of potential risk reduction measures to prevent, mitigate and safeguard against these main risk contributors should be undertaken at detailed design stage, in order to ensure that risks are ALARP.

The risk from blowouts decreases significantly in the post-drilling phase, as the blowout risk associated with drilling activities is greater than that associated with well activities carried out on production wells. The risk from process loss of containment increases slightly in the post-drilling phase as it is dependent on the number of wells in production and it is assumed that the maximum number of wells will be in production once drilling is complete.

Comparison of the Individual Risk levels in Tables 11.3 and 11.4 with the Hebron Target Levels of Safety (presented in Section 4) concludes that risks are below the intolerable IR criterion threshold of 1×10^{-3} per year, and within the ‘ALARP’ region defined by the criteria.

To comply with the Target Levels of Safety, it will also be necessary to show, for hazards that are assessed as being in the ALARP region, that all practicable means of risk reduction have been employed to ensure that the risk is demonstrably ALARP. To achieve, this cost benefit studies may be required at detailed design stage to ensure that appropriate measures of risk reduction are incorporated into the final design.

It is concluded that there are no areas for concern that could prevent demonstration that risks have been reduced to a level that is ALARP at the detailed design stage. Further detailed studies will, however, be required at detailed design stage, to confirm or refine the assumptions that have been made in this Concept Safety Analysis.

12. Sensitivity Analysis

It has been necessary to make a number of assumptions in the development of the CSA, because of the inevitable lack of detailed information at this stage of the Project.

Sensitivity studies have therefore been undertaken on a number of these assumptions to ensure that the information used is robust and appropriate at this stage. This section outlines those studies and considers the significance of the assumptions on calculated risk levels. Specifically, this section details the sensitivity analyses that have been performed on:

- Isolation probabilities.
- Precautionary Evacuation.

In addition, there are potential changes to the proposed development that could affect risks to personnel. These include:

- A subsea development, which would require additional hydrocarbon equipment on the platform.
- Produced water re-injection, which could result in higher concentrations of toxic gas in some of the process streams.

Each of these analyses is discussed in the following sections.

12.1 Isolation Probabilities

In the base case assessment, for all inventories other than manifold inventories, isolation probability is calculated based on two Emergency Shutdown Valves (ESVs) and one blowdown valve operating successfully (Section 7.4). For manifold inventories, the number of ESVs that must close to isolate the inventory is based on an estimate of the number of flowlines.

A sensitivity study was undertaken to investigate the impact on overall risk levels of assuming, for non-manifold inventories, that (i) two valves must operate successfully to ensure isolation of a typical inventory occurs and (ii) six valves must operate successfully to ensure isolation occurs.

Table 12.1 compares the TALL values for the base case and the cases where it is assumed that (i) two valves and (ii) six valves must operate to successfully isolate inventories other than manifold inventories. TALL values are presented for the drilling and production phase of the project, and the production only phase of the project when all drilling activities have ceased. The isolation probabilities for manifold inventories are not varied for this assessment, since the approach adopted in the assessment is more asset-specific in these cases.

Changing the number of valves that must operate to successfully isolate inventories from three (the base case) to:

- Two valves results in a decrease in TALL of 2.8×10^{-6} and 1.5×10^{-7} for the drilling and production phase and the production only phase, respectively.
- Six valves results in an increase in TALL of 7.8×10^{-6} and 4.2×10^{-6} for the drilling and production phase and the production only phase, respectively.

In both cases, the effect on risk is negligible and the original assumption (three valves) is therefore retained. It is, however, expected that an assessment of the number of valves that would have to operate successfully to ensure isolation of each inventory would be undertaken for the detailed QRA at design stage, once detailed Process and Instrumentation Diagrams are available.

12.2 Precautionary Evacuation

Precautionary evacuation represents a significant contribution to the overall risk presented in Section 11. Therefore, sensitivity studies were undertaken to investigate the impact on risk levels of using precautionary evacuation fatality rates of 2 % and 2.5 % rather than the 3 % assumed in the risk model. The sensitivity studies performed consider the impact of varying the precautionary evacuation fatality rate for all events. In addition, in cases where it is assumed in the risk model that an emergency evacuation is initiated, a fatality rate equal to twice the precautionary evacuation fatality rate is applied, in line with the assumption made in Sections 10.1.1, 10.2 and 10.4.

The results for the drilling and production and production only phases of the project are given in Tables 12.1 and 12.2.

	Theoretical Annual Loss of Life (TALL)		
	2 %	**2.5 %**	**3 %**
Immediate Fatalities	3.3×10^{-2}	3.3×10^{-2}	3.3×10^{-2}
Escape/Escalation Fatalities	1.9×10^{-4}	1.9×10^{-4}	1.9×10^{-4}
Precautionary Evacuation Fatalities	1.6×10^{-2}	2.0×10^{-2}	2.4×10^{-2}
TSR Impairment Fatalities	6.2×10^{-4}	6.2×10^{-4}	6.2×10^{-4}
Total	$\mathbf{5.0 \times 10^{-2}}$	$\mathbf{5.4 \times 10^{-2}}$	$\mathbf{5.8 \times 10^{-2}}$

Table 12.1: TALL Values for Precautionary Evacuation Fatality Rates of 2%, 2.5% and 3% for the Drilling and Production Phase

For the drilling and production phase of the project, the TALL contributions from precautionary evacuation for fatality rates of 2%, 2.5% and 3% are equivalent to approximately 32%, 37% and 41% respectively of the total platform TALL.

	Theoretical Annual Loss of Life (TALL)		
	2 %	**2.5 %**	**3 %**
Immediate Fatalities	1.9×10^{-2}	1.9×10^{-2}	1.9×10^{-2}
Escape/Escalation Fatalities	7.3×10^{-5}	7.3×10^{-5}	7.3×10^{-5}
Precautionary Evacuation Fatalities	2.1×10^{-3}	2.7×10^{-3}	3.2×10^{-3}
TSR Impairment Fatalities	3.1×10^{-4}	3.1×10^{-4}	3.1×10^{-4}
Total	$\mathbf{2.1 \times 10^{-2}}$	$\mathbf{2.2 \times 10^{-2}}$	$\mathbf{2.3 \times 10^{-2}}$

Table 12.2: TALL Values for Precautionary Evacuation Fatality Rates of 2%, 2.5% and 3% for the Production Only Phase

For the production only phase of the project, the TALL contributions from precautionary evacuation for fatality rates of 2%, 2.5% and 3% are equivalent to approximately 10%, 12% and 14% respectively of the total platform TALL.

The results of the sensitivity studies indicate that modifying the assumed precautionary evacuation fatality rate has a significant effect on the overall risk levels. Therefore, given the sensitivity of the results to this assumption, it is recommended that further studies be undertaken at detailed design stage to determine an appropriate precautionary evacuation fatality rate for the Project. However, the 3% fatality rate, which is based on experience of assessing evacuation risk for other installations, assuming a lifeboat evacuation under controlled conditions, is retained for this assessment, as it is considered to be appropriately conservative at this stage.

12.3 Pool 3 Subsea Development

ExxonMobil are currently considering developing a hydrocarbon resource (known as Pool 3) via a subsea development. It is anticipated that the development will consist of 10 oil production wells, 2 gas injection wells and 6 water injection wells that will be drilled remotely and tied back to the Hebron installation. Production from Pool 3 could start as early as 2018. Additional topsides equipment will be installed on a new module to be located on the side of the platform Process Area, and the risks associated with the potential for loss of containment from this equipment are discussed in Section 12.3.1. The risks to Hebron personnel associated with blowouts from the subsea wells are discussed in Section 12.3.2. Section 12.3.3 presents the risk results.

The potential for H_2S associated with the Pool 3 development, in later years of the project, is not considered here but will be assessed, if necessary, when more details are available. However, any risks associated with well souring will be small in comparison to risks associated with ignited events and the impact on overall risks to personnel on the platform is likely to be negligible.

12.3.1 Process Loss of Containment

12.3.1.1 Event Frequencies

Process hydrocarbon release events considered in the assessment of the 'base case' development are identified in Tables 7.1a to 7.1e. The leak frequencies for events associated with the additional equipment required for the subsea development, estimated using the methodology outlined in Section 7.1.1, are summarized in Table 12.3.

Release Event	Type of Equipment	Frequency Per Year
Cellar Deck – Release From:		
Oil Fiscal Metering	Oil Metering	3.69×10^{-2}
	Total	**3.69×10^{-2}**
Lower Deck – Release From:		
Inlet Heater	Heat Exchanger, Shell & Tube HC in Shell	7.97×10^{-3}
Inlet Separator (Gas)	Pressure Vessel, Horizontal	1.12×10^{-3}
Inlet Separator (Liquid)	Pressure Vessel, Horizontal	1.12×10^{-3}
Methanol Separator (Gas)	Pressure Vessel, Horizontal	1.12×10^{-3}
Methanol Separator (Liquid)	Pressure Vessel, Horizontal	1.12×10^{-3}
Gas Lift Compressor Suction Scrubber	Scrubber	1.79×10^{-3}
Gas Lift Compressor	Compressor	1.88×10^{-2}
	Total	**3.30×10^{-2}**
Main Deck – Release From:		
Gas Fiscal Metering	Gas Metering	2.89×10^{-2}
Pig Launcher & Pig Receiver	Pigging Equipment	2.34×10^{-2}
	Total	**5.23×10^{-2}**

Table 12.3: Subsea Development Release Event Frequencies

The total platform leak frequencies for the drilling and production and the production only phases, taking into account the topsides equipment associated with the subsea development, are 1.42 and 1.52, respectively, as compared to 1.30 and 1.40 without the subsea development (see Section 7.1).

12.3.1.2 Immediate Fatalities

Fatalities for ignited events associated with the additional equipment are estimated by assigning the fatalities estimated for similar events assessed as part of the base case development (as outlined in Section 7.7.1 and 7.7.2), taking into account fluid type, equipment type and operating conditions.

12.3.1.3 Escalation Fatalities due to Impairment of Fire and Blast Walls

It is expected that the blast floors and walls will be designed in FEED with sufficient allowance for future module addition, and that future module design will take into account existing blast floor and wall ratings so as not to change the validity of the assumptions considered in the base case assessment regarding the consequences of an explosion (see Section 7.7.4). It is however recommended that further consideration is given to the potential for impairment of fire and blast walls at detailed design stage.

12.3.1.4 Escape Fatalities

In line with the discussion presented in Section 7.7.5, it is not considered that the additional release events associated with the subsea development have the potential to result in escape fatalities.

12.3.1.5 Precautionary Evacuation and TSR Impairment Fatalities

As discussed in Section 7.7.6:

- Long duration ignited releases of oil or 2-phase fluids have the potential to result in smoke impairment of the TSR, if they occur coincident with other unfavourable conditions.
- Large unisolated unignited releases from the production or gas lift flowlines or manifolds (which are unisolated from a well and therefore of long duration) have the potential to result in gas impairment of the TSR, if they occur coincident with other unfavourable conditions.
- Large unisolated ignited releases from the production or gas lift flowlines or manifolds are considered to have the potential to eventually impair the platform structure and therefore the TSR, and it is therefore assumed that the OIM will initiate a precautionary evacuation.

Similar assumptions are retained for the assessment of additional events associated with the Pool 3 topsides equipment. In particular, it is assumed, due to the size of the pipeline inventory, that a large topsides release that is not isolated from the import riser/pipeline will have the potential to result in TSR impairment if unignited and will result in initiation of a precautionary evacuation if ignited.

12.3.2 Blowouts

Wells associated with the subsea development will be drilled by a MODU (mobile offshore drilling unit). There is not considered to be any risk to Hebron personnel from a subsea well blowout, either during drilling or during normal operations, as there would be no potential for such an event to impact the platform, due to the distance between the platform and the subsea development.

12.3.3 Risk Results

The results for the drilling and production and production only phases of the project are given in Tables 12.4 and 12.5 respectively.

	Theoretical Annual Loss of Life (TALL)	
	Base Case	**Including Pool 3**
Immediate Fatalities	3.3×10^{-2}	3.4×10^{-2}
Escape/Escalation Fatalities	1.9×10^{-4}	2.0×10^{-4}
Precautionary Evacuation Fatalities	2.4×10^{-2}	2.4×10^{-2}
TSR Impairment Fatalities	6.2×10^{-4}	6.2×10^{-4}
Total	$\mathbf{5.8 \times 10^{-2}}$	$\mathbf{5.9 \times 10^{-2}}$

Table 12.4: TALL Values for the Drilling and Production Phase – Including Pool 3 Topsides Equipment

	Theoretical Annual Loss of Life (TALL)	
	Base Case	**Including Pool 3**
Immediate Fatalities	1.9×10^{-2}	1.9×10^{-2}
Escape/Escalation Fatalities	7.3×10^{-5}	7.6×10^{-5}
Precautionary Evacuation Fatalities	3.2×10^{-3}	3.4×10^{-3}
TSR Impairment Fatalities	3.1×10^{-4}	3.1×10^{-4}
Total	$\mathbf{2.3 \times 10^{-2}}$	$\mathbf{2.3 \times 10^{-2}}$

Table 12.5: TALL Values for the Production Only Phase - Including Pool 3 Topsides Equipment

As can be seen, the overall increase in risks to personnel on the platform associated with the additional equipment required for the subsea development is very low.

12.4 Produced Water Re-injection

If, in addition to the seawater injection considered in the base case, produced water is re-injected, higher concentrations of toxic gas may occur in some process streams in future years. Further details of the expected H_2S concentrations and the dispersion calculations are given in Appendix 12.

As discussed in Section 7.7.3, a concentration of H_2S gas in air of 500ppm is considered to have the potential to result in fatalities.

The revised risk results for the production only phase of the project, accounting for the higher H_2S concentrations associated with produced water re-injection, are given in Table 12.6. As discussed in Section 7.7.3, high concentrations of H_2S are not expected during the drilling and production phase.

Fatality Classification	Theoretical Annual Loss of Life (TALL)	
	Sea Water Injection Only (Base Case)	Sea Water Injection and Produced Water Re-Injection (Worst Case)
Immediate (Fire/Explosions)	7.1×10^{-3}	7.1×10^{-3}
Immediate (Toxic Gas)	1.2×10^{-5}	5.7×10^{-5}
Immediate (Helicopter)	1.2×10^{-2}	1.2×10^{-2}
Escape/Escalation	7.3×10^{-5}	7.3×10^{-5}
Evacuation	1.9×10^{-2}	1.9×10^{-2}
TSR Impairment	3.1×10^{-4}	3.1×10^{-4}
Total	$\mathbf{2.3 \times 10^{-2}}$	$\mathbf{2.3 \times 10^{-2}}$
Contribution Toxic Gas (%)	**0.05%**	**0.25%**

Table 12.6: TALL Values for the Production Only Phase

13. Recommendations

Where uncertainty exists in the risk analysis, conservative assumptions (that is, assumptions that over-estimate the risk, rather than under-estimate the risk) have been made. Several recommendations have therefore been made in this report advising that these assumptions should be reviewed and revised at detailed design stage, when more detailed information is available, to facilitate a more robust and representative assessment.

This section therefore summarizes the recommendations made in this report for work that should be performed at detailed design.

1. Based on the assumption that blast walls will be designed to withstand predicted worst-case overpressure explosions, this CSA does not consider that there is any potential for escalation of explosions to areas protected by blast walls. This assumption should be reviewed and detailed studies performed if necessary (Section 7.7.4).

2. Detailed smoke, gas and flame modelling studies, and escape, evacuation and rescue, including TSR impairment, studies should be performed (Section 7.7.6).

3. The potential for explosions in the GBS should be evaluated further to ensure that risk is tolerable, despite the fact that the potential for ignition in the normally unmanned shaft is low (Sections 8.1 and 9.1).

4. Consideration should be given to performing a parts count, based on piping and instrumentation drawings, in order to refine leak frequency estimates (Section 7.1.1).

5. A Dropped Object Study should be carried out, to either confirm the assumptions made or identify dropped object events that should be considered in the design stage QRA (Section 5.1).

6. Further studies should be undertaken to determine an appropriate precautionary evacuation fatality rate, as the results of the sensitivity studies indicate that modifying the assumed precautionary evacuation fatality rate has a significant effect on the overall risk levels (Section 12.2).

7. A review of the adequacy of potential risk reduction measures to prevent, mitigate and safeguard against the scenarios identified in Section 11.4 as major risk contributors should be undertaken.

8. An assessment of the number of valves that would have to operate successfully to ensure isolation of each inventory should be undertaken for the detailed QRA, once Piping and Instrumentation Diagrams are available (Section 7.4).

9. Consideration should be given to developing a more complex model to assess the risk due to iceberg impact (Section 10.1.1).

10. The assumption that the support and standby vessels and shuttle tankers will be suitably ice-strengthened to permit their use in most sea ice conditions should be reviewed to ensure that the possibility of sea ice is considered when selecting evacuation systems (Section 10.1.3).

11. Further consideration should be given to the ability of the GBS to withstand powered passing vessel collisions, and the assessment of risk due to ship collision refined accordingly (Section 10.2).

In addition, all assumptions made in the assessment should be reviewed, in developing the detailed Quantified Risk Assessment for the project, in order to ensure that they remain valid and appropriate.

14. References

1. Register of Identified Hazards, RMRI Ref. No. EXM/0256, Technical Document 002, Rev. 2, March 2011.

2. The Hydrocarbon Releases (HCR) System Database, HSE, Data from 1992 to 2009.

3. The Probability Distribution of Hole Sizes for Process Leaks Offshore, RMRI In-house Study, 1999.

4. A Guide to Quantitative Risk Assessment for Offshore Installations, CMPT, CMPT Publications 99/100, 1999.

5. Ignition Probability Review, Model Development and Look-up Correlations, Energy Institute, January 2006.

6. Quantitative Risk Assessment Datasheet Directory, E&P Forum, Report 11.8/250, 1996.

7. OREDA 2002, Offshore Reliability Data, Prepared by Sintef, 2002.

8. The Effects of Explosions in the Process Industries, Institute of Chemical Engineers, 1989.

9. Acid Gas Content for Years 2027, 2033, 2034, 2035, 2040, 2042 and 2045, Hebron Project FEED/EPC Topsides, CAHE-WP-PRSIM-21-000-0003, Rev. C0, 2011.

10. OGP Risk Assessment Data Directory, Blowout Frequencies, Report No. 434 – 2, International Association of Oil and Gas Producers, March 2010.

11. General Requirements, Design Criteria, the Environment, and Loads, Canadian Standards Association, CAN/CSA-S471-04.

12. Hebron Site Meteorological and Oceanographic Design Criteria, V1.9, May 2001.

13. Working Environment related to Weather Conditions, Doc. No. 40187-AKT-TN-0002, Rev. 1, September 2003.

14. Selection of Ice Design Basis Criteria, Doc. No. HEBRON-FAC-024, Draft A.

15. OGP Risk Assessment Data Directory, Ship/Installation Collisions, Report No. 434-16, International Association of Oil and Gas Producers, March 2010.

16. Concept Safety Evaluation of the Proposed Hibernia Production, Drilling and Quarters Platform, Ref. L4281/1, Cremer and Warner Ltd, October 1991.

17. OGP Risk Assessment Data Directory, Aviation Transport Accident Statistics, Report No. 434 – 11.1, International Association of Oil and Gas Producers, March 2010.

APPENDIX 1:

REPRESENTATIVE LOSS OF CONTAINMENT EVENT TREE

	Event Tree Probabilities						ID	Event Frequency	TALL Contribution	Fatalities				Total Fatalities
	Non-Explosive Ignition	Fire/Gas Detection	Isolation	Deluge	Explosive Ignition	Explosion Overpressure				Immediate Fatalities	Escape and Escalation Fatalities	Evacuation Fatalities	TSR Impairment Fatalities	
IF: 3.35E-05	Yes: 0.019	a) Yes: 0.99	a) Yes: 0.885	a) Yes: 0.985			(E1)	5.49E-07	2.87E-07	0.522	0	0	0	0.522
				b) No: 0.015			(E2)	8.37E-09	4.36E-09	0.522	0	0	0	0.522
			b) No: 0.115	a) 0.985			(E3)	7.14E-08	3.72E-08	0.522	0	0	0	0.522
				b) 0.015			(E4)	1.09E-09	5.67E-10	0.522	0	0	0	0.522
		b) No: 0.01					(E5)	6.37E-09	3.32E-09	0.522	0	0	0	0.522
	No: 0.981	a) 0.99	a) 0.885	a) 0.0	a) Yes: 2.42E-03	a) <0.2 Bar: 0.2	(E6)	0	0	0.625	0	0	0	0.625
						b) 0.2 Bar to 1.0 Bar: 0.8	(E7)	0	0	1.25	0	0	0	1.25
						c) 1.0 Bar to 2.0 Bar: 0.0	(E8)	0	0	1.25	0.625	0	0	1.875
						d) >2.0 Bar: 0.0	(E9)	0	0	1.25	1.25	0	0	2.5
					b) No: 0.998		(E10)	0	0	0	0	0	0	0
				b) 1.0	a) 2.42E-03	a) 0.1	(E11)	6.97E-09	4.35E-09	0.625	0	0	0	0.625
						b) 0.4	(E12)	2.79E-08	3.48E-08	1.25	0	0	0	1.25
						c) 0.5	(E13)	3.48E-08	6.53E-08	1.25	0.625	0	0	1.875
						d) 0.0	(E14)	0	0	1.25	1.25	0	0	2.5
					b) 0.998		(E15)	2.87E-05	0	0	0	0	0	0
			b) 0.115	a) 0.0	a) 2.42E-03	a) 0.2	(E16)	0	0	0.625	0	0	0	0.625
						b) 0.8	(E17)	0	0	1.25	0	0	0	1.25
						c) 0.0	(E18)	0	0	1.25	0.625	0	0	1.875
						d) 0.0	(E19)	0	0	1.25	1.25	0	0	2.5
					b) 0.993		(E20)	0	0	0	0	0	0	0
				b) 1.0	a) 2.42E-03	a) 0.1	(E21)	9.05E-10	5.66E-10	0.625	0	0	0	0.625
						b) 0.4	(E22)	3.62E-09	4.53E-09	1.25	0	0	0	1.25
						c) 0.5	(E23)	4.53E-09	8.49E-09	1.25	0.625	0	0	1.875
						d) 0.0	(E24)	0	0	1.25	1.25	0	0	2.5
					b) 0.998		(E25)	3.73E-06	0	0	0	0	0	0
		b) 0.01			a) 2.42E-03	a) 0.1	(E26)	7.95E-11	9.94E-11	1.25	0	0	0	1.25
						b) 0.4	(E27)	3.18E-10	7.95E-10	2.5	0	0	0	2.5
						c) 0.5	(E28)	3.98E-10	1.49E-09	2.5	1.25	0	0	3.75
						d) 0.0	(E29)	0	0	2.5	2.5	0	0	5
					b) 0.998		(E30)	3.28E-07	0	0	0	0	0	0
									4.52E-07					

Hazard :	Inventory :	Hole Size :		Project :
Process Loss of Containment	MP Separator (Gas)	Large		Hebron CSA Production Only

APPENDIX 2:

IMMEDIATE FATALITIES DUE TO FIRES

A2.1 Estimation of Fire Fatalities

As described in Section 7.7.1, immediate fatalities from jet fires are calculated as:

Fatalities = Fatality Area x Population Density

where Population Density is a characteristic of the area of the platform in which the release event occurs. It is calculated as:

$$\text{Population Density} = \frac{\text{Number of Personnel in Release Location}}{\text{Area of Release Location}}$$

Tables A2.1 to A2.7 show, for each release event and release size:

- The fatality area, based on gas contour modelling.
- The area of the section of deck in which the release occurs (if the Fatality Area for a release is greater than this area the number of personnel in the area is taken as an upper bound on the number of immediate fatalities).
- The fatality percentage, which is derived as:

$$\text{Fatality Percentage} = \frac{\text{Fatality Area}}{\text{Area of Release Location}}$$

- The number of fatalities, which is estimated based on the fatality percentage and the number of personnel in the area of the platform in which the release occurs (taken from Table 6.1).

Process Area CD Inventories	Hole Size	Fatality Area (m^2)	Fatality Rate	Fatalities
Crude Oil Pumps	Small	146	0.09	0.1389
	Medium	2502	1.00	1.5000
	Large	11060	1.00	1.5000
Export Pumps	Small	232	0.15	0.2210
	Medium	4041	1.00	1.5000
	Large	16393	1.00	1.5000
Fiscal Metering Skid	Small	232	0.15	0.2210
	Medium	4041	1.00	1.5000
	Large	16393	1.00	1.5000
Flare KO Drum (Gas)	Small	0	0.00	0.0000
	Medium	21	0.01	0.0197
	Large	223	0.14	0.2124
Flare KO Drum and Pumps (Liquid)	Small	95	0.06	0.0903
	Medium	2007	1.00	1.5000
	Large	9907	1.00	1.5000

Table A2.1: Jetfire Fatality Estimates for Process Area CD Release Events

Process Area LD Inventories	Hole Size	Fatality Area (m^2)	Fatality Rate	Fatalities
Oil Water/Separator	Small Medium Large	98 1648 7643	0.06 0.94 1.00	0.0835 1.4027 1.5000
LP Inlet Heater	Small Medium Large	95 2007 9907	0.05 1.00 1.00	0.0807 1.5000 1.5000
Compact Electrostatic Coalescer	Small Medium Large	30 524 2129	0.02 0.30 1.00	0.0255 0.4458 1.5000
Crude Oil Cooler	Small Medium Large	98 1648 7643	0.06 0.94 1.00	0.0835 1.4027 1.5000
Oil/Oil Exchanger – Downstream from MP Separator	Small Medium Large	95 2007 9907	0.05 1.00 1.00	0.0807 1.5000 1.5000
Oil/Oil Exchanger – Downstream from Crude Oil Pumps	Small Medium Large	146 2502 11060	0.08 1.00 1.00	0.1241 1.5000 1.5000
MP Inlet Heater	Small Medium Large	0 674 3593	0.00 0.38 1.00	0.0000 0.5735 1.5000
Fuel Gas Scrubber	Small Medium Large	4 478 2812	< 0.01 0.27 1.00	0.0037 0.4066 1.5000
Fuel Gas Heater	Small Medium Large	4 478 2812	< 0.01 0.27 1.00	0.0037 0.4066 1.5000
Fuel Gas Calorimeter	Small Medium Large	4 478 2812	< 0.01 0.27 1.00	0.0037 0.4066 1.5000
Power Generator Turbine and Compressor Turbine Fuel Gas Filter/Scrubber Packages	Small Medium Large	4 478 2812	< 0.01 0.27 1.00	0.0037 0.4066 1.5000
TEG Flash Drum (Gas)	Small Medium Large	5 52 478	< 0.01 0.03 0.27	0.0040 0.0446 0.4070
Stripping Gas Column (Gas), Still Column (Gas) and Vent Cooler	Small Medium Large	0 11 35	0.00 0.01 0.02	0.0000 0.0090 0.0297

Table A2.2: Jetfire Fatality Estimates for Process Area LD Release Events

Process Area LD Inventories	**Hole Size**	**Fatality Area (m^2)**	**Fatality Rate**	**Fatalities**
TEG Vent Scrubber	Small Medium Large	0 11 35	0.00 0.01 0.02	0.0000 0.0090 0.0297
TEG Vent Blower to 1st Stage LP Suction Cooler	Small Medium Large	0 11 35	0.00 0.01 0.02	0.0000 0.0090 0.0297
OLS Pig Launchers/Receivers	Small Medium Large	232 4041 16393	0.13 1.00 1.00	0.1975 1.5000 1.5000

Table A2.2 (cont.): Jetfire Fatality Estimates for Process Area LD Release Events

Process Area MD Inventories	**Hole Size**	**Fatality Area (m^2)**	**Fatality Rate**	**Fatalities**
LP Separator (Gas)	Small Medium Large	0 21 223	0.00 0.01 0.10	0.0000 0.0226 0.2433
LP Separator (Liquid)	Small Medium Large	30 524 2129	0.01 0.23 0.93	0.0327 0.5714 2.3227
MP Separator (Gas)	Small Medium Large	5 52 478	< 0.01 0.02 0.21	0.0052 0.0571 0.5216
MP Separator (Liquid)	Small Medium Large	95 2007 9907	0.04 0.88 1.00	0.1034 2.1896 2.5000
LP Compression 1st Stage Suction Scrubber	Small Medium Large	0 0 23	0.00 0.00 0.01	0.0000 0.0000 0.0254
LP Gas Compressor (1st Stage)	Small Medium Large	0 21 223	0.00 0.01 0.10	0.0000 0.0226 0.2433
LP Compression 2nd Stage Suction Scrubber	Small Medium Large	0 21 223	0.00 0.01 0.10	0.0000 0.0226 0.2433
LP Gas Compressor (2nd Stage)	Small Medium Large	5 66 577	< 0.01 0.03 0.25	0.0053 0.0718 0.6293

Table A2.3: Jetfire Fatality Estimates for Process Area MD Release Events

Process Area MD Inventories	Hole Size	Fatality Area (m^2)	Fatality Rate	Fatalities
MP Compression Suction Scrubber	Small	5	< 0.01	0.0052
	Medium	52	0.02	0.0571
	Large	478	0.21	0.5216
MP Gas Compressor	Small	6	< 0.01	0.0061
	Medium	249	0.11	0.2716
	Large	1659	0.72	1.8100
HP Compression Suction Scrubber	Small	6	< 0.01	0.0061
	Medium	249	0.11	0.2716
	Large	1659	0.72	1.8100
HP Gas Compressor	Small	12	0.01	0.0128
	Medium	830	0.36	0.9051
	Large	4469	1.00	2.5000
Gas Lift Compression Suction Scrubber	Small	12	0.01	0.0128
	Medium	830	0.36	0.9051
	Large	4469	1.00	2.5000
Gas Lift Compressor	Small	58	0.03	0.0631
	Medium	2389	1.00	2.5000
	Large	11646	1.00	2.5000
Gas Injection Compression Suction Scrubber	Small	58	0.03	0.0631
	Medium	2389	1.00	2.5000
	Large	11646	1.00	2.5000
Gas Injection Compressor	Small	91	0.04	0.0995
	Medium	3267	1.00	2.5000
	Large	15765	1.00	2.5000
Dehydration Contactor	Small	12	0.01	0.0128
	Medium	830	0.36	0.9051
	Large	4469	1.00	2.5000
Dehydration Scrubber	Small	12	0.01	0.0128
	Medium	830	0.36	0.9051
	Large	4469	1.00	2.5000
Dehydration Filter Coalescer	Small	12	0.01	0.0128
	Medium	830	0.36	0.9051
	Large	4469	1.00	2.5000
TEG Vent and Flash Gas to LP Suction Cooler	Small	0	0.00	0.0000
	Medium	11	<0.01	0.0116
	Large	35	0.02	0.0381
Produced Water Degassing Drum (Gas)	Small	0	0.00	0.0000
	Medium	11	<0.01	0.0116
	Large	35	0.02	0.0381

Table A2.3 (cont): Jetfire Fatality Estimates for Process Area MD Release Events

Process Area UD Inventories	Hole Size	Fatality Area (m^2)	Fatality Rate	Fatalities
HP Separator (Gas)	Small	6	< 0.01	0.0061
	Medium	249	0.11	0.2716
	Large	1659	0.72	1.8100
HP Separator (Liquid)	Small	200	0.09	0.2182
	Medium	3605	1.00	2.5000
	Large	16999	1.00	2.5000
MP Test Separator (Gas)	Small	5	< 0.01	0.0052
	Medium	52	0.02	0.0571
	Large	478	0.21	0.5216
MP Test Separator (Liquid)	Small	95	0.04	0.1034
	Medium	2007	0.88	2.1896
	Large	9907	1.00	2.5000
MP Test Separator Inlet Heater	Small	0	0.00	0.0000
	Medium	674	0.29	0.7350
	Large	3593	1.00	2.5000
HP Test Separator (Gas)	Small	6	< 0.01	0.0061
	Medium	249	0.11	0.2716
	Large	1659	0.72	1.8100
HP Test Separator (Liquid)	Small	200	0.09	0.2182
	Medium	3605	1.00	2.5000
	Large	16999	1.00	2.5000
HP Test Separator Inlet Heater	Small	136	0.06	0.1484
	Medium	2382	1.00	2.5000
	Large	11219	1.00	2.5000
LP Compression 1st Stage Suction Cooler	Small	0	0.00	0.0000
	Medium	21	0.01	0.0226
	Large	223	0.10	0.2433
LP Compression 2nd Stage Suction Cooler	Small	0	0.00	0.0000
	Medium	21	0.01	0.0226
	Large	223	0.10	0.2433
MP Compression Suction Cooler	Small	5	< 0.01	0.0052
	Medium	52	0.02	0.0571
	Large	478	0.21	0.5216
HP Compression Suction Cooler	Small	6	< 0.01	0.0061
	Medium	249	0.11	0.2716
	Large	1659	0.72	1.8100
Gas Lift Compression Recycle Cooler	Small	12	0.01	0.0128
	Medium	830	0.36	0.9051
	Large	4469	1.00	2.5000

Table A2.4: Jetfire Fatality Estimates for Process Area UD Release Events

Process Area UD Inventories	Hole Size	Fatality Area (m^2)	Fatality Rate	Fatalities
Gas Injection Compression Suction Cooler	Small	58	0.03	0.0631
	Medium	2389	1.00	2.5000
	Large	11646	1.00	2.5000
Dehydration Inlet Cooler	Small	12	0.01	0.0128
	Medium	830	0.36	0.9051
	Large	4469	1.00	2.5000
Gas/Glycol Heat Exchanger	Small	12	0.01	0.0128
	Medium	830	0.36	0.9051
	Large	4469	1.00	2.5000
Gas Lift Cooler	Small	58	0.03	0.0631
	Medium	2389	1.00	2.5000
	Large	11646	1.00	2.5000

Table A2.4 (cont): Jetfire Fatality Estimates for Process Area UD Release Events

Export Booster Pump CD Inventories	Hole Size	Fatality Area (m^2)	Fatality Rate	Fatalities
Crude Recirculation Heater	Small	98	0.23	0.2279
	Medium	1648	1.00	1.0000
	Large	7643	1.00	1.0000

Table A2.5 Jetfire Fatality Estimates for Export Booster Pump Area CD Release Event

Power Generation Area Inventories	Hole Size	Fatality Area (m^2)	Fatality Rate	Fatalities
Main Power Generators	Small	4	< 0.01	0.0044
	Medium	478	0.32	0.4875
	Large	2812	1.00	1.5000

Table A2.6 Jetfire Fatality Estimates for Power Generation Area Release Event

Wellhead/Manifold LD Inventories	Hole Size	Fatality Area (m^2)	Fatality Rate	Fatalities	
				Drilling and Production Phase	Production Only Phase
HP Production/Test Manifolds	Small	136	0.11	0.9173	0.4586
	Medium	2382	1.00	8.0000	4.0000
	Large	11219	1.00	8.0000	4.0000
MP Production/Test Manifolds	Small	0	0.00	0.0000	0.0000
	Medium	674	0.57	4.5423	2.2711
	Large	3593	1.00	8.0000	4.0000
Gas Lift Manifold	Small	58	0.05	0.3898	0.1949
	Medium	2389	1.00	8.0000	4.0000
	Large	11646	1.00	8.0000	4.0000
Distribution Manifold	Small	98	0.08	0.6613	0.3306
	Medium	1648	1.00	8.0000	4.0000
	Large	7643	1.00	8.0000	4.0000
Offloading Manifold	Small	146	0.12	0.9832	0.4916
	Medium	2502	1.00	8.0000	4.0000
	Large	11060	1.00	8.0000	4.0000

Table A2.7 Jetfire Fatality Estimates for Manifold/Wellhead Area LD Release Events

APPENDIX 3:

Explosion Fatalities

A3.1 Estimation of Explosion Fatalities

As discussed in Sections 7.7.2 and 7.7.4, the rule set in Table A3.1 is used to estimate fatalities resulting from explosions, accounting for the effects of explosion overpressure on personnel and also for the effects of the size of a gas cloud on the overpressure generated.

Overpressure Range	Immediate Area	Adjacent Areas (not Protected by Blast Rated Wall/Deck)
< 0.2 Bar	50%	0%
0.2 Bar to 1.0 Bar	100%	0%
1.0 Bar to 2.0 Bar	100%	50%
> 2.0 Bar	100%	100%

Table A3.1: Explosion Fatality Rule Set

Tables A3.2 and A3.3 show, for each release event and release size, for both the drilling and production phase and the production only phase:

- The number of fatalities in the immediate area, estimated based on the fatality percentage and the number of personnel in the area of the platform in which the release occurs (taken from Table 6.1).
- The number of fatalities in adjacent areas, estimated taking account of the location of blast walls, the fatality percentages in Table A3.1 and the number of personnel in the areas adjacent to where the release occurs (taken from Table 6.1).

Location	Adjacent Area(s)	Overpressure	Fatalities in Immediate Area	Fatalities in Adjacent Area(s)	Total Fatalities
Process - CD	Process - LD	< 0.2	0.375	0	0.375
	Process - LD	0.2 - 1	0.75	0	0.75
	Process - LD	1 - 2	0.75	0.375	1.125
	Process - LD	> 2	0.75	0.75	1.5
Process - LD	Process - CD	< 0.2	0.375	0	0.375
	Process - CD	0.2 - 1	0.75	0	0.75
	Process - CD	1 - 2	0.75	0.375	1.125
	Process - CD	> 2	0.75	0.75	1.5

Table A3.2: Explosion Fatalities, Detected Releases

Location	Adjacent Area(s)	Overpressure	Fatalities in Immediate Area	Fatalities in Adjacent Area(s)	Total Fatalities
Process - MD	Process - UD	< 0.2	0.625	0	0.625
	Process - UD	0.2 - 1	1.25	0	1.25
	Process - UD	1 - 2	1.25	0.625	1.875
	Process - UD	> 2	1.25	1.25	2.5
Process - UD	Process – MD & DSM	< 0.2	0.625	0	0.625
	Process - MD & DSM	0.2 - 1	1.25	0	1.25
	Process - MD & DSM	1 - 2	1.25	4.375[1] 0.625[2]	5.625[1] 1.875[2]
	Process - MD & DSM	> 2	1.25	8.75[1] 1.25[2]	10[1] 2.5[2]
Export Booster Pump - CD	Wellhead/Manifold - LD	< 0.2	0.25	0	0.25
	Wellhead/Manifold - LD	0.2 - 1	0.5	0	0.5
	Wellhead/Manifold - LD	1 - 2	0.5	2[1] 1[2]	2.5[1] 1.5[2]
	Wellhead/Manifold - LD	> 2	0.5	4[1] 2[2]	4.5[1] 2.5[2]
Wellhead/ Manifold - LD	Export Booster Pump - CD & Wellhead/Intervention - MD	< 0.2	2[1] 1[2]	0[1] 0[2]	2[1] 1[2]
	Export Booster Pump - CD & Wellhead/Intervention - MD	0.2 - 1	4[1] 2[2]	0[1] 0[2]	4[1] 2[2]
	Export Booster Pump - CD & Wellhead/Intervention - MD	1 - 2	4[1] 2[2]	2[1] 1.25[2]	6[1] 3.25[2]
	Export Booster Pump - CD & Wellhead/Intervention - MD	> 2	4[1] 2[2]	4[1] 2.5[2]	8[1] 4.5[2]
Power Generation	N/A	< 0.2	0.375	0	0.375
	N/A	0.2 - 1	0.75	0	0.75
	N/A	1 - 2	0.75	0	0.75
	N/A	> 2	0.75	0	0.75

1: Drilling and production phase.
2: Production only phase.

Table A3.2 (cont): Explosion Fatalities, Detected Releases

Location	Adjacent Area(s)	Overpressure	Fatalities in Immediate Area	Fatalities in Adjacent Area(s)	Total Fatalities
Process - CD	Process - LD	< 0.2	0.75	0	0.75
	Process - LD	0.2 - 1	1.5	0	1.5
	Process - LD	1 - 2	1.5	0.75	2.25
	Process - LD	> 2	1.5	1.5	3
Process - LD	Process - CD	< 0.2	0.75	0	0.75
	Process - CD	0.2 - 1	1.5	0	1.5
	Process - CD	1 - 2	1.5	0.75	2.25
	Process - CD	> 2	1.5	1.5	3
Process - MD	Process - UD	< 0.2	1.25	0	1.25
	Process - UD	0.2 - 1	2.5	0	2.5
	Process - UD	1 - 2	2.5	1.25	3.75
	Process - UD	> 2	2.5	2.5	5
Process - UD	Process - MD & DSM	< 0.2	1.25	0	1.25
	Process - MD & DSM	0.2 - 1	2.5	0	2.5
	Process - MD & DSM	1 - 2	2.5	8.75[1] 1.25[2]	11.25[1] 3.75[2]
	Process - MD & DSM	> 2	2.5	17.5[1] 2.5[2]	20[1] 5[2]
Export Booster Pump - CD	Wellhead/Manifold - LD	< 0.2	0.5	0	0.5
	Wellhead/Manifold - LD	0.2 - 1	1	0	1
	Wellhead/Manifold - LD	1 - 2	1	4[1] 2[2]	5[1] 3[2]
	Wellhead/Manifold - LD	> 2	1	8[1] 4[2]	9[1] 5[2]
Wellhead/ Manifold - LD	Export Booster Pump - CD & Wellhead/Intervention - MD	< 0.2	4[1] 2[2]	0[1] 0[2]	4[1] 2[2]
	Export Booster Pump - CD & Wellhead/Intervention - MD	0.2 - 1	8[1] 4[2]	0[1] 0[2]	8[1] 4[2]
	Export Booster Pump - CD & Wellhead/Intervention - MD	1 - 2	8[1] 4[2]	4[1] 2.5[2]	12[1] 6.5[2]
	Export Booster Pump - CD & Wellhead/Intervention - MD	> 2	8[1] 4[2]	8[1] 5[2]	16[1] 9[2]

1: Drilling and production phase.
2: Production only phase.

Table A3.3: Explosion Fatalities, Undetected Releases

Location	Adjacent Area(s)	Overpressure	Fatalities in Immediate Area	Fatalities in Adjacent Area(s)	Total Fatalities
Power Generation	N/A	< 0.2	0.75	0	0.75
	N/A	0.2 - 1	1.5	0	1.5
	N/A	1 - 2	1.5	0	1.5
	N/A	> 2	1.5	0	1.5

Table A3.3 (cont): Explosion Fatalities, Undetected Releases

APPENDIX 4:

ICEBERG COLLISION EVENT TREE

R M R I	ID	Event Frequency	TALL Contribution	Fatalities				Total Fatalities
				Immediate Fatalities	Escape and Escalation Fatalities	Evacuation Fatalities	TSR Impairment Fatalities	
IF: 1.00E-05	(E1)	1.00E-05	7.50E-04	0	0	7.5	0	7.5
			7.50E-04					

Hazard : Iceberg Collision				Project : Hebron CSA Production Only

APPENDIX 5:

PASSING VESSEL COLLISION EVENT TREE

R M R I

Event	ID	Event Frequency	TALL Contribution	Fatalities				Consequence Estimate Total
High Energy Collision				Immediate Fatalities	Escape and Escalation Fatalities	Evacuation Fatalities	TSR Impairment Fatalities	
IF: 2.50E-05 — Yes: 0.1	(E1)	2.50E-06	1.88E-05	0	0	7.5	0	7.5
No: 0.9	(E2)	2.25E-05	0	0	0	0	0	0
			1.88E-05					

Hazard :
Passing Vessel Collision

Project :
Hebron CSA Production Only

APPENDIX 6:

REPRESENTATIVE HELICOPTER CRASH EVENT TREE

Event	Fatality Accident	ID	Event Frequency	TALL Contribution	Fatalities: Immediate Fatalities	Fatalities: Escape and Escalation Fatalities	Fatalities: Evacuation Fatalities	Fatalities: TSR Impairment Fatalities	Total Fatalities
IF: 4.23E-03	Yes: 0.2	(E1)	8.46E-04	1.22E-02	14.45	0	0	0	14.45
	No: 0.8	(E2)	3.38E-03	0	0	0	0	0	0
				1.22E-02					

Hazard :	Flight Stage :			Project :
Helicopter Crash	During Flight			Hebron CSA Production Only

APPENDIX 7:

SEISMIC ACTIVITY
EVENT TREE

R M R I

Event		ID	Event Frequency	TALL Contribution	Fatalities				Total Fatalities
	Severe Earthquake?				Immediate Fatalities	Escape and Escalation Fatalities	Evacuation Fatalities	TSR Impairment Fatalities	
IF: 5.00E-04	Yes: 0.1	(E1)	5.00E-05	2.81E-04	0	0	1.875	3.75	5.625
	No: 0.9	(E2)	4.50E-04	0	0	0	0	0	0
				2.81E-04					

Hazard : Seismic Activity				Project : Hebron CSA Production Only

APPENDIX 8:

REPRESENTATIVE SMOKE INGRESS EVENT TREE

R M R I

Event Tree Probabilities					ID	Event Frequency	E(Prec. Evacuation Fatalities)	E(Smoke Impairment Fatalities)	Precautionary Evacuation Fatalities	Smoke Impairment Fatalities
	Wind in TSR Direction	Smoke Enters TSR	Lifeboats Impaired	TSR Impaired						
IF: 1.0	Yes: 0.3	Yes: 0.1	Yes: 0.2	Yes: 0.5	(E1)	3.00E-03	0	0.188	0	62.5
				No: 0.5	(E2)	3.00E-03	0	0	0	0
			No: 0.8		(E3)	0.024	0.09	0	3.75	0
		No: 0.9			(E4)	0.27	0	0	0	0
	No: 0.7				(E5)	0.7	0	0	0	0
							0.09	0.188		

Hazard :	Sub-category 1 :			Project :
Smoke Ingress	Process Area			Hebron CSA Production Only

APPENDIX 9:

GAS INGRESS EVENT TREE

Event Tree Probabilities			ID	Event Frequency	E(Prec. Evacuation Fatalities)	E(Smoke Impairment Fatalities)	Precautionary Evacuation Fatalities	Smoke Impairment Fatalities
	Wind in TSR Direction	Gas Enters TSR						
IF: 1.0	Yes: 0.3	Yes: 0.2	(E1)	0.06	0.225	0	3.75	0
		No: 0.8	(E2)	0.24	0	0	0	0
	No: 0.7		(E3)	0.7	0	0	0	0
					0.225	0		

Hazard :	Sub-category 1 :			Project :
Gas Ingress	Wellbay/Manifold Area			Hebron CSA Production Only

APPENDIX 10:

SMOKE AND GAS IMPAIRMENT OF TSR/EVACUATION SYSTEMS

A10.1 Smoke Ingress

A10.1.1 Impairment Events

Smoke is generated by any burning hydrocarbon but, in general, significant quantities of smoke are only generated by long duration liquid fires. Therefore, it is assumed that any unisolated ignited large oil or 2-phase release will result in a large long duration fire, which if coincident with unfavourable conditions, could impair the TSR.

A10.1.2 Smoke Impairment Event Tree

For the TSR to be affected by smoke, the following conditions would have to occur, coincident with a long duration fire:

- Wind blows smoke from the fire towards the TSR.
- Smoke reaches TSR at high concentration.
- Smoke enters the TSR (for example, via the HVAC inlet or any other penetrations such as doors).

The event tree used to account for the likelihood of the coincident conditions that must occur for the TSR to be affected by smoke from a long duration fire is shown in Appendix 7. The event tree branch events are:

1. Smoke travels towards the TSR.
2. Smoke reaches the TSR in high concentration and enters the TSR.
3. Smoke impairs the evacuation systems.
4. Smoke impairment conditions are reached inside the TSR.

The event tree identifies five possible outcomes. These outcomes represent four 'TSR Conditions', see Table A10.1.

Condition No.	TSR Condition
1	No smoke hazard in the TSR (Outcomes E4 and E5)
2	Smoke reaches the TSR and begins to ingress into the TSR, but does not impair the lifeboats (Outcome E3)
3	Smoke reaches the TSR, begins to ingress, and also impairs the lifeboat evacuation systems. Personnel remain in TSR. (Outcome E2)
4	Smoke impairment conditions are also reached in the TSR (Outcome E1)

Table A10.1: Smoke Impairment Event Tree, TSR Conditions

Any decision to evacuate the platform will be at the discretion of the OIM. If smoke enters the TSR, the OIM will not necessarily wait until the concentration reaches impairment levels before considering an evacuation of the platform.

It is assumed that if smoke begins to ingress the TSR and the lifeboat evacuation system are not impaired by smoke (Condition 2), the OIM will order a 'precautionary' evacuation. That is, the OIM will tactically decide to evacuate by lifeboat whilst they are available, to protect personnel from the possibility of further smoke ingress and the possibility of subsequent coincident impairment of both TSR and evacuation systems.

However, if the evacuation systems are impaired by smoke when smoke begins to ingress the TSR, it is assumed that personnel remain in the TSR. That is, to wait either for the event to be brought under control or for wind conditions to improve (Condition 3). Should impairment conditions subsequently be reached in the TSR (Condition 4) however, the OIM would have to order an 'emergency evacuation' of the installation under smoke impairment conditions.

A10.1.2.1 Event Tree Branch Probabilities

The branch probabilities used in the smoke impairment event trees are shown in Table A10.2. These probabilities are subjectively estimated, based on experience of undertaking studies for similar installations. It may be necessary, at detailed design stage, to review these probabilities in a detailed TSR impairment analysis and revise the risk assessment accordingly.

Branch	Location	Probability
1	All Areas	0.3
2	Process Area	0.1
	Wellhead/Manifold and Intervention Areas	0.2
	Power Generation/Utility Areas	0.5
	Drilling Equipment Sets	0.05
3	All Areas	0.2
4	All Areas	0.5

Table A10.2: Branch Probabilities for Smoke Impairment Event Trees

Branch 1:

Smoke will only travel towards the TSR if wind direction is from the fire towards the TSR. The probability is taken to be 0.3, which, based on metocean data for the Hebron site, is considered to be very conservative.

Branch 2:

The distance from the Process Area to the TSR is approximately 80 metres. If smoke from a fire blows towards the TSR, the distance it has to travel would result in significant dilution. Heat from the fire would generate buoyant products, which would tend to carry smoke above the TSR.

If smoke, nevertheless, does reach the TSR in high concentration, it could enter the TSR via the HVAC intakes or any other penetrations such as doors. Smoke could ingress rapidly if drawn in through the HVAC intakes, or would ingress only slowly through the various other TSR penetrations.

However, if smoke is detected at the HVAC intakes, the HVAC system shuts down and the dampers close, to prevent rapid ingress. The likelihood of rapid smoke ingress due to the HVAC system failing to shut down is not considered here. It is assumed that the HVAC inlets will be located in a sheltered area of the platform and that the reliability of the smoke detectors and dampers will be addressed during detailed design. Smoke could enter the TSR slowly through the various other TSR penetrations, but a modern TSR design should ensure that this is unlikely.

Therefore, the probability that smoke from a fire in the process area reaches the TSR in ‘high’ concentration and enters the TSR is considered to be low (0.1). For the areas nearer to the TSR, higher probabilities are assigned. A probability of 0.2 and 0.5 is assigned for the Wellhead/Manifold and Intervention Areas and Power Generation/Utility Areas respectively. The DES is at an elevated position, therefore smoke from a fire at this location is likely to be carried above the TSR. The probability of smoke reaching and entering the TSR is taken to be 0.05 for an event originating in the DES.

Branch 3:

The lifeboats are sheltered from all potential fire events by the TSR and are located at the lowest (Cellar Deck) level. Therefore, a low probability of 0.2 is assigned for the evacuation systems being impaired by smoke when smoke of high concentration reaches the TSR.

Branch 4:

If the evacuation systems are impaired by smoke, it is assumed that personnel will remain in the TSR. They would wait either for the event to be brought under control, or for wind conditions to improve (so that smoke moves away from the TSR and evacuation systems).

Should impairment conditions subsequently be reached in the TSR, the OIM would have to order an 'emergency evacuation' of the installation under smoke impairment conditions.

A modern TSR design should ensure that this is unlikely, however, in order to ensure a conservative analysis, the probability that smoke reaches a concentration that constitutes impairment conditions is assumed to be 0.5.

A10.1.2.2 Statistical Fatalities

The smoke impairment event tree (Appendix 8) identifies four possible 'TSR Conditions' (see Table A10.1). The number of statistical fatalities assigned, in the event tree analysis, for each TSR Condition are shown in Table A10.3.

Condition No.	**TSR Condition**	**Drilling and Production Phase**		**Production Only Phase**	
		Lifeboat Evacuation Fatalities	**Smoke Impairment Fatalities**	**Lifeboat Evacuation Fatalities**	**Smoke Impairment Fatalities**
1	No smoke hazard in the vicinity of the TSR	-	-	-	-
2	Smoke ingress into the TSR, but does not impair the lifeboats	7.02	-	3.75	-
3	Smoke ingress into the TSR and lifeboat impairment. Personnel remain in TSR.	-	-	-	-
4	Smoke impairment conditions are also reached in the TSR	-	117	-	67.5

Table A10.3: Smoke Impairment Event Tree Statistical Fatalities

Condition 1:

No hazard, no fatalities assigned.

Condition 2:

This refers to an outcome where smoke enters the TSR (but does not reach impairment concentration) and the evacuation systems are unimpaired. The OIM will not necessarily wait until the concentration reaches impairment levels before considering an evacuation of the platform. Therefore, for this situation, 'precautionary evacuation fatalities' are accounted for. It is assumed that a lifeboat evacuation will be undertaken, and a weather-averaged fatality rate of 3% is applied. Detailed asset-specific evacuation modelling will be required at design stage, but the 3% fatality rate, which is based on experience of assessing evacuation risk for other installations, assuming a lifeboat evacuation under controlled conditions, is considered sufficiently conservative for this assessment.

Condition 3:

If, however, the evacuation systems are impaired by smoke, the OIM would not be able to initiate a precautionary evacuation. Personnel would remain in the TSR. No fatalities are assigned (unless impairment conditions are reached in the TSR, see below).

Condition 4:

If both the TSR and the evacuation systems are impaired by smoke, a 50% fatality rate is assumed for emergency evacuation under smoke impairment conditions. This is based on the fact that personnel may still be able to use the evacuation systems by wearing smoke hoods. There is also the possibility of escape to sea using the escape chutes.

A10.1.2.3 Statistical Fatality Rates

Based on the event tree (branch probability and fatality) data described above, the smoke impairment event trees (Appendix 8) determine statistical fatality rates for a potential impairment event (see Section A10.1.1). Statistical fatality rates are determined for:

- Precautionary evacuation of the TSR, as a result of smoke ingress.
- Smoke impairment of the TSR.

The fatality rates depend on fire location, see Section A10.1.2.1.

Based on the event trees described in Section A10.1.1 and statistical fatalities given in Table A10.3, Table A10.4 presents the statistical fatalities for potential smoke impairment events for the drilling and production phase, and Table A10.5 presents the statistical fatalities for potential smoke impairment events for the production only phase.

Release Location	Precautionary Evacuation Statistical Fatality Rates	TSR Impairment Statistical Fatality Rates
Process Area	0.168	0.351
Manifold and Wellhead/ Intervention Areas	0.337	0.702
Drilling Equipment Sets	0.084	0.176
Power Generation/Utility Areas	0.842	1.755

Table A10.4: Statistical Fatality Rates for Potential Smoke Impairment Events (Drilling and Production Phase)

Release Location	Precautionary Evacuation Statistical Fatality Rates	TSR Impairment Statistical Fatality Rates
Process Area	0.090	0.188
Manifold and Wellhead/ Intervention Areas	0.180	0.375
Drilling Equipment Sets	0.045	0.094
Power Generation/Utility Areas	0.450	0.938

Table A10.5: Statistical Fatality Rates for Potential Smoke Impairment Events (Production Only Phase)

A10.2 Gas Ingress

A10.2.1 Impairment Events

If gas from a large long duration release reaches the TSR at LFL concentration, it could ingress into the TSR and result in the potential for an explosion within the TSR.

In general, gas releases from the process systems will be transient events, even in the case of an ESV failure. This is particularly true in the case of large gas releases.

However, if a large release occurs from the production or gas lift flowlines or manifolds in the wellhead/manifold area and, upon ESD, a well fails to shut in, a long duration gas or 2-phase release could occur.

Therefore, it is considered that any non-ignited unisolated large release from the production or gas lift flowlines or manifolds, coincident with unfavourable conditions, could impair the TSR.

A10.2.2 Gas Impairment Event Tree

For the TSR to be affected by gas, the following coincident conditions would have to occur:

- Wind blows gas from the release towards the TSR.
- Gas reaches the TSR at high concentration.
- Gas enters the TSR (for example, via the HVAC inlet or any other penetrations such as doors).

The event tree used to account for the likelihood of the coincident conditions that must occur for the TSR to be affected by gas from a large long duration release is shown in Appendix 9. The event tree branch events are:

1. Gas travels towards the TSR.
2. Gas reaches the TSR at high concentration and enters the TSR.

The event tree identifies three possible outcomes. These outcomes represent two 'TSR Conditions', see Table A10.6.

Condition No.	TSR Condition
1	No gas hazard at the TSR (Outcomes E2 and E3)
2	Gas reaches the TSR and begins to ingress into the TSR (Outcome E1)

Table A10.6: Gas Impairment Event Tree, TSR Conditions

Any decision to evacuate the platform will be at the discretion of the OIM. If gas enters the TSR, the OIM will not wait until the concentration reaches LFL levels before considering an evacuation of the platform.

Because the potential impairment event involves failure of a well to shut-in, and is therefore unlikely to be transient, it is assumed that the OIM will order a 'precautionary' evacuation. That is, the OIM will tactically decide to evacuate by lifeboat, to protect personnel from the possibility of further gas ingress and the possibility of a subsequent explosion within the TSR.

A10.2.2.1 Event Tree Branch Probabilities

The branch probabilities used in the gas impairment event trees are shown in Table A10.7. These probabilities are subjectively estimated, based on experience of undertaking studies for similar installations. It may be necessary, at detailed design stage, to review these probabilities in a detailed TSR impairment analysis and revise the risk assessment accordingly.

Branch	Condition	Probability
1	Wind Blows Towards TSR	0.3
2	Gas Enters TSR at High Concentration	0.2

Table A10.7: Branch Probabilities for Gas Impairment Event Trees

<u>Branch 1:</u>

Gas will only travel towards the TSR if wind direction is from the release towards the TSR. The probability is taken to be 0.3, which, based on metocean data for the Hebron site, is considered to be very conservative.

<u>Branch 2:</u>

If gas reaches the TSR in high concentration, it could enter the TSR via the HVAC intakes or any other penetrations such as doors. Gas could ingress rapidly if drawn in through the HVAC intakes, or would ingress only slowly through the various other TSR penetrations.

However, if gas is detected at the HVAC intakes, the HVAC system shuts down and the dampers close, to prevent rapid ingress. The likelihood of rapid gas ingress due to the HVAC system failing to shut down is not considered here. It is assumed that the HVAC inlets will be located in a sheltered area of the platform and that the reliability of the gas detectors and dampers will be addressed during detailed design. Gas could enter the TSR slowly through the various other TSR penetrations, but a modern TSR design should ensure that this is unlikely.

Based on this discussion, the probability that gas reaches the TSR in high concentration and enters the TSR is considered to be low (0.2).

A10.2.2.2 Fatality Rates

The gas impairment event tree (Appendix 9) identifies two possible ‘TSR Conditions’ (see Table A10.6). The number of statistical fatalities assigned, in the event tree analysis, for each TSR Condition is shown in Table A10.8.

Condition No.	TSR Condition	Lifeboat Evacuation Fatality Rates
1	No gas hazard at the TSR	-
2	Gas ingress to TSR	3%

Table A10.8: Gas Impairment Event Tree Fatality Rates

Condition 1:

No hazard, no fatalities assigned.

Condition 2:

This refers to an outcome where gas enters the TSR. The OIM will not wait until the gas concentration reaches LFL levels before considering an evacuation of the platform. Therefore, for this situation, ‘precautionary evacuation fatalities’ are accounted for. It is assumed that a lifeboat evacuation will be undertaken, and a weather-averaged fatality rate of 3% is applied. Detailed asset-specific evacuation modelling will be required at design stage, but the 3% fatality rate, which is based on experience of assessing evacuation risk for other installations, assuming a lifeboat evacuation under controlled conditions, is considered sufficiently conservative for this assessment.

A10.2.2.3 Statistical Fatality Rate

Based on the event tree (branch probability and fatality) data described above, the gas impairment event trees (Appendix 9) determine the statistical fatality rates for potential gas impairment events, accounting for the full complement of platform personnel mustering and evacuating from the TSR, to be:

- 0.421 during the drilling and production phase.
- 0.225 during the production only phase.

APPENDIX 11:

PHAST JET FIRE MODELLING

A11.1 Process Release Event Jet Fire Modelling

In the event of a hydrocarbon release, the process conditions (temperature and pressure etc.) of the section where the release occurs and the composition of the fluid released affect the physical consequences (mass release rate, ignition probability, flame dimensions etc.) of the release.

The process conditions and fluid composition for each piece of equipment on the Hebron installation are given in heat and material balance sheets.

Based on fluid composition and process conditions, DNV's consequence modelling software, PHAST, is used to determine the mass release rate and, if ignited, the dimensions of the 25kW/m^2 radiation contour, which is taken as the thermal radiation level at which personnel are considered to be immediate fatalities.

Process conditions and fluid compositions for the release events considered in this assessment are discussed in Section A11.1.1 and Section A11.1.2 respectively. Results of the consequence modelling are given in Section A11.1.3.

A11.1.1 Process Conditions

Table A11.1 provides process conditions (pressure, temperature) for each release event considered in the assessment.

Ref.	Release Event	Stream Code	Pressure (bara)	Temperature (°C)
1A/2	Crude Oil Pumps	620-207	5	86.3
1A/5	Oil Water/Separator	620-206	1.6	86.2
1A/6	LP Inlet Heater	620-201	9.0	73.1
1A/7	Compact Electrostatic Coalescer	620-204	1.6	86.2
1A/8	Crude Oil Cooler	620-208	4	74.3
1A/10	Oil/Oil Exchanger – Downstream from MP Separator	620-106	10.0	64.3
1A/11	Oil/Oil Exchanger – Downstream from Crude Oil Pumps	620-207	5	86.3
1A/12	MP Inlet Heater	620-103/ 620-104	11.0	49.2
1A/13	LP Separator (Gas)	620-203	1.5	85.7
1A/14	LP Separator (Liquid)	620-204	1.6	86.2
1A/15	MP Separator (Gas)	620-105	10.0	64.3
1A/16	MP Separator (Liquid)	620-106	10.0	64.3
1A/17	HP Separator (Gas)	620-101	30.0	52.0
1A/18	HP Separator (Liquid)	620-102	11.0	52.0
1A/19	MP Test Separator (Gas)	620-105	10.0	64.3

Table A11.1: Process Hydrocarbon Release Event Process Conditions

Ref.	Release Event	Stream Code	Pressure (bara)	Temperature (°C)
1A/20	MP Test Separator (Liquid)	620-106	10.0	64.3
1A/21	MP Test Separator Inlet Heater	620-103/ 620-104	11.0	49.2
1A/22	HP Test Separator (Gas)	620-101	30.0	52.0
1A/23	HP Test Separator (Liquid)	620-102	11.0	52.0
1A/24	HP Test Separator Inlet Heater	560-102	30.0	52.0
1A/29	HP Production/Test Manifolds	560-102	30.0	52.0
1A/30	MP Production/Test Manifolds	560-204	11.0	46.5
1B/4	Gas Lift Manifold and Flowlines	654-106	199.5	90.0
1B/5	Fuel Gas Scrubber	966-101	48.0	12.2
1B/6	Fuel Gas Heater	966-104/ 966-102	47.8	12.1
1B/7	Fuel Gas Calorimeter	966-102	47.3	40.1
1B/8	Power Generator Turbine and Compressor Turbine Fuel Gas Filter/Scrubber Packages	966-102	47.3	40.1
1B/10	TEG Flash Drum	661-203	6	80.0
1B/11	Stripping Gas Column TEG Still Column TEG Vent Cooler	661-202	1.03	98.8
1B/12	TEG Vent Scrubber	661-209	1.03	30
1B/13	TEG Vent Blower	661-210	1.6	85.5
1B/14	LP Compression 1st Stage Scrubber	657-103	1.1	28.9
1B/15	LP Gas Compressor, 1st Stage	657-104	4.5	110.9
1B/16	LP Compression 2nd Stage Scrubber	657-106	3.6	29.4
1B/17	LP Gas Compressor, 2nd Stage	657-107	10	95.4
1B/18	MP Compression Suction Scrubber	659-106	8.9	29.9
1B/19	MP Gas Compressor	659-108	30.0	136.7
1B/20	HP Compression Suction Scrubber	651-207	29.3	29.9
1B/21	HP Gas Compressor	651-208	75.0	113.0
1B/22	Gas Lift Compression Suction Scrubber	654-102	72.1	23.4
1B/23	Gas Lift Compressor	654-103	202.0	116.5
1B/24	Gas Injection Compressor Suction Scrubber	653/102	199.3	51.0
1B/25	Gas Injection Compressor	653-103	320.0	90.0
1B/26	Dehydration Contactor	661-108	72.5	23.6
1B/27	Dehydration Inlet Scrubber	661-104	74.5	24.0
1B/28	Dehydration Filter Coalescer	661-105	74.5	24.0
1B/29	TEG Vent & Flash Gas to LP Compression	661-211	1.6	80.9
1B/30	LP Compression 1st Stage Suction Cooler	657-102	1.2	29.4
1B/31	LP Compression 2nd Stage Suction Cooler	657-105	3.8	29.6
1B/32	MP Compression Suction Cooler	659-105/ 659-106	9.6	29.9

Table A11.1 (Cont.): Process Hydrocarbon Release Event Process Conditions

Ref.	Release Event	Stream Code	Pressure (bara)	Temperature (°C)
1B/33	HP Compression Suction Cooler	651-104/ 651-106	30.0	30.0
1B/34	Gas Lift Compression Recycle Cooler	654-102	72.1	23.4
1B/35	Gas Injection Compressor Suction Cooler	653-101/ 653-102	200.0	51.0
1B/36	Dehydration Inlet Cooler	661-103/ 661-104	75	24.0
1B/37	Gas/Glycol Heat Exchanger	661-108	72.5	23.6
1B/38	Gas Lift Cooler	654-104	200.0	116.2
1B/39	Main Power Generator	966-102	47.3	40.1
1C/4	Distribution Manifold	620-207	2.1	45.0
1C/5	Recirculation/ Offloading Manifold	620-207	6.5	45.0
1C/6	OLS Pig Launchers/Receivers	620-207	17.0	45.0
1C/7	Crude Recirculation Heater	620-207	2.1	45.0
1C/8	Export Pumps	620-207	20.0	45.0
1C/9	Fiscal Metering Skid	620-207	20.0	45.0
1D/1	Flare KO Drum (Gas)	*	4.9	60.4
1D/2	Flare KO Drum and Pumps (Liquid)	*	5.0	60.4
1E/8	Produced Water Degassing Drum, Gas	681-204	1.6	64

* The Flare KO Drum stream composition will vary depending on where the flare gas is taken from. Therefore, the liquid inlet and gas outlet of the LP Separator is taken as representative.

Table A11.1 (Cont.): Process Hydrocarbon Release Event Process Conditions

For the purposes of consequence modelling, release events with similar process conditions are grouped, as presented in Table A11.2, and representative process conditions are assigned to each group, as given in Table A11.3.

Stream Group	Stream Codes
G-1	620/101, 620-105, 651-104, 651-106, 651-207, 651-208, 653-101, 653-102, 654-102, 654-103, 654-104, 659-105, 659-106, 659-108, 661-103, 661-104, 661-108, 661-203
G-2	620-203, 657-102, 661-202
G-3	657-103, 657-105, 657-106, 657-107
G-4	661-210, 661-211, 681-204
L-1	620-103, 620-104
L-2	620-106, 620-201
L-3	620-204
L-4	620-206, 620-207, 620-208
L-5	560-102
L-6	620-102

Table A11.2: Stream Codes and Groups

Consequence ID	Release Events	Pressure (barg)	Temperature (ºC)	Stream Group
A	1A/13, 1B15, 1B/16, 1B/30, 1B/31, 1D/1	3.9	29.8	G-2
B	1A/15, 1A/19, 1B/10, 1B/18, 1B/32	9.0	29.9	G-1
C	1A/17, 1A/22, 1B/19, 1B/20, 1B/33	29.0	29.9	G-1
D	1B/4, 1B/23, 1B/24, 1B/35, 1B/38	199.0	47.6	G-1
E	1B/5, 1B/6, 1B/7, 1B/8, 1B/39	47.2	20.1	G-1
F	1B/14	0.1	29.8	G-1
G	1B/17	9.0	86.0	G-3
H	1B/21, 1B/22, 1B/26, 1B/27, 1B/28, 1B/34, 1B/36, 1B/37	74.0	23.9	G-1
I	1B/25	319.0	90.0	G-1
J	1B11, 1B/12, 1B/13, 1E/8	0.6	64	G-4
K	1A/2, 1A/11, 1C/5	5.5	45.0	L-4
L	1A/5, 1A/8, 1C/4, 1C/7	2.1	45.0	L-4
M	1A/14, 1A/7	0.6	84.0	L-3
N	1A/6, 1A/10, 1A/16, 1A/20, 1D/2	9.0	60.4	L-2
O	1A/12, 1A/21, 1A/30	10.0	48.7	L-1
P	1A/18, 1A/23	29.0	52.0	L-6
Q	1A/24, 1A/29	29.0	52.0	L-5
R	1C/6, 1C/8, 1C/9	19.0	45.0	L-4

Table A11.3: Representative Process Conditions

A11.1.2 Fluid Composition

A representative composition, with the greatest proportion of heavy hydrocarbons, is selected for each of the stream groups considered in Table A11.3. The representative fluid compositions assumed are provided in Table A11.4.

	% Mol*									
Stream Group (Code)	**G-1**	**G-2**	**G-3**	**G-4**	**L-1**	**L-2**	**L-3**	**L-4**	**L-5**	**L-6**
Component										
H_2O	-	35.0%	3.2%	14.0%	84.8%	80.7%	63.9%	7.4%	41.9%	70.1%
Nitrogen	0.6%	0.2%	0.2%	0.4%	0.1%	-	-	-	0.2%	-
CO_2	1.4%	0.9%	1.4%	4.8%	0.2%	-	-	-	0.7%	0.1%
Methane	85.9%	30.3%	47.3%	65.7%	9.8%	0.8%	-	0.1%	36.3%	2.0%
Ethane	5.2%	4.9%	7.6%	5.4%	0.6%	0.1%	-	0.1%	2.3%	0.5%
Propane	3.5%	7.0%	10.9%	4.1%	0.4%	0.2%	0.1%	0.3%	2.0%	1.0%
Butane	2.0%	8.3%	12.6%	2.8%	0.3%	0.3%	0.3%	0.8%	1.3%	1.2%
Pentane	0.8%	5.6%	8.2%	1.2%	0.2%	0.4%	0.5%	1.4%	0.9%	1.2%
Hexane+	0.5%	8.0%	8.4%	2.0%	3.7%	17.5%	35.1%	90.0%	14.4%	23.8%

* Percentages may not add to 100% due to rounding in the input document

Table A11.4: Stream Compositions

A11.1.3 PHAST Output

Mass release rates and dimensions of the 25kW/m^2 thermal radiation region for each consequence group, generated by PHAST, are given in Table A11.5.

Group	Hole Size	Initial Mass Release Rate (kg/s)	25 kW/m^2 Downwind Semi Axis (m)	25 kW/m^2 Crosswind Semi Axis (m)	25 kW/m^2 Area (m^2)
A	Small	0.04	0.00	0.00	0.00
	Medium	0.86	5.14	1.28	20.73
	Large	4.55	11.64	6.10	223.06
B	Small	0.06	1.44	1.05	4.73
	Medium	1.39	6.27	2.66	52.35
	Large	7.39	14.67	10.38	478.18
C	Small	0.20	1.63	1.09	5.58
	Medium	4.34	11.19	7.09	249.04
	Large	23.03	25.30	20.88	1659.44
D	Small	1.49	6.48	2.84	57.83
	Medium	33.15	29.71	25.59	2388.56
	Large	175.80	60.18	61.60	11646.40
E	Small	0.33	2.63	0.52	4.30
	Medium	7.38	14.66	10.37	477.79
	Large	39.17	31.92	28.04	2812.02

Table A11.5: Mass Release Rates and Thermal Radiation Dimensions

Group	Hole Size	Initial Mass Release Rate (kg/s)	25 kW/m^2 Downwind Semi Axis (m)	25 kW/m^2 Crosswind Semi Axis (m)	25 kW/m^2 Area (m^2)
F	Small	0.00	0.00	0.00	0.00
	Medium	0.07	0.00	0.00	0.00
	Large	0.35	6.16	1.20	23.25
G	Small	0.08	1.47	1.05	4.86
	Medium	1.73	6.63	3.16	65.80
	Large	9.16	15.67	11.72	576.97
H	Small	0.54	3.89	0.96	11.75
	Medium	11.97	18.62	14.18	829.83
	Large	63.50	39.13	36.35	4469.26
I	Small	2.06	7.57	3.84	91.26
	Medium	45.74	34.09	30.50	3266.80
	Large	242.60	69.30	72.42	15765.27
J	Small	0.01	0	0	0
	Medium	0.18	3.21	1.04	10.63
	Large	0.96	6.99	1.59	34.91
K	Small	0.67	7.27	6.39	145.85
	Medium	14.84	28.48	27.97	2502.45
	Large	78.70	59.21	59.46	11060.10
L	Small	0.41	6.12	5.10	98.09
	Medium	9.17	23.29	22.53	1648.21
	Large	48.63	49.12	49.52	7642.84
M	Small	0.23	4.98	1.92	30.01
	Medium	5.15	16.54	10.08	523.82
	Large	27.31	31.30	21.65	2129.44
N	Small	0.94	8.50	3.55	94.77
	Medium	20.84	32.53	19.64	2007.39
	Large	110.52	68.31	46.17	9907.17
O	Small	0.86	0.00	0.00	0.00
	Medium	19.10	26.13	8.21	673.82
	Large	101.28	54.66	20.92	3592.94
P	Small	1.60	9.43	6.76	200.02
	Medium	35.59	36.96	31.05	3604.96
	Large	188.75	78.19	69.20	16998.85

Table A11.5 (Cont.): Mass Release Rates and Thermal Radiation Dimensions

Group	Hole Size	Initial Mass Release Rate (kg/s)	25 kW/m^2 Downwind Semi Axis (m)	25 kW/m^2 Crosswind Semi Axis (m)	25 kW/m^2 Area (m^2)
Q	Small	1.09	7.52	5.76	136.07
	Medium	24.19	29.22	25.95	2382.32
	Large	128.29	62.00	57.60	11219.47
R	Small	1.24	8.95	8.25	232.01
	Medium	27.56	35.82	35.91	4041.36
	Large	146.20	72.29	72.18	16393.05

Table A11.5 (Cont.): Mass Release Rates and Thermal Radiation Dimensions

APPENDIX 12:

TOXIC GAS - PHAST MODELLING AND FATALITY ESTIMATES

A12.1 Process Release Event Toxic Gas Modelling

In the event of a toxic gas release, the process conditions (temperature and pressure etc.) of the section where the release occurs and the H_2S concentration in the stream affect the physical consequences (mass release rate, toxic gas cloud size etc.) of the release.

Based on H_2S concentration, gas composition and process conditions, DNV's consequence modelling software, PHAST, is used to determine the mass release rate and the dimensions of the 500ppm H_2S concentration contour, which is taken as the level at which personnel are considered to be immediate fatalities.

The release events identified in Section 7 as having the potential to result in fatalities due to H_2S are:

- LP separator (gas releases only).
- Fuel gas scrubber.
- Fuel gas heater.
- LP gas compression train (1^{st} and 2^{nd} stage).
- Dehydration filter coalescer.
- TEG flash drum (gas releases only).
- Stripping gas column.
- TEG still column.
- TEG vent cooler.
- TEG vent scrubber.
- TEG vent blower.
- TEG vent and flash gas to 1st stage LP suction cooler.
- Produced water degassing drum (gas releases only).

Process conditions and gas compositions for these events are given in Section A12.1.1. Results of the consequence modelling are presented in Section A12.1.2.

A12.1.1 Toxic Gas Release Event Details

Table A12.1 presents H_2S concentration and release location for the identified release events. Table A12.2 presents the gas composition assumed for each event. The process conditions are presented in Appendix 11. It should be noted that, unlike for the jet fire consequence modelling reported in Appendix 11, the TEG regeneration events have not been grouped, as the H_2S concentration differs significantly. This is not considered to impact the jet fire modelling, but does have a significant impact on the toxic gas dispersion modelling.

Release Event	**Stream**	**Location**	**Module Area (m^2)**	**H_2S Concentration (ppm)**
LP Separator, Gas	G-2T	Main Deck	2292	1,000
Fuel Gas Scrubber	G-1T	Lower Deck	1762	770
Fuel Gas Heater	G-1T	Lower Deck	1762	770
TEG Flash Drum	661-203	Lower Deck	1762	5,700
Stripping Gas Column TEG Still Column TEG Vent Cooler	661-202	Lower Deck	1762	2,400
TEG Vent Scrubber	661-209	Lower Deck	1762	39,800
TEG Vent Blower	661-210	Lower Deck	1762	39,800
LP Compression Suction Scrubber 1st Stage	G-1T	Main Deck	2292	1,800
LP Compressor 1st Stage	G-2T	Main Deck	2292	1,800
LP Compression Suction Scrubber 2nd Stage	G-2T	Main Deck	2292	1,800
LP Compressor 2nd Stage	G-3T	Main Deck	2292	2,000
Dehydration Filter Coalescer	G-1T	Main Deck	2292	770
TEG Vent and Flash Gas to 1st Stage LP Suction Cooler	661-211	Main Deck	2292	19,200
LP Compression Suction Cooler 1st Stage	G-2T	Upper Deck	2292	1,800
LP Compression Suction Cooler 2nd Stage	G-2T	Upper Deck	2292	1,800
Produced Water Degassing Drum, Gas	681-204	Main Deck	2292	2,700

Table A12.1: Toxic Gas Release Event Details

	Stream Group (Code)	% Mol*							
		G1-T	**G-2T**	**G-3T**	**(661-202)**	**(661-203)**	**(661-210)**	**(661-211)**	**(681-204)**
Component	H_2O	-	35.0	3.2	95.5	2.1	4.1	2.8	14.0
	Nitrogen	0.6%	0.2	0.2	0.1	2.7	2.9	2.8	0.4
	CO_2	1.4%	0.9	1.4	0.85	8.7	25.4	12.0	4.5
	H_2S	[1]	[2]	0.2	0.25	0.6	4.0	2.0	0.3
	Methane	85.9%	30.3	47.3	2.2	68.1	47.5	61.2	65.7
	Ethane	5.2%	4.9	7.6	0.4	8.7	8.6	8.7	5.4
	Propane	3.5%	7.0	10.9	0.5	6.7	10.3	7.9	4.1
	Butane	2.0%	8.3	12.6	0.1	1.7	2.1	1.8	2.8
	Pentane	0.8%	5.6	8.2	-	0.4	0.6	0.4	1.2
	Hexane	0.5%	-	-	-	0.2	0.5	0.3	1.0
	Heptane+	-	8.0	8.4	-	-	0.1	0.1	1.0

* Percentages may not add to 100% due to rounding.
1) H_2S concentrations: 0.077% for Fuel Gas and Dehydration equipment, 0.18% for LP Compression 1st Stage Scrubber.
2) H_2S concentrations: 0.1% for LP Separator, 0.18% for releases from LP Compression train.

Table A12.2: Stream Compositions

A12.1.2 PHAST Output and Fatality Estimation

In line with the fatality calculation for jet fire events, immediate fatalities from toxic releases are calculated as:

$$\text{Fatalities} = \text{Fatality Area x Population Density}$$

Population Density is a characteristic of the area of the platform in which the release event occurs. It is calculated as:

$$\text{Population Density} = \frac{\text{Number of Personnel in Release Location}}{\text{Area of Release Location}}$$

The assumed number of personnel in each area of the platform is detailed in Section 6.

The fatality area is calculated based on the area occupied by gas with an H_2S concentration higher than 500ppm.

Table A12.3 presents the fatality areas, fatality rates and estimated number of fatalities for each of the identified toxic gas release events.

Gas Release Event	Location	Hole Size	500ppm H_2S Area (m^2)	Fatality Rate	Fatalities
LP Separator (Gas)	Process – Main Deck	Small	2.92×10^{-5}	1.27×10^{-8}	3.18×10^{-8}
		Medium	6.28×10^{-3}	2.74×10^{-6}	6.85×10^{-6}
		Large	3.28×10^{-2}	1.43×10^{-5}	3.58×10^{-5}
Fuel Gas Scrubber Fuel Gas Heater	Process – Lower Deck	Small	1.00×10^{-3}	5.67×10^{-7}	8.51×10^{-7}
		Medium	3.06×10^{-2}	1.74×10^{-5}	2.60×10^{-5}
		Large	1.56×10^{-1}	8.85×10^{-5}	1.33×10^{-4}
TEG Flash Drum	Process – Lower Deck	Small	1.92×10^{-2}	1.09×10^{-5}	1.63×10^{-5}
		Medium	3.76×10^{-1}	2.13×10^{-4}	3.20×10^{-4}
		Large	2.15	1.22×10^{-3}	1.83×10^{-3}
Stripping Gas Column TEG Still Column TEG Vent Cooler	Process – Lower Deck	Small	2.07×10^{-4}	1.17×10^{-7}	1.76×10^{-7}
		Medium	1.83×10^{-2}	1.04×10^{-5}	1.56×10^{-5}
		Large	8.77×10^{-2}	4.98×10^{-5}	7.46×10^{-5}
TEG Vent Scrubber	Process – Lower Deck	Small	4.98×10^{-2}	2.83×10^{-5}	4.24×10^{-5}
		Medium	8.13×10^{-1}	4.61×10^{-4}	6.92×10^{-4}
		Large	3.47	1.97×10^{-3}	2.95×10^{-3}
TEG Vent Blower	Process – Lower Deck	Small	9.34×10^{-2}	5.30×10^{-5}	7.95×10^{-5}
		Medium	1.61	9.15×10^{-4}	1.37×10^{-3}
		Large	12.01	6.81×10^{-3}	1.02×10^{-2}
LP Compression Suction Scrubber (1st Stage)	Process – Main Deck	Small	7.11×10^{-5}	3.10×10^{-8}	7.76×10^{-8}
		Medium	1.11×10^{-2}	4.84×10^{-6}	1.21×10^{-5}
		Large	6.17×10^{-2}	2.69×10^{-5}	6.73×10^{-5}
LP Compressor (1st Stage) LP Suction Scrubber (2nd Stage)	Process – Main Deck	Small	2.74×10^{-4}	1.20×10^{-7}	2.99×10^{-7}
		Medium	2.49×10^{-2}	1.09×10^{-5}	2.72×10^{-5}
		Large	1.26×10^{-1}	5.50×10^{-5}	1.37×10^{-4}
LP Compressor (2nd Stage)	Process – Main Deck	Small	1.01×10^{-3}	4.41×10^{-7}	1.10×10^{-6}
		Medium	5.14×10^{-2}	2.24×10^{-5}	5.61×10^{-5}
		Large	2.70×10^{-1}	1.18×10^{-4}	2.95×10^{-4}
LP Compression Suction Coolers (1st and 2nd Stage)	Process – Upper Deck	Small	2.74×10^{-4}	1.20×10^{-7}	2.99×10^{-7}
		Medium	2.49×10^{-2}	1.09×10^{-5}	2.72×10^{-5}
		Large	1.26×10^{-1}	5.50×10^{-5}	1.37×10^{-4}
TEG Vent and Flash Gas to LP 1st Stage Suction Cooler	Process – Main Deck	Small	4.06×10^{-2}	1.77×10^{-5}	4.43×10^{-5}
		Medium	7.21×10^{-1}	3.15×10^{-4}	7.86×10^{-4}
		Large	3.24	1.41×10^{-3}	3.54×10^{-3}
Dehydration Filter Coalescer	Process – Main Deck	Small	1.89×10^{-3}	8.25×10^{-7}	2.06×10^{-6}
		Medium	4.92×10^{-2}	2.15×10^{-5}	5.37×10^{-5}
		Large	2.72×10^{-1}	1.19×10^{-4}	2.97×10^{-4}
Produced Water Degassing Drum, Gas	Process – Main Deck	Small	6.28×10^{-4}	2.74×10^{-7}	6.85×10^{-7}
		Medium	3.68×10^{-2}	1.61×10^{-5}	4.01×10^{-5}
		Large	2.02×10^{-1}	8.81×10^{-5}	2.20×10^{-4}

Table A12.3: Toxic Gas Cloud Dimensions & Fatalities (Sea Water Injection)

Section 12.4 discusses the impact on risk to personnel due to higher concentrations of H_2S in the streams if produced water is re-injected. Table A12.4 presents H_2S concentrations for the streams presented in Table A12.2 for the produced water re-injection case.

	Stream Group (Code)	**% Mol***							
		G1-T	**G-2T**	**G-3T**	**(661-202)**	**(661-203)**	**(661-210)**	**(661-211)**	**(681-204)**
Component	H_2O	-	35.0	3.2	95.5	2.1	4.1	2.8	14.0
	Nitrogen	0.6%	0.2	0.2	0.1	2.7	2.9	2.8	0.4
	CO_2	1.4%	0.9	1.4	0.6	8.4	23.3	11.0	4.3
	H_2S	[1]	[2]	0.3	0.4	0.9	6.1	3.0	0.5
	Methane	85.9%	30.3	47.3	2.2	68.1	47.5	61.2	65.7
	Ethane	5.2%	4.9	7.6	0.4	8.7	8.6	8.7	5.4
	Propane	3.5%	7.0	10.9	0.5	6.7	10.3	7.9	4.1
	Butane	2.0%	8.3	12.6	0.1	1.7	2.1	1.8	2.8
	Pentane	0.8%	5.6	8.2	-	0.4	0.6	0.4	1.2
	Hexane	0.5%	-	-	-	0.2	0.5	0.3	1.0
	Heptane+	-	8.0	8.4	-	-	0.1	0.1	1.0

* Percentages may not add to 100% due to rounding.

1) H_2S concentrations: 0.12% for Fuel Gas and Dehydration equipment, 0.27% for LP Compression 1st Stage Scrubber.
2) H_2S concentrations: 0.18% for LP Separator, 0.28% for releases from LP Compression train.

Table A12.4: Stream Compositions (Worst Case)

As a sensitivity case, Table A12.5 provides details of the dimensions of gas clouds containing greater than 500ppm H_2S, based on Year 2045 stream data with produced water re-injection. Table A12.5 also provides corresponding fatality rates and numbers of fatalities, based on the fatality area, the proportion of the module that the area would occupy and the average number of personnel in the area.

Gas Release Event	Location	Hole Size	500ppm H_2S Area (m^2)	Fatality Rate	Fatalities
LP Separator (Gas)	Process – Main Deck	Small	2.74×10^{-4}	1.20×10^{-7}	2.99×10^{-7}
		Medium	2.50×10^{-2}	1.09×10^{-5}	2.73×10^{-5}
		Large	1.26×10^{-1}	5.50×10^{-5}	1.37×10^{-4}
Fuel Gas Scrubber Fuel Gas Heater	Process – Lower Deck	Small	6.09×10^{-3}	3.46×10^{-6}	5.18×10^{-6}
		Medium	1.30×10^{-1}	7.38×10^{-5}	1.11×10^{-4}
		Large	7.70×10^{-1}	4.37×10^{-4}	6.55×10^{-4}
TEG Flash Drum	Process – Lower Deck	Small	4.49×10^{-2}	2.55×10^{-5}	3.82×10^{-5}
		Medium	9.40×10^{-1}	5.33×10^{-4}	8.00×10^{-4}
		Large	4.65	2.64×10^{-3}	3.96×10^{-3}
Stripping Gas Column TEG Still Column TEG Vent Cooler	Process – Lower Deck	Small	9.13×10^{-4}	5.18×10^{-7}	7.77×10^{-7}
		Medium	4.37×10^{-2}	2.48×10^{-5}	3.72×10^{-5}
		Large	2.03×10^{-1}	1.15×10^{-4}	1.73×10^{-4}
TEG Vent Scrubber	Process – Lower Deck	Small	8.77×10^{-2}	4.98×10^{-5}	7.46×10^{-5}
		Medium	1.36	7.70×10^{-4}	1.16×10^{-3}
		Large	5.85	3.32×10^{-3}	4.98×10^{-3}
TEG Vent Blower	Process – Lower Deck	Small	2.01×10^{-1}	1.14×10^{-4}	1.71×10^{-4}
		Medium	3.30	1.87×10^{-3}	2.81×10^{-3}
		Large	33.66	1.91×10^{-2}	2.86×10^{-2}
LP Compression Suction Scrubber (1st Stage)	Process – Main Deck	Small	3.86×10^{-4}	1.68×10^{-7}	4.21×10^{-7}
		Medium	2.47×10^{-2}	1.08×10^{-5}	2.69×10^{-5}
		Large	1.22×10^{-1}	5.32×10^{-5}	1.33×10^{-4}
LP Compressor (1st Stage) LP Suction Scrubber (2nd Stage)	Process – Main Deck	Small	1.18×10^{-3}	5.15×10^{-7}	1.29×10^{-6}
		Medium	6.75×10^{-2}	2.95×10^{-5}	7.36×10^{-5}
		Large	3.33×10^{-1}	1.45×10^{-4}	3.63×10^{-4}
LP Compressor (2nd Stage)	Process – Main Deck	Small	3.44×10^{-3}	1.50×10^{-6}	3.75×10^{-6}
		Medium	1.01×10^{-1}	4.41×10^{-5}	1.10×10^{-4}
		Large	5.83×10^{-1}	2.54×10^{-4}	6.36×10^{-4}
LP Compression Suction Coolers (1st and 2nd Stage)	Process – Upper Deck	Small	1.18×10^{-3}	5.15×10^{-7}	1.29×10^{-6}
		Medium	6.75×10^{-2}	2.95×10^{-5}	7.36×10^{-5}
		Large	3.33×10^{-1}	1.45×10^{-4}	3.63×10^{-4}
TEG Vent and Flash Gas to LP 1st Stage Suction Cooler	Process – Main Deck	Small	8.30×10^{-2}	3.62×10^{-5}	9.05×10^{-5}
		Medium	1.46	6.37×10^{-4}	1.59×10^{-3}
		Large	8.99	3.92×10^{-3}	9.81×10^{-3}
Produced Water Degassing Drum, Gas	Process – Main Deck	Small	3.27×10^{-3}	1.43×10^{-6}	3.57×10^{-6}
		Medium	9.15×10^{-2}	3.99×10^{-5}	9.98×10^{-5}
		Large	4.55×10^{-1}	1.99×10^{-4}	4.96×10^{-4}

Table A12.5: Toxic Gas Release Fatalities (Sea Water Injection & Produced Water Re-Injection)

Gas Release Event	**Location**	**Hole Size**	**500ppm H_2S Area (m^2)**	**Fatality Rate**	**Fatalities**
Dehydration Filter Coalescer	Process – Main Deck	Small	1.05×10^{-2}	4.58×10^{-6}	1.15×10^{-5}
		Medium	2.41×10^{-1}	1.05×10^{-4}	2.63×10^{-4}
		Large	1.24	5.40×10^{-4}	1.35×10^{-3}
Fuel Gas Calorimeter Power Generator Turbine and Compressor Turbine Fuel Gas	Process – Lower Deck	Small	1.00×10^{-3}	5.67×10^{-7}	8.51×10^{-7}
		Medium	3.06×10^{-2}	1.74×10^{-5}	2.60×10^{-5}
		Large	1.56×10^{-1}	8.85×10^{-5}	1.33×10^{-4}
Main Power Generator	Power Generation	Small	1.00×10^{-3}	6.80×10^{-7}	1.02×10^{-6}
		Medium	3.06×10^{-2}	2.08×10^{-5}	3.12×10^{-5}
		Large	1.56×10^{-1}	1.06×10^{-4}	1.59×10^{-4}
MP Separator, gas MP Compression Suction Scrubber	Process – Main Deck	Small	4.63×10^{-5}	2.02×10^{-8}	5.05×10^{-8}
		Medium	6.01×10^{-3}	2.62×10^{-6}	6.56×10^{-6}
		Large	3.12×10^{-2}	1.36×10^{-5}	3.40×10^{-5}
MP Test Separator, gas MP Compression Suction Cooler	Process – Upper Deck	Small	4.63×10^{-5}	2.02×10^{-8}	5.05×10^{-8}
		Medium	6.01×10^{-3}	2.62×10^{-6}	6.56×10^{-6}
		Large	3.12×10^{-2}	1.36×10^{-5}	3.40×10^{-5}
MP Compressor HP Compression Suction Scrubber	Process – Main Deck	Small	3.76×10^{-4}	1.64×10^{-7}	4.10×10^{-7}
		Medium	1.87×10^{-2}	8.16×10^{-6}	2.04×10^{-5}
		Large	9.82×10^{-2}	4.28×10^{-5}	1.07×10^{-4}
HP Separator, gas HP Test Separator, gas HP Compression Suction Cooler	Process – Upper Deck	Small	3.76×10^{-4}	1.64×10^{-7}	4.10×10^{-7}
		Medium	1.87×10^{-2}	8.16×10^{-6}	2.04×10^{-5}
		Large	9.82×10^{-2}	4.28×10^{-5}	1.07×10^{-4}
Gas Lift Compressor Gas Injection Compression Suction Scrubber	Process – Main Deck	Small	6.60×10^{-3}	2.88×10^{-6}	7.20×10^{-6}
		Medium	1.40×10^{-1}	6.13×10^{-5}	1.53×10^{-4}
		Large	7.08×10^{-1}	3.09×10^{-4}	7.72×10^{-4}
Gas Injection Compression Suction Cooler Gas Lift Cooler	Process – Upper Deck	Small	6.60×10^{-3}	8.25×10^{-7}	2.06×10^{-6}
		Medium	1.40×10^{-1}	2.15×10^{-5}	5.37×10^{-5}
		Large	7.08×10^{-1}	1.19×10^{-4}	2.97×10^{-4}
Gas Lift Suction Scrubber Dehydration Contactor Dehydration Scrubber HP Compressor	Process – Main Deck	Small	1.89×10^{-3}	8.25×10^{-7}	2.06×10^{-6}
		Medium	4.92×10^{-2}	2.15×10^{-5}	5.37×10^{-5}
		Large	2.72×10^{-1}	1.19×10^{-4}	2.97×10^{-4}
Gas Lift Recycle Cooler Dehydration Inlet Cooler Gas/Glycol Heat Exchanger	Process – Upper Deck	Small	1.89×10^{-3}	8.25×10^{-7}	2.06×10^{-6}
		Medium	4.92×10^{-2}	2.15×10^{-5}	5.37×10^{-5}
		Large	2.72×10^{-1}	1.19×10^{-4}	2.97×10^{-4}

Table A12.5 (Cont.): Toxic Gas Release Fatalities (Sea Water Injection & Produced Water Re-Injection)

Gas Release Event	**Location**	**Hole Size**	**500ppm H_2S Area (m^2)**	**Fatality Rate**	**Fatalities**
Gas Injection Compressor	Process – Main Deck	Small	8.48×10^{-3}	3.70×10^{-6}	9.25×10^{-6}
		Medium	1.80×10^{-1}	7.85×10^{-5}	1.96×10^{-4}
		Large	9.94×10^{-1}	4.34×10^{-4}	1.08×10^{-3}
Gas Lift Manifold	Manifold Area	Small	6.60×10^{-3}	5.56×10^{-6}	2.22×10^{-5}
		Medium	1.40×10^{-1}	1.18×10^{-4}	4.73×10^{-4}
		Large	7.08×10^{-1}	5.97×10^{-4}	2.39×10^{-3}

Table A12.5 (Cont.): Toxic Gas Release Fatalities (Sea Water Injection & Produced Water Re-Injection)