Husky Energy

Report

Concept Safety Assessment of South White Rose Extension Project

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Contents

Section Page

List of Tables

List of Figures

ABBREVIATIONS

BOP	Blowout Preventer
CO	Carbon Monoxide
C-NLOPB	Canada Newfoundland and Labrador Offshore Petroleum Board
DSV	Dive Support Vessel
ESD	Emergency Shutdown
FB	Full Bore
FE	Finite Element
FPSO	Floating Production, Storage and Offloading Vessel
IRPA	Individual Risk Per Annum
MODU	Mobile Offshore Drilling Unit
OGP	Oil & Gas Producers
PLL	Potential Loss of Life
QRA	Quantitative Risk Analysis
ROV	Remotely Operated Vehicle
SDC	South Drill Center
SDU	Subsea Distribution Unit
SGH	Southern Glory Hole
SWRX	South White Rose Extension Project
TEMPSC	Totally Enclosed Motor Propelled Survival Craft
TR	Temporary Refuge
TRIF	Temporary Refuge Impairment Frequency

Executive Summary

Husky Energy Ltd (Husky) is planning the development of the South White Rose Extension (SWRX) area. This area is located approximately 4km south of the current Southern Glory Hole (SGH) in approximately 120m of water. Within the new glory hole, one new drill centre will be constructed with wells tied back to the SeaRose FPSO. The SWRX drill centre will comprise three production wells, two gas injection wells and a water injection well with Extension capacity for up to twelve wells. The initial stage of the SWRX project shall be to route a gas injection pipeline from the Northern drill centre to the new glory hole and tie this in to the gas injection well, which will be the first well to be drilled in the SWRX glory hole.

As part of the development, Husky is intending to submit a Development Plan Amendment to C-NLOPB. To support this amendment, Husky has requested that Atkins assess the potential impact of the new development on existing White Rose safety studies. The main focus of this report is on the risks associated with the drilling of the gas injection well and tie-back of the gas injection pipeline from the Northern drill centre, although the risks from drilling later wells have also been considered.

The purpose of this study is to review existing safety studies that were developed for the White Rose project to determine the potential impact of the new SWRX development. The studies which have been identified as requiring review are:

- MODU Blowout Risk Assessment (WR-HSE-RP-0015) [1];
- MODU Dropped Object Analysis (WR-HSE-RP-0028) [2];
- MODU Risk Assessment (WR-HSE-RP-0020) [3].

In addition, this report details the hazards and risks associated with Diving Support Vessel (DSV) operations, as these were not specifically addressed within the studies listed above. Finally, the impact of extending the gas injection flowline to the new SWRX glory hole and of tying the SWRX production fluids into the North Amethyst flowlines are assessed in terms of potential impact on the SeaRose FPSO.

S1.1 Blowout Risk Assessment

The annual frequency of blowouts during the drilling and completion of the six new wells for the SWRX project is predicted to be 4.68E-03 per annum.

The blowout frequencies used in the MODU Risk Assessment are as follows:

Drillfloor Blowout – Gas Wells:

Drillpipe: 1.16E-04 Annulus: 4.72E-04 Unconfined: 1.73E-05

Drillfloor Blowout – Production Wells:

Drillpipe: 1.08E-04 Annulus: 8.27E-04 Unconfined: 3.29E-05

Subsea Blowout – Gas Wells:

Deep Reservoir: 2.64E-05 Shallow Gas: 1.02E-03

Subsea Blowout – Production Wells:

Deep Reservoir: 3.62E-05 Shallow Gas: 2.03E-03

This assessment is considered to be conservative as the blowout frequency and consequences from a water injection well are taken to be the same as a blowout from a production well. Any changes to the number or type of wells being drilled will have an effect on the frequencies and risks calculated here.

S1.2 Dropped Object Risk Assessment

A dropped objects study was conducted in order to establish the likelihood of an object dropped during the drilling and completion of the new SWRX wells to impact on equipment items already installed subsea. The impact energy between the dropped item and the equipment determines if damage – conservatively assumed here to result in a loss of hydrocarbon containment – is expected to occur.

The results of the damage frequency assessment for the MODU have been split according to the fluid that could be released, as the consequences of gas or production fluid releases will be different. The study gives a subsea gas release frequency of **6.27E-04 per annum** and a subsea production fluids release frequency of **1.83E-03 per annum**. These figures are carried forward to the MODU risk assessment in Section 5.

A dropped objects study was also carried out for the DSV, representing objects lifted during the installation of manifolds etc. The damage frequency due to objects dropped by the DSV is almost negligible compared to the MODU results, due to the low number of lifts conducted. The total DSV damage frequency is **2.68E-06 per annum**. This value is carried forward to the DSV risk assessment in Section 6.

S1.3 MODU Risk Assessment

The analysis presented here is based upon the use of a semi-submersible MODU, the Global Santa Fe (GSF) Grand Banks, for planned development drilling and completion activities. Husky has not yet selected the MODU that will be used for the SWRX project, however, as the Grand Banks is the smallest of those under consideration, with the shortest crane reach, it will give the most conservative dropped object results, as the dropped object impact locations on the sea bed will be concentrated over a smaller area and therefore the probability of impacting on a given subsea target will be greater (assuming the same lift manifest is used). No other aspects of the MODU risk assessment will be significantly affected by the MODU size and therefore it is expected that basing the MODU risk assessment on the Grand Banks should present the worst case scenario. This study should be revisited once a specific MODU has been selected.

This assessment has identified hazards to which MODU personnel will be exposed during the well operations in the SWRX project. The analysis has assessed the potential consequences of such hazards and subsequently determined the associated risk to personnel.

The risk levels for the MODU carrying out the drilling activities for the South White Rose Extension Project have been assessed and are well below the Target Levels of Safety for TR impairment and individual risk.

The frequency of hydrocarbon TR impairment is 6.80E-05 per annum, or once every 14,700 years. The impairment based TR integrity frequency is calculated to be 3.39E-04 per annum, and includes all events capable of failing the integrity of the TR. There are no hydrocarbon events causing failure of the TR integrity that exceed Husky's 1E-04 per annum criteria for a single major accident hazard.

The total PLL is 5.08E-02 fatalities per annum or one fatality every 20 years. The highest risk worker category is the Motorman Crew, with an IRPA of 4.53E-04 per annum.

S1.4 DSV Risk Assessment

There will be a requirement to use a DSV and a construction vessel for the installation of subsea equipment, i.e. flowlines, manifolds etc. Whilst these vessels will be present at both locations, the DSV risk assessment investigates the risks to personnel on board the DSV whilst it is on-station at the SWRX Drill Centre.

The risk levels for the DSV carrying out activities for the South White Rose Extension Project are predicted to be low.

The frequency of hydrocarbon TR impairment is 1.82E-05 per annum, or once in 55,000 years. The impairment based TR integrity frequency is calculated to be 2.91E-04 per annum should all hazards that may impair the DSV TR be taken into account. The total PLL is 3.26E-02 per annum or one fatality every 31 years. The highest risk worker category is the Maintenance / Deck Crew, whose IRPA is calculated to be 2.95E-04 per annum.

It should be noted, however, that these risk figures assume continuous operation throughout a full year. The operations that are to be carried out by the DSV for the South White Rose Extension Project are predicted to last for just 25 days. The risks for the actual period of operation can therefore be calculated; the TRIF is predicted to be 2.39E-06 and the PLL to be 4.29E-03.

S1.5 Target Levels of Safety

Table S-1 shows the key risk figures from the MODU and DSV risk assessments calculated for the operations associated with the SWRX project. These risk figures have been compared, where appropriate, to Husky's Target Levels of Safety [27].

Risk Parameter	Target Level of Safety	MODU	DSV
TRIF	1E-03	6.80E-05	1.82E-05
PLL	N/A	5.08E-02	3.26E-02
Max IRPA	5E-04	4.53E-04	2.95E-05

Table S-1: Risk Assessment Results and Target Levels of Safety

S1.6 Recommendations

1) As the SWRX Project progresses it is recommended that this safety assessment is updated to reflect any changes that may occur to the design. It is particularly important that assumptions made within this study are reviewed and updated to ensure that the conclusions drawn remain valid.

2) The potential frequency and consequence of an impact between the MODU and visiting OSVs (Offshore Supply Vessel) should be reviewed by Husky and the results incorporated into a later revision of the MODU risk assessment.

3) This report should be revisited and updated once the actual MODU to be used has been selected and once the glory hole layout and SWRX tie-back arrangements have been finalised.

The following recommendations were made in the previous review of SWRX activities; Husky should confirm that these have been reviewed and closed out where appropriate.

1) A review of the traffic management procedures at the White Rose field should be undertaken by Husky to ensure that there are sufficient measures in place to protect the SWRX equipment, and any MODU working at the SWRX Glory Hole, from vessels passing through the field.
2) A White Rose specific field traffic survey should be undertaken to provide a better understanding of the vessels that may pass through the field. The results of this study should be used to develop a ship collision assessment that determines the collision risk to the FPSO as well as any MODU that may be operating in the field.
3) Husky should also review in more detail the potential for icebergs to cause damage or scouring of equipment in the SWRX Glory Hole or flowlines. This review should also include the Ice Management procedures to ensure that the SWRX equipment can be protected to a similar level as existing subsea equipment.
4) The potential for MODU mooring chains to damage the flowlines or umbilicals has previously been assessed by the White Rose project. However, the potential damage that drifting anchors could cause to the flowlines or umbilical has not been assessed and should be reviewed to ensure that the potential frequency of damage is acceptable.

1. Introduction

Husky Energy Ltd (Husky) is planning the development of the South White Rose Extension (SWRX) area. This area is located approximately 4km south of the current Southern Glory Hole (SGH) in approximately 120m of water. Within the new glory hole, one new drill centre will be constructed with wells tied back, indirectly, to the SeaRose FPSO. The SWRX drill centre will comprise three production wells, two gas injection wells and a water injection well with expansion capacity for up to twelve wells. As SWRX facilities will be routed to and from the SeaRose FPSO via the existing tie-back from the North Amethyst drill centre, there shall be minimum requirement to make modification to the FPSO. The initial stage of the SWRX project shall be to route a gas injection pipeline from the Northern drill centre to the new glory hole and tie this in to the gas injection well, which will be the first well to be drilled in the SWRX glory hole.

As part of the development, Husky is intending to submit a Development Plan Amendment to C-NLOPB. To support this amendment, Husky has requested that Atkins assess the potential impact of the new development on existing White Rose safety studies. This report has been prepared to assist in the Development Plan Amendment application and reflects the current stage of the SWRX design. It is the intention for this study to be updated and reviewed as the design progresses.

1.1 Scope of Work

The purpose of this study is to review existing safety studies that were developed for the White Rose project to determine the potential impact of the new SWRX development. The studies which have been identified as requiring review are:

- MODU Blowout Risk Assessment (WR-HSE-RP-0015) [1];
- MODU Dropped Object Analysis (WR-HSE-RP-0028) [2];
- MODU Risk Assessment (WR-HSE-RP-0020) [3].

This report is largely based on the previous Safety Assessment for SWRX [4] prepared in October 2006. This report has updated the previous assessment to use the latest glory hole layout, drilling plan / schedule, lift manifest etc. In addition, this report details the hazards and risks associated with Diving Support Vessel (DSV) and Pipelay barge operations, as these were not specifically addressed within the studies listed above. Finally, the impact of extending the gas injection flowline to the new SWRX glory hole and of tying the SWRX production fluids into the North Amethyst flowlines are assessed in terms of potential impact on the SeaRose FPSO.

1.2 Structure of Report

Section 2 of the report gives details of the South White Rose Extension Project, including diagrams representing the new equipment layouts.

The changes to the frequency of blowouts and impairment from dropped objects have been identified within sections 3 and 4 and the revised frequencies are carried into sections 5 and 6 to establish the subsequent change in risk levels. Any direct changes to the Risk Assessments are also discussed in sections 5 and 6.

Section 7 assesses the potential impact that the additional inventory in the SGH flowlines may have on hydrocarbon releases that occur back at the FPSO.

2. South White Rose Extension Project

The South White Rose Extension (SWRX) area is being considered for development as shown in Figure 2-1. This area is located approximately 4 km south of the current Southern Glory Hole (SGH), in approximately 120 m of water. Within the new glory hole, one new drill centre will be constructed that tie back to the SeaRose FPSO via the Prod/WI&GI flowlines between the North Amethyst and Southern Drill Centres. The SWRX drill centre will be comprised of three production wells, 2 gas injection wells and a water injection well with potential for a total of 10 wells. A new gas injection flowline will be routed from the Northern Drill Centre (NDC) to tie in to the SWRX gas injection well, as shown in Figure 2-1.

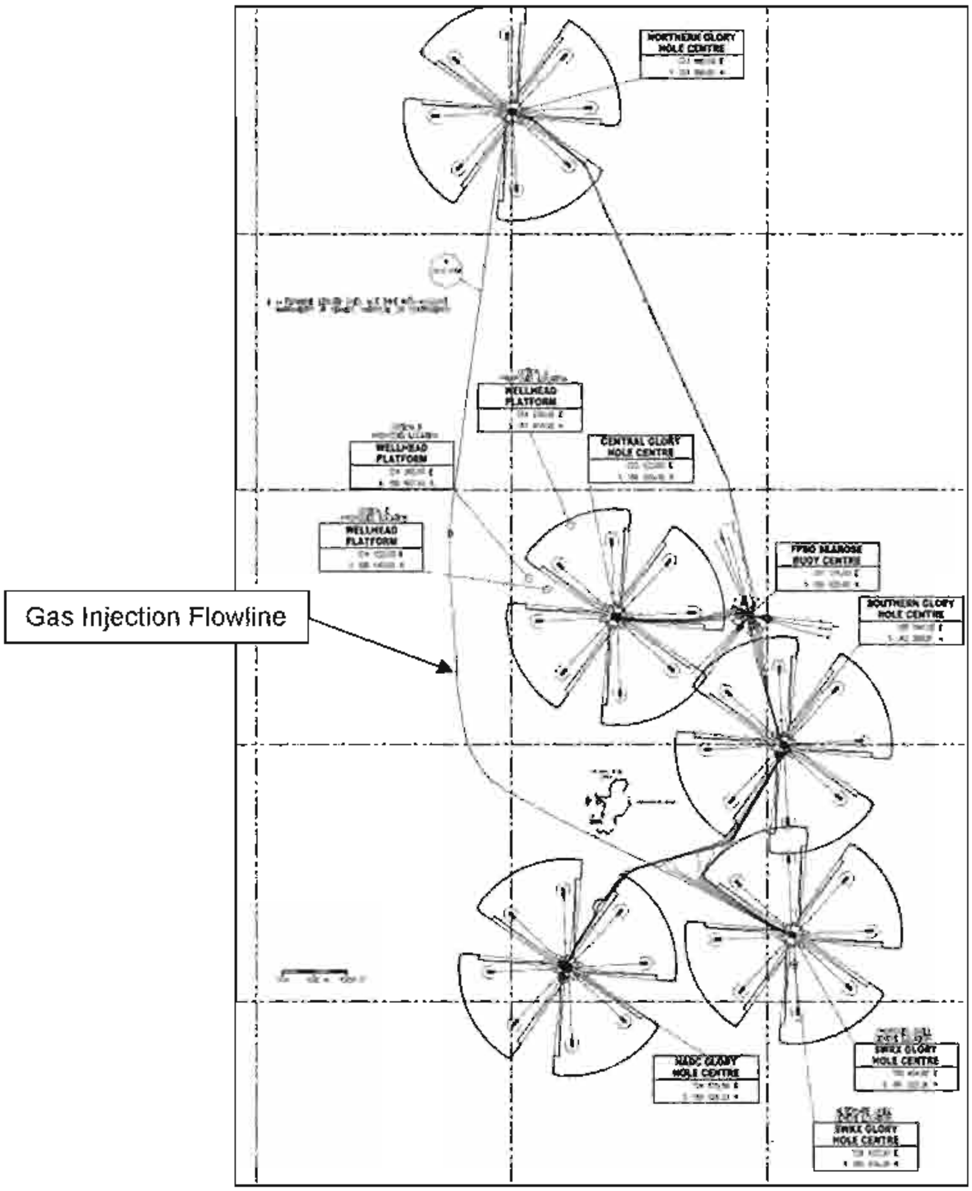


Figure 2-1: SWRX Tieback to SeaRose FPSO

2.1 Subsea Equipment

The subsea facilities at SWRX will include all equipment necessary for the safe and efficient operation and control of the subsea wells and transportation of production and injection fluids between the wells and the FPSO. The flowlines will tie into the North Amethyst flowlines in order to transport fluids to the FPSO. No additional risers, flowlines or control lines will be installed on the FPSO and no modifications are required to the North Amethyst drill centre. Procedures for installation of subsea facilities and subsequent operations for SWRX are anticipated to be the same as those currently employed for the existing White Rose Development.

2.1.1 SWRX Glory Hole Construction

The glory hole needed to support establishment of the drill centre will be excavated to a maximum of 11m below existing seabed level with a maximum "floor" dimension of 80m by 45m and graded side slopes as required for stability and the flowline ramps.

The proposed glory hole layout for SWRX is indicated in Figure 2-2.

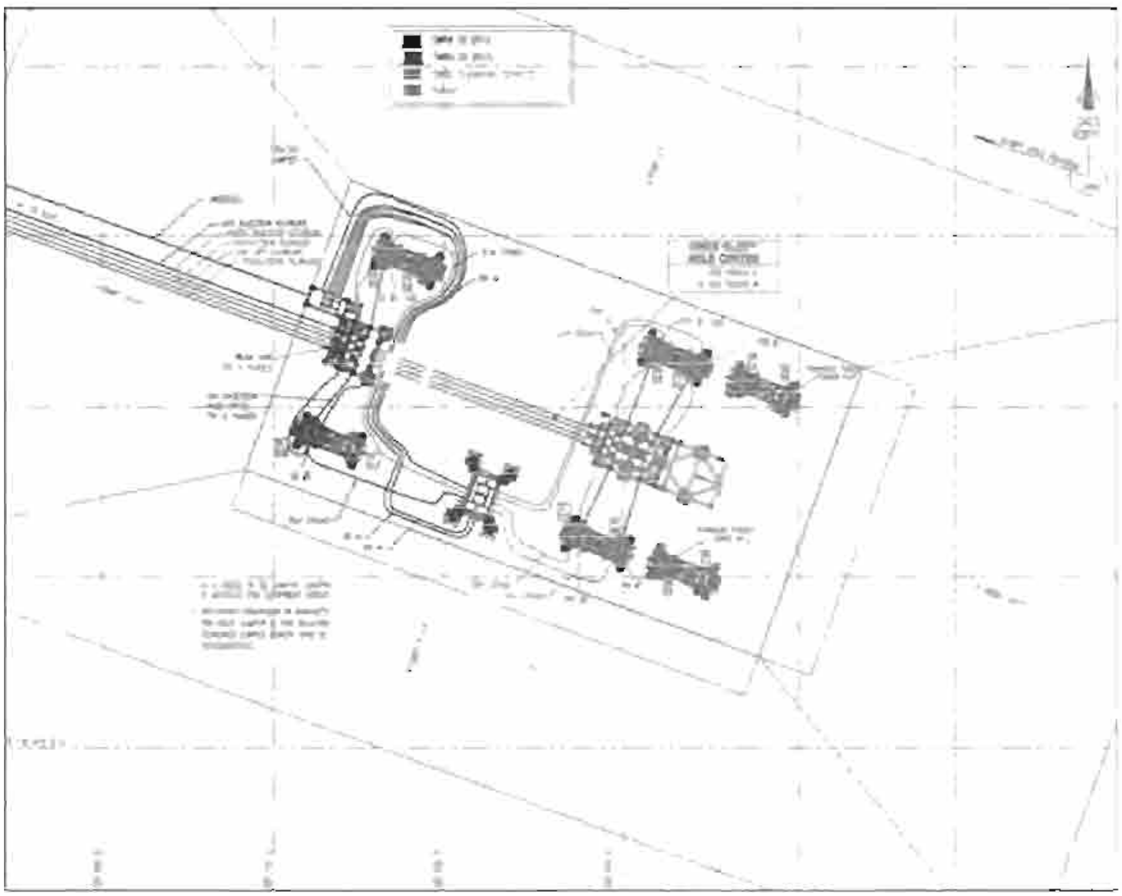


Figure 2-2: SWRX Glory Hole Layout

Table 2-1 shows the preliminary well schedule provided by the SWRX project [5].

Well	Estimated online date
SWRX Gas Injection Well G1V1	mid Nov 2013
South Avalon Production Well (SA)	end Aug 2014
South Avalon Gas Injection Well (SA)	end Oct 2014
SWRX Oil Producer Well	beg Feb 2015
SWRX Oil Producer Well	mid May 2015
SWRX Water Injector Well I3	end Aug 2015

Table 2-1: Preliminary SWRX Well Schedule

3. Blowout Assessment

This blowout assessment establishes the consequences and risks associated with the various types of blowouts that could affect the MODU and the personnel on board during drilling and well intervention activities.

In order to achieve this, a number of factors are taken into consideration. These include:

- Type and frequency of well operations (drilling, completion etc.);
- Probability of blowout for each type of well operation;
- Location of blowout (drill floor, subsea etc);
- Size of blowout (through the drill string, annulus, unrestricted etc);
- Ignition probability;
- Time to ignition (immediate or delayed).

The frequency and consequences of blowouts during the development of SWRX are assessed next.

3.1 Well Operations

Well operations under consideration during this evaluation of the risk from blowout for the SWRX project are:

- development drilling from the MODU;
- well completion.

Blowout frequency data for each well operation considered, and quoted in Table 3-1 below, has been based upon data contained in the OGP Risk Assessment Data Directory for Blowout Frequencies (2010) [6]. This data in the OGP document is based on historic data from the North Sea and US Gulf of Mexico. Blowout frequencies are presented in [6]for offshore operations that are of North Sea standard and for those that are not of North Sea standard. It is assumed that the operations conducted as part of the SWRX project will use equipment of North Sea standard. Account has been taken of the general downward trend in blowout probability in recent years due to advances in both technology and safety management systems. For the purposes of this assessment, these blowout frequencies are assumed to apply to the drilling and completion of both the production and gas injection wells.

Well Operation		Base Blowout Per Operation
Development Drilling from the MODU	Shallow Gas	1.21E-03
	Reservoir Drilling - Oil	4.80E-05
	Reservoir Drilling - Gas	7.00E-05
Well Completion	Oil Well	5.40E-05
	Gas Well	1.40E-04
Gas injection well (production phase only)		1.80E-05

Table 3-1: Summary of the Base Blowout Frequency Data for Each Well Operation

3.1.1 Development Drilling from the MODU

During development drilling, two elements of blowout risk must be considered. These are:

- blowout involving shallow gas;
- blowout from the deep reservoir (hereafter referred to as reservoir blowout).

It is necessary to consider these events separately as they differ both in terms of frequency of occurrence and hazard potential.

3.1.2 Well Completion

Completion of a well is carried out when a development well has been drilled successfully and is required to be brought into production or for injection of gas or water. The completion operation is defined as any installation of production tubing, packers and other equipment as well as perforation and stimulation in production and injection wells.

3.2 Blowout Frequency

Table 3-2 shows the preliminary well schedule provided by the SWRX project.

Well	Estimated online date
SWRX Gas Injection Well G1V1	mid Nov 2013
South Avalon Production Well (SA)	end Aug 2014
South Avalon Gas Injection Well (SA)	end Oct 2014
SWRX Oil Producer Well	beg Feb 2015
SWRX Oil Producer Well	mid May 2015
SWRX Water Injector Well I3	end Aug 2015

Table 3-2: Preliminary SWRX Well Schedule

Husky has advised that it will take 100 days to drill and complete one well. Therefore the blowout assessment uses 600 days as the basis for the time required to drill and complete the 6 wells.

Table 3-3 shows the proportion of blowouts that could be expected to occur on the drillfloor of the MODU or subsea (taken from [6]).

SWRX	Drilling - Deep Reservoir		
Blowout Type	Drillpipe	Annulus	Unconfined
Drillfloor	36%	22%	3%
Subsea		31%	
	Drilling - Shallow Gas		
Blowout Type	Drillpipe	Annulus	Unconfined
Drillfloor		25%	1%
Subsea		69%	
	Completion		
Blowout Type	Drillpipe	Annulus	Unconfined
Drillfloor	50%	50%	
Subsea			

Note that 8% of deep reservoir blowouts are assumed to occur underground.
Note that 5% of shallow gas blowouts are assumed to be safely diverted.

Table 3-3: Proportion of Blowout Frequencies by Source Location

Table 3-4 shows the blowout frequency for the SWRX project based on the well operations and the general frequency per operation shown in Table 3-1.

E.g. Unconfined Deep Reservoir Drillfloor blowout during the Drilling phase:

Blowout Frequency = [4 (number of oil + water injection wells drilled) x 4.80E-05 (total blowout frequency for deep reservoir oil wells) + 2 (number of gas wells drilled) x 7.00E-05 (total blowout frequency for deep reservoir gas wells)] x 3% (proportion of blowouts that are unconfined and on drillfloor) = **9.96E-06.** Note that this is the total frequency and to annualise, this value is multiplied by 365/600, giving an annual unconfined deep reservoir drillfloor blowout frequency of **6.06E-06 per annum**. It should also be noted that the blowout frequency for gas wells is used, as the gas injection blowout frequency applies to the production phase only.

SWRX	Drilling - Deep Reservoir		
Blowout Type	Drillpipe	Annulus	Unconfined
Drillfloor	1.20E-04	7.30E-05	9.96E-06
Subsea		1.03E-04	
	Drilling - Shallow Gas		
Blowout Type	Drillpipe	Annulus	Unconfined
Drillfloor		1.82E-03	7.26E-05
Subsea		5.01E-03	
	Completion		
Blowout Type	Drillpipe	Annulus	Unconfined
Drillfloor	2.48E-04	2.48E-4	
Subsea			

Table 3-4: Total Blowout Frequency Results for All SWRX Operations

SWRX	Drilling - Deep Reservoir		
Blowout Type	Drillpipe	Annulus	Unconfined
Drillfloor	7.30E-05	4.43E-05	6.06E-06
Subsea		6.26E-05	
	Drilling - Shallow Gas		
Blowout Type	Drillpipe	Annulus	Unconfined
Drillfloor		1.11E-03	4.41E-05
Subsea		2.44E-03	
	Completion		
Blowout Type	Drillpipe	Annulus	Unconfined
Drillfloor	1.51E-04	1.51E-04	
Subsea			

Table 3-5 - Annualised Blowout Frequencies for SWRX Ops

3.3 Blowout Consequences

3.3.1 Blowout Hydrocarbon Release Rates

The consequences of a blowout incident will depend upon the size and location of the blowout. As stated previously two main blowout types are being considered, deep reservoir blowouts and shallow gas blowouts, resulting in releases subsea or at the drillfloor. Each of these has been split into two events, one representing a blowout from one of the gas wells and the other representing the production wells.

3.3.2 Deep Reservoir Blowouts

Historically, for deep reservoir blowouts occurring at the drill floor the following flowrates are considered to be typical:

- Drill pipe Blowout 50kg/s
- Annulus Blowout 100kg/s
- Unconfined Blowout 250kg/s

A more detailed assessment of the flowrates associated with blowouts was completed during the initial White Rose Project phase to assess the potential environmental impact of deep reservoir blowout incidents from White Rose wells [7]. This analysis used detailed modelling techniques to simulate a number of specific blowout scenarios. However, it was found that the results predicted by the detailed analysis did not cover all the scenarios shown above. In addition, for those scenarios that were similar, the outflow rate from the detailed analysis was lower than that predicted by the historical information. For this reason, the historical outflow rates were retained for this assessment to model blowouts at the drill floor.

For the deep reservoir release, the maximum subsea blowout rate quoted in the detailed analysis was 36kg/s (32kg/s oil and 4kg/s gas). This value has been used in the consequence analysis.

3.3.3 Shallow Gas Blowouts

For the shallow gas blowout, a release rate based upon historical shallow gas blowouts is taken as 100MMSCFD (30kg/s) of methane.

3.3.4 Ignition Probability

If ignited, the potential for loss of life from any blowout incident increases dramatically.

Blowouts that do not ignite can result in large releases of hydrocarbons to the environment, however the threat to personnel and the MODU are generally considered to be low. Such events would only really threaten personnel if high levels of H_2S were released from the well fluids, which is not the case for the White Rose field.

Using historical data analysed by Scandpower within [8], between 1980 and 1993 a total (covering all well operations) of 120 blowout events were reported to have occurred in the North Sea and the Gulf of Mexico regions. Of these 120 incidents, 19 were reported to have ignited resulting in a fire. Based upon the above figures, an average ignition probability of 0.16 may be derived.

However, it should be noted that of these 120 blowouts, a significant proportion (around 30%) have been shallow gas blowouts which have been safely diverted. Where this is the case these incidents have been considered to be non-hazardous and therefore have been discounted.

If it is assumed that diverted blowouts do not ignite then the probability of ignition for undiverted blowouts is around 23% [19/0.7x120].

The Scandpower analysis does not provide a breakdown or assessment of blowout ignition probability according to blowout location. Consequently, it will be assumed that the ignition probability for all blowouts, irrespective of location, will be 0.23.

3.3.5 Blowout Hazard Assessment

Although White Rose wellfluids do not contain significant concentrations of H_2S, there is still a threat of unignited flammable gas entering Accommodation spaces on the MODU. As a result unignited releases have been examined within this section as well as ignited releases.

3.3.6 Drill floor Blowouts

Ignited drill floor blowouts would burn as jet fires which would be mostly vertical in orientation although there could be a degree of deflection through either wind effects or by the fire impinging on the drill derrick.

Consequence analysis has been conducted, based on production blowouts, using in-house TORCH software [9] examining the impact of thermal radiation on the Accommodation and TEMPSC facilities of the MODU for each of the scenarios examined.

The results of this analysis are presented next in Table 3-6.

Blowout Rate	Wind Speed	Heat Flux at TR	Heat Flux at TEMPSC
50kg/s	0m/s 5m/s 10m/s	Low $50kW/m^2$ $70kW/m^2$	Low $30kW/m^2$ $70kW/m^2$
100kg/s	0m/s 5m/s 10m/s	Low $60kW/m^2$ $70kW/m^2$	Low $40kW/m^2$ $70kW/m^2$
250kg/s	0m/s 5m/s 10m/s	Low $70kW/m^2$ $>70kW/m^2$	Low $70kW/m^2$ $>70kW/m^2$

Table 3-6: Heat Fluxes Caused by Vertical Blowouts - Wind Towards the Accommodation

The above results have been generated by superimposing thermal radiation contour plots onto an elevation of the MODU. Example plots are presented in Appendix B showing the impact of drillpipe blowouts at the drillfloor with various wind speeds blowing towards the MODU Accommodation. Table 3-7 shows the vulnerability of humans to various levels of thermal radiation [10].

kW/m^2	Effect
1.2	Received from the sun at noon in the summer
2	Minimum to cause pain after 60 seconds
5	Pain within 15 to 20 seconds Injury after 30 seconds 2^o burns after 2 minutes 50% fatality probability after 5 minutes.
6	Pain within 10 seconds 50% fatality after 3 minutes
12.5	Pain within 4 seconds 2^o burns after 40 seconds. 50% fatality probability after 80 seconds.
35	Pain threshold instantaneous 2^o burns after 8 secs 50% fatality probability after 8 seconds. Cellulosic material will pilot ignite within 60 seconds

Table 3-7: Vulnerability of Humans to Thermal Radiation

It is clear that some degree of heat flux will be experienced on most exposed areas of the installation due to the fires described above. Personnel exposed to such thermal radiation levels would suffer fatality.

However, it is worth noting that in the case of an impending reservoir blowout, adequate warning should, in most cases, be available which would result in all non-essential personnel being mustered in the TR either before hydrocarbons are released at the drillfloor or before ignition occurs.

3.3.7 Subsea Blowouts

Two blowout types have been considered here, the first being a shallow gas blowout which could occur whilst drilling the top hole and the second being a release from either the wellhead or outside of the casing during deep drilling or completion of the well.

For both scenarios ignited releases can result in a sea pool fire whilst unignited releases can result in hydrocarbon gas being drawn into Accommodation spaces.

For small subsea releases, the diameter of the fire on the sea surface is calculated based on 1/5 x water depth. This approximate relationship is based on work reported in SINTEF's Fire Risk Assessment Manual [11] although this could potentially be an underestimate for larger releases [12]. An alternative fire diameter can also be modelled using a fireball model, calculating the diameter as $D = 6Q^{0.4}$ (Q = outflow rate in kg/s).

For the shallow gas release, the fire size on the sea surface will be the larger of the plume based model (assumed in 120m of water in the White Rose Area) and the fireball model.

For the deep reservoir blowout there is a further fire type to consider, this being an oil pool fire on the sea surface. Fire sizes for both scenarios are shown in Table 3-8.

Breach Size	Fire Type / Model Used	Fire Diameter
Shallow Gas	Gas Plume Model	24m
	Gas Fireball Model	23m
Deep Reservoir	Gas Plume Model	24m
	Gas Fireball Model (4kg/s Gas)	10m
	Oil Pool Fire Model (32 kg/s Oil)	24m

Table 3-8: Subsea Blowout Fire Sizes

Importantly, the smoke generated from these fires may have a significant effect on the MODU. This will only be problematic for the deep reservoir blowout as the concentration of smoke generated by a well ventilated gas pool fire in the case of a shallow gas release will be relatively low. For a well ventilated pool fire on the sea surface, the Carbon Monoxide (CO) production rate will be of the order of 0.5% or 5,000ppm [13]. Table 3-9 shows the effects of different levels of CO on personnel.

Dispersion analysis has been conducted using the in-house PLUME software [14] and the results presented in Appendix B. The analysis shows the concentrations that could be expected on the MODU for the case where there is a 5m/s wind blowing the smoke towards the Accommodation.

This is an idealised view of events as the plume contours assume free field dispersion. In reality the smoke will billow up around the sides of the vessel and through the moonpool.

Concentration	Effect
400ppm CO	Lower Toxicity Limit, hallucinations after 0.5-2 hours
800ppm CO	4m visibility (likely to prevent or discourage escape and evacuation)
3000ppm CO	Fatal after 30 minutes

Table 3-9: Effect of Smoke Concentration

Finally, unignited gas releases from a subsea blowout, and in particular a shallow gas blowout, could engulf the MODU in flammable gas with the potential for gas to be drawn into accommodation spaces and result in an explosion. Gas dispersion analysis using PLUME [14] has been conducted examining this scenario also. Results are presented in Appendix B for the cases where there is little or no wind and the case where 5m/s wind is blowing towards the accommodation.

3.4 Blowout Assessment Conclusion

The annual frequency of blowouts during the drilling and completion of the six new wells for the SWRX project is predicted to be 4.68E-03 per annum.

The blowout frequencies carried forward to the MODU Risk Assessment (Section 5) are as follows:

Drillfloor Blowout – Gas Wells:

Drillpipe: 1.16E-04 Annulus: 4.72E-04 Unconfined: 1.73E-05

Drillfloor Blowout – Production Wells:

Drillpipe: 1.08E-04 Annulus: 8.27E-04 Unconfined: 3.29E-05

Subsea Blowout – Gas Wells:

Deep Reservoir: 2.64E-05 Shallow Gas: 1.02E-03

Subsea Blowout – Production Wells:

Deep Reservoir: 3.62E-05 Shallow Gas: 2.03E-03

This assessment is considered to be conservative as the blowout frequency and consequences from a water injection well are taken to be the same as a blowout from a production well. Any changes to the number or type of wells being drilled will have an effect on the frequencies and risks calculated here.

It should be noted that the blowout frequencies are different to those previously identified for the MODU [3] because they are based on a different number of wells and are based on a more recent statistical data set.

4. Dropped Object Risk Assessment

As a part of the SWRX safety assessment, a dropped object study has been carried out. This study determined the dropped object risks associated with creating the new glory hole, drilling the new wells and installing equipment required for the new Drill Centre.

The study investigated the potential for equipment to be dropped from the MODU during well operations within the drilling and completion phases of the project. For the SWRX Glory Hole the study estimated:

- the frequency of equipment being dropped in the area of the subsea equipment.
- the probability of dropped objects impacting the subsea equipment.
- the likelihood of dropped object impacts resulting in impairment of equipment i.e. impact energy greater than pipeline impact resistance.

4.1.1 Dropped Object Model

The dropped object model estimated:

- impact energies of falling objects;
- the likelihood (or probability) of dropped objects impacting a given location;
- the probability that the dropped object will result in damage to the subsea targets.

It was assumed that all the lifts have a dropped object probability of 1E-05 per lift, with the exception of the very heavy lifts of the BOP which will have a dropped object probability of 2E-04 per lift. These values have been extracted from the best available HSE dropped object data [15] and are consistent with the previous dropped object study conducted for Husky [2] during the field development.

It should be recognised that there have been two incidents in the White Rose field where the BOP has been dropped during the final positioning of the BOP within the glory hole. This would imply that the frequency of dropping the BOP should be higher for this particular MODU than the historical frequency suggests. However, it is also noted that a stand-off distance is used when carrying out very heavy lifts and this limits the time which the BOP spends over subsea equipment during lowering into position.

Husky has advised that the drilling and completion of each well will take 100 days (65 days for drilling and 35 for completion). The dropped object risks have been calculated for the entire SWRX project (i.e. for the drilling and completion of all 6 wells) – this gives a total frequency of impact on and damage to the subsea equipment. In order to establish annualised frequencies, the total frequencies have been factored by 365/600 (100 days x 6 wells). The DSV is assumed to be on station at the SWRX glory hole for 25 days [16] and the annnualisation factor is therefore (365/25).

4.2 Glory Hole Installation Schedule

The well installation process at the SWRX drill centre is expected to follow the schedule outlined next.

i) The SWRX gas injection well is drilled and the flowline from the Northern drill centre is hooked up.

ii) MODU drills the South Avalon Production Well and production is started.

iii) The MODU returns to drill the South Avalon (SA) Gas injection well.

iv) The next 2 production wells are drilled and completed allowing production from the 3 wells to commence.

v) The MODU returns to drill the final well (SWRX water injection well I3).

A range of ancillary subsea equipment will be also be installed at various stages throughout the operation such as manifolds and a subsea distribution unit (SDU). These items will be installed in two stages: the gas injection manifold and related items will be installed in 2013, before the first gas injection well is live, the production / water injection manifold and related items will be installed in 2014, after the gas injection well is live.

The dropped object risks to all installed equipment, including live subsea equipment, as a result of installation operations, are calculated at each stage of the process given above.

4.3 MODU Details

Husky has not yet selected the MODU that will be used for the SWRX project. A number of MODUs are under consideration. Atkins has chosen to use the dimensions and crane details of the GSF Grand Banks MODU. As this is the smallest of the MODUs under consideration, with the shortest crane reach, it will give the most conservative dropped object results, as the dropped object impact locations on the sea bed will be concentrated over a smaller area and therefore the probability of impacting on a given subsea target will be greater (assuming the same lift manifest is used).

Once the MODU to be used has been selected, this study can be revisited and updated where necessary to reflect the details of the actual MODU to be used.

4.3.1 Crane Locations

It has been assumed that, while on-station above the installation locations, 80% of the supply boat to MODU lifts will be performed using the port-side crane and 20% with the starboard-side - this is likely to be the case if the GSF Grand Banks MODU is used. A sensitivity has been conducted to calculate the results based on a 50%:50% split of port and starboard crane usage, which may be more likely on other rigs.

Heavy lifts are performed through the moonpool. Very heavy lifts (xtrees and BOP) which have a higher drop frequency will be performed with the MODU moved a distance of 60m off-station in order to reduce the risk of impact on the subsea equipment should the item be dropped. This off-set distance was previously assessed during the White Rose Project as being the optimum distance to move off station to reduce the potential for heavy lifts to impact on subsea equipment should they be dropped – it is assumed this approach will be adopted again.

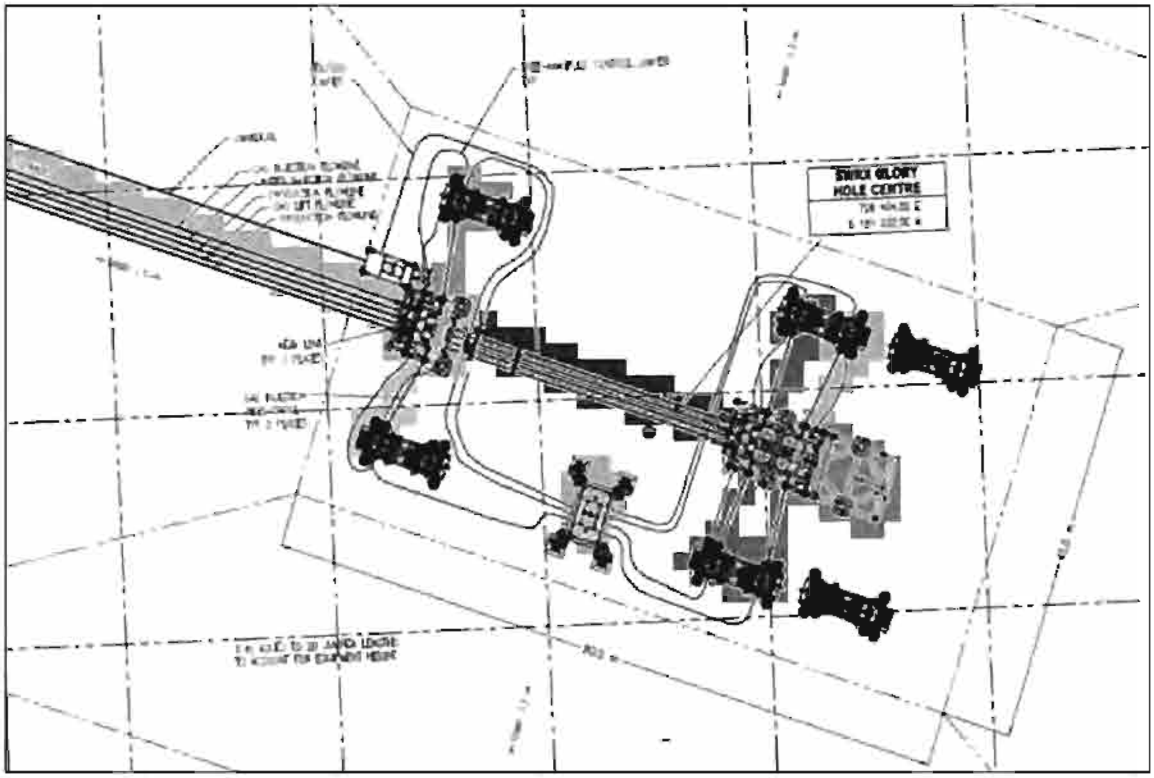
When modelling dropped objects, the MODU is assumed to be positioned with the moonpool directly above the well being drilled.

4.4 Hydrodynamic Modelling

Hydrodynamic models used in the study were based on extensive previous analysis of dropped objects using AQWA, Atkins' trajectory analysis program. From the results of these studies, it was found that the object types could be divided into broad categories with different responses to wave action, current flow and still water displacement. The most appropriate generic hydrodynamic model (hydromodel) which best represents the specific lift manifest item is chosen in the model. As long as an approximate match for equipment in terms of shape and size can be used it is considered that the hydromodel will react in a similar way to the dropped object in being assessed.

4.5 Subsea Equipment Targets

The equipment to be installed at the SWRX Glory Hole has been divided into eleven target areas, the frequency of impact and/or damage to each of these targets will be determined separately. Figure 4-1 shows the division of the subsea equipment into target areas.



Flowlines between SeaRose and SWRX	1	
SWRX Gas Injection Well 1	2	
Gas Injection Manifold	3	
SDU	4	
Central Section of Pipeline	5	
Production/Water Injection Manifold	6	
South Avalon Oil Producer Well 2	7	
South Avalon Gas Injection Well 3	8	
SWRX Oil Producer Well 4	9	
SWRX Oil Producer Well 5	10	
SWRX Water Injection Well	11	

Figure 4-1: SWRX GH Target Areas

The impact and damage frequency results have been calculated based on the order in which the wells will be drilled. When the first well is drilled, the only subsea target will be target 2 , as none of the other wells or items of equipment will be in place at that time. For each subsequent well drilled, the number of target increases by 1 well (i.e. the previously drilled well becomes a target) until the final well is drilled, at which point, the other equipment will be present as targets. It should be noted that, for conservatism, the well being drilled is included as a target for objects dropped during the drilling process.

Table 4-2 shows which targets are included in the dropped object assessment for each well drilled (and the installation of the additional (manifold etc) items).

	Is Target Included in Dropped Object Assessment for Drilling/Installation of:							
Target	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	2013 items	2014 items
1 – Flowlines between Sea Rose and SWRX	N	Y	Y	Y	Y	Y	Y	Y
2 – SWRX Gas Injection Well 1	Y	Y	Y	Y	Y	Y	Y	Y
3 – Gas Injection Manifold	N	Y	Y	Y	Y	Y	Y	Y
4 – SDU	N	Y	Y	Y	Y	Y	N	Y
5 – Central Section of Pipeline	N	Y	Y	Y	Y	Y	N	Y
6 – Production/Water Injection Manifold	N	Y	Y	Y	Y	Y	N	Y
7 – South Avalon Oil Producer Well 2	N	Y	Y	Y	Y	Y	N	Y
8 – South Avalon Gas Injection Well 3	N	N	Y	Y	Y	Y	N	Y
9 – SWRX Oil Producer Well 4	N	N	N	Y	Y	Y	N	N
10 – SWRX Oil Producer Well 5	N	N	N	N	Y	Y	N	N
11 - SWRX Water Injection Well	N	N	N	N	N	Y	N	N

Table 4-1: Targets Included in Dropped Objects Study

4.5.1 Lift Manifest

A drilling lift manifest has been created for the SWRX Drill Centre, to show the details of the objects to be lifted and the number of lifts, as shown in Table 4-2. The lift manifest is based on the previous MODU dropped object study and reviewed and modified where appropriate by Husky for the SWRX project and has been used for the installation operation at each of the 6 well locations. The lift manifest shows the usage per zone – which is the proportion of lifts that will be carried out by each crane, where:

- SC represents the starboard-side crane (MODU located directly above well being drilled);
- PC represents the port-side crane (MODU located directly above well being drilled);
- MP represents a moonpool lift (MODU located directly above well being drilled);
- MP2 represents a moonpool lift (MODU located 60m North/South of well being drilled);

The lift manifest below shows all the lifts associated with drilling and completing each well. In addition, those items presented in Table 4-3 will be lifted as part of the glory hole construction (not per well). These items will be lifted by a DSV / construction vessel, rather than the MODU. The items will be installed in two stages, some items will be installed in 2013, before the gas injection well is live (though after it has been drilled) and the remaining items will be installed in 2014, after the gas injection well is live.

Number	Name	Hydro Model	Lifts/year	Lift Frequency	Weight	Length	Width/ Diameter	Height	Usage Per Crane SC	PC	MP	MP2
1	mini Container full	Small Container	1500	0.00001	1620	1.83	1.52	2.44	0.5	0.5		
2	mini Container empty	Small Container	925	0.00001	660	1.83	1.52	2.44	0.5	0.5		
3	maxi Container full	Medium Container	365	0.00001	3350	3.05	2.44	2.44	0.5	0.5		
4	maxi Container empty	Medium Container	235	0.00001	1140	3.05	2.44	2.44	0.5	0.5		
5	H/H Container full	Medium Container	95	0.00001	3170	3.05	2.44	1.22	0.5	0.5		
6	H/H Container empty	Medium Container	50	0.00001	990	3.05	2.44	1.22	0.5	0.5		
7	H/H Container full	Medium Container	95	0.00001	4250	6.10	2.44	1.22	0.5	0.5		
8	H/H Container empty	Medium Container	85	0.00001	1400	6.10	2.44	1.22	0.5	0.5		
9	Tote full	Small Container	140	0.00001	4960	1.83	1.52	2.44	0.5	0.5		
10	Tote empty	Small Container	70	0.00001	660	1.83	1.52	2.44	0.5	0.5		
11	Open Container full	Medium Container	50	0.00001	5070	6.10	2.44	2.44	0.5	0.5		
12	Open Container empty	Medium Container	50	0.00001	1890	6.10	2.44	2.44	0.5	0.5		
13	Closed Container full	Medium Container	50	0.00001	4630	6.10	2.44	2.44	0.5	0.5		
14	Closed Container empty	Medium Container	140	0.00001	1910	6.10	2.44	2.44	0.5	0.5		
15	Basket full	Mtbasket Data	95	0.00001	1650	3.05	1.22	1.22	0.5	0.5		
16	Basket empty	Mtbasket Data	140	0.00001	660	3.05	1.22	1.22	0.5	0.5		
17	Basket full	Mtbasket Data	95	0.00001	2610	6.10	1.22	1.22	0.5	0.5		
18	Basket empty	Mtbasket Data	95	0.00001	1110	6.10	1.22	1.22	0.5	0.5		
19	Basket full	Mtbasket Data	95	0.00001	3040	9.14	1.22	1.22	0.5	0.5		
20	Basket empty	Mtbasket Data	95	0.00001	1480	9.14	1.22	1.22	0.5	0.5		
21	Basket full	Mtbasket Data	50	0.00001	3510	12.19	1.22	1.22	0.5	0.5		
22	Basket empty	Mtbasket Data	50	0.00001	1850	12.19	1.22	1.22	0.5	0.5		
23	Helifuel Tank Full	Medium Container	20	0.00001	6000	2.5	2.5	2.5	0.5	0.5		
24	Helifuel Tank Empty	Medium Container	20	0.00001	2500	2.5	2.5	2.5	0.5	0.5		
25	5 7/8" Drill Pipe Bundle [5]	TUBE06BNDDATA	50	0.00001	2910	9.45	0.15		0.5	0.5		
26	9 1/2" Drill Collars Bundle [5]	TUBE09BNDDATA	15	0.00001	2952	9.45	0.24		0.5	0.5		
27	8 1/4" Drill Collars Bundle [5]	TUBE09BNDDATA	15	0.00001	4218	9.45	0.21		0.5	0.5		
28	6 1/2" Drill Collars Bundle [5]	TUBE06BNDDATA	15	0.00001	6327	9.45	0.17		0.5	0.5		
29	7" Tubing	TUBE06DATA	160	0.00001	4354	12.5	0.18		0.5	0.5		
30	7" Liner Bundle of 9	TUBE09BNDDATA	50	0.00001	4354	12.5	0.18		0.5	0.5		
31	7" Liner Single Shoe Joint	TUBE06DATA	10	0.00001	4354	12.5	0.18		0.5	0.5		
32	30" Casing	TUBE30DATA	35	0.00001	5765	12.5	0.76		0.5	0.5		
33	30" Casing Shoe Joint	TUBE30DATA	5	0.00001	5765	12.5	0.76		0.5	0.5		
34	16" Casing	TUBE16DATA	55	0.00001	3523	12.5	0.41		0.5	0.5		
35	16" Casing Shoe Joint	TUBE16DATA	5	0.00001	1762	12.5	0.41		0.5	0.5		
36	13 3/8" Casing	TUBE13DATA	160	0.00001	1265	12.5	0.34		0.5	0.5		
37	13 3/8" Casing Shoe Joint	TUBE13DATA	10	0.00001	1265	12.5	0.34		0.5	0.5		
38	9 5/8" Casing	TUBE09DATA	200	0.00001	995	12.5	0.24		0.5	0.5		
39	9 5/8" Casing Shoe Joint	TUBE09DATA	10	0.00001	995	12.5	0.24		0.5	0.5		
40	5 7/8" HW Drill Pipe Joint	TUBE06DATA	30	0.00001	2531	12.5	0.15		0.5	0.5		
41	5 7/8" Drill Pipe	TUBE06DATA	160	0.00001	970	9.45	0.15		0.5	0.5		
42	Marine Riser Joint	Marine Riser Data	5	0.00001	3000	15.55	0.53		0.5	0.5		
43	Riser Slip Joint	PINCNT	5	0.00001	18000	12.2	0.64		0.5	0.5		
44	PGB	X&SKD	5	0.00001	3000	4.1	3.90	4.1	0.5	0.5		
45	Wellhead	TUBE36DATA	5	0.00001	10000	10.67	0.91		0.5	0.5		
46	Xmas Tree	Xmas Tree	5	0.0002	37000	4.1	3.90	4.1				
47	Xmas Tree Frame	X&SKD	5	0.00001	3000	4.1	3.90	4.1	0.5	0.5		
48	H.P.U Controls	HPU Controls	5	0.00001	4000	2	1.20	1.2	0.5	0.5		
49	Spares Workshop Container	Medium Container	5	0.00001	8000	6	2.80	2.8	0.5	0.5		
50	Container Completion Equipment	Small Container	5	0.00001	8000	6	1.20	1.2	0.5	0.5		
51	Workshop Container	Large Container	5	0.00001	8000	6	2.80	2.8	0.5	0.5		
52	Clamp Container	Medium Container	5	0.00001	4000	6	2.80	2.8	0.5	0.5		
53	Power Tong Box	Medium Container	5	0.00001	4000	3	2.00	2	0.5	0.5		
54	Handling Tools	Handling Tools	5	0.00001	6000	10	8.00	4	0.5	0.5		
55	Jumper Basket	Mtbasket Data	5	0.00001	4000	9	1.20	1.2	0.5	0.5		
56	Completion Equipment 1	Mtbasket Data	5	0.00001	6000	17	1.20	1.2	0.5	0.5		
57	Completion Equipment 2	Mtbasket Data	5	0.00001	6000	10	1.20	1.2	0.5	0.5		
58	Spare Cable Basket	Mtbasket Data	5	0.00001	6000	10	1.20	1.2	0.5	0.5		
59	Completion Basket	Mtbasket Data	5	0.00001	4000	20	4.00	4	0.5	0.5		
60	Choke Manifold	CTPP_MIU_TR	5	0.00001	4000	2	2.00	1	0.5	0.5		
61	Pipe Basket	Large Container	15	0.00001	4000	6	1.20	1.2	0.5	0.5		
62	Lubricator skid	CTPP_MIU_TR	10	0.00001	6000	5	2.00	2	0.5	0.5		
63	High Pressure Pump	PP_SLF_HPP_P	5	0.00001	4000	2	2.00	2.8	0.5	0.5		
64	Control Line Spooler	CT_I_EL	10	0.00001	3000	2	2.00	2	0.5	0.5		
65	Chemical Injection Spooler	PP_SLF_HPP_P	10	0.00001	5000	2	3.00	2	0.5	0.5		
66	Compressor	Air Compressor	15	0.00001	12000	4	2.00	2	0.5	0.5		
67	Methanol Tank	Medium Container	5	0.00001	2000	2	2.00	2	0.5	0.5		
68	surge tank	Large Container	10	0.00001	5000	7	3.00	3	0.5	0.5		
69	internal subsea test tree	TUBE20DATA	10	0.00001	5000	13	1.20		0.5	0.5		
70	Tubing Hangar	Marine Riser data	5	0.00001	2000	3	1.30	1.3	0.5	0.5		
71	Tubing Hangar landing string accessories	Medium Container	5	0.00001	1000	3	1.20	1.2	0.5	0.5		
72	Tubing Hangar landing string bundles	TUBE16BNDDATA	5	0.00001	1000	3	1.20		0.5	0.5		
73	5 7/8" HW Drill Pipe Joint	TUBE06DATA	30	0.00001	2531	12.5	0.15				1	
74	5 7/8" Drill Pipe	TUBE06DATA	160	0.00001	970	9.45	0.15				1	
75	Marine Riser Joint	Marine Riser Data	220	0.00001	3000	15.55	0.53				1	
76	Riser Slip Joint	PINCNT	20	0.00001	18000	12.2	0.64				1	
77	9 1/2" Drill Collar	DC_9_5	20	0.00001	2952	9.45	0.24				1	
78	PGB	X&SKD	5	0.00001	3000	4.1	3.90	4.1			1	
79	Xmas Tree + Frame + Wellhead	Xmas Tree	5	0.0002	50000	4.1	3.90	4.1				1
80	BOP	BOP	10	0.0002	200000	4.1	4.80	12.5				1
81	30" Casing	TUBE30DATA	35	0.00001	5765	12.5	0.76				1	
82	30" Casing Shoe Joint	TUBE30DATA	5	0.00001	5765	12.5	0.76				1	
83	16" Casing	TUBE16DATA	55	0.00001	3523	12.5	0.41				1	
84	16" Casing Shoe Joint	TUBE16DATA	5	0.00001	1761.5	12.5	0.41				1	

Table 4-2: Lift Manifest – Lifts per Well Drilled & Completed (Lifted by MODU)

Number	Name	Hydro Model	Lifts/year	Lift Frequency	Weight	Length	Width/ Diameter	Height	Usage Per Crane SC	PC	MP	MP2
2013												
85	installation of GI manifold base	Extra Large Container	1	0.00001	54000	22.68	12.48	4.464	0.5	0.5		
86	installation of GI manifold	Extra Large Container	1	0.00001	54000	22.68	12.48	4.464	0.5	0.5		
87	installation of SDU base	Extra Large Container	1	0.00001	54000	22.68	12.48	4.464	0.5	0.5		
88	Piles	TUBE30DATA	4	0.00001	8000	22	0.61		0.5	0.5		
89	S280 Piling Hammer c/w Sleeve	TUBE30DATA	4	0.00001	26500	13.4	1		0.5	0.5		
90	Pile Follower	TUBE30DATA	4	0.00001	3000	7.8	0.6		0.5	0.5		
2014												
91	Piles	TUBE30DATA	4	0.00001	8000	22	0.61		0.5	0.5		
92	S280 Piling Hammer c/w Sleeve	TUBE30DATA	4	0.00001	26500	13.4	1		0.5	0.5		
93	Pile Follower	TUBE30DATA	4	0.00001	3000	7.8	0.6		0.5	0.5		
94	Installation of Prod/WI manifold base	Extra Large Container	1	0.00001	54000	22.68	12.48	4.464	0.5	0.5		
95	installation of production manifold	Extra Large Container	1	0.00001	20000	15.376	5.176	6	0.5	0.5		
96	Installation of SWRX WI manifold	Extra Large Container	1	0.00001	20000	15.376	5.176	6	0.5	0.5		
97	installation of SWRX SDU	Extra Large Container	1	0.00001	20000	15.376	5.176	6	0.5	0.5		
98	Rigid spool installation@SWRX to WI x-tree	TUBE16x2Data	1	0.00001	10700	40	0.43		0.5	0.5		
99	Rigid spool installation@SWRX to Prod x-tree	TUBE16x2Data	3	0.00001	10700	40	0.43		0.5	0.5		
100	Rigid spool installation@SWRX to GI x-tree	TUBE16x2Data	2	0.00001	10700	40	0.43		0.5	0.5		

Table 4-3: Lift Manifest – Additional Items (Lifted by DSV)

4.5.2 Impact Frequency

Applying the number of lifts for each particular type of object modelled, and the probability of dropping the object, a frequency of dropped objects landing on any given area of the seabed can be predicted.

By defining the locations of all the subsea equipment targets in a grid structure relative to the locations of the cranes, the frequency of any dropped object landing on any given subsea target can be determined.

4.5.3 Impairment Probability

The probability that impact results in damage / impairment is based on the probability of the dropped object hitting the target equipment with sufficient energy.

The damage probability rule sets, use the same principles that were applied in earlier dropped object studies for the White Rose development. This method not only took credit for the dropped object damaging the subsea equipment by a direct hit but also took account of the object causing damage from an indirect hit (i.e. impact occurs off the centre of gravity of the object).

In the event of a dropped object impacting on a pipeline, there is the potential for the targets to be impaired. The probability of impairment is dependent on the impact energy of the object and the resistance of the pipeline. Energies greater than the capacity of the subsea equipment (section 4.5.4), have the potential to impair the equipment. Where the impact energy is greater than 3 times the equipment resistance, it is assumed that the probability of causing impairment is 1. Where the impact energy is between the resistance and 3 times that value, the probability of impairment on impact is interpolated linearly between 0 and 1.

4.5.4 Impairment Capacity of Subsea Equipment

Based on previous FE analysis of a dropped object striking subsea equipment, it was estimated that each of the targets could be impaired by an impact of 25kJ with the exception of the flowlines, which could be impaired by an impact of 5kJ. As a conservative estimate, it is assumed that this level of impairment would be sufficient to cause a loss of hydrocarbon containment.

4.5.5 Items Causing Impairment

Based on the impact energy and the calculated impairment probabilities, the items that could cause impairment of the subsea equipment can be identified. The items from the lift manifest can be split into three categories; those that would not have sufficient impact energy to cause impairment (probability = 0), those that may cause impairment (0<probability<1) and those that would be expected to cause impairment if impact occurred (probability = 1). Table 4-4 is based on a subsea equipment resistance of 25kJ (and therefore applies to all items except the flowlines). Table 4-5 is based on an impact resistance of 5kJ and is therefore applicable to the flowlines only.

No Damage Expected (Prob = 0)		Potential Damage (0<prob<1)			Expected Damage (Prob = 1)	
Item #	Item Name	Item #	Item Name	Probability	Item #	Item Name
2	mini Container empty	20	Basket empty	0.07	3	maxi Container full
6	H/H Container empty	34	16" Casing	0.11	9	Tote full
8	H/H Container empty	26	9 1/2" Drill Collars Bundle [5]	0.12	11	Open Container full
10	Tote empty	76	9 1/2" Drill Collar	0.12	13	Closed Container full
16	Basket empty	22	Basket empty	0.14	23	Helifuel Tank Full
18	Basket empty	4	maxi Container empty	0.17	28	6 1/2" Drill Collars Bundle [5]
35	16" Casing Shoe Joint	15	Basket full	0.23	43	Riser Slip Joint
36	13 3/8" Casing	25	5 7/8" Drill Pipe Bundle [5]	0.32	44	PGB
37	13 3/8" Casing Shoe Joint	69	Tubing Hangar	0.36	45	Wellhead
38	9 5/8" Casing	5	H/H Container full	0.39	46	Xmas Tree Frame
39	9 5/8" Casing Shoe Joint	66	Methanol Tank	0.46	47	H.P.U Controls
40	5 7/8" HW Drill Pipe Joint	59	Choke Manifold	0.60	48	Spares Workshop Container
41	5 7/8" Drill Pipe	17	Basket full	0.63	49	Container Completion Equipment
42	Marine Riser Joint	29	7" Tubing	0.70	50	Workshop Container
70	Tubing Hangar landing string accessories	30	7" Liner Bundle of 9	0.70	51	Clamp Container
71	Tubing Hangar landing string bundles	31	7" Liner Single Shoe Joint	0.70	52	Power Tong Box
72	5 7/8" HW Drill Pipe Joint	19	Basket full	0.74	53	Handling Tools
73	5 7/8" Drill Pipe	1	mini Container full	0.76	54	Jumper Basket
74	Marine Riser Joint	21	Basket full	0.76	55	Completion Equipment 1
83	16" Casing Shoe Joint	27	8 1/4" Drill Collars Bundle [5]	0.78	56	Completion Equipment 2
		12	Open Container empty	0.88	57	Spare Cable Basket
		7	H/H Container full	0.89	58	Completion Basket
		14	Closed Container empty	0.90	60	Pipe Basket
		32	30" Casing	0.90	61	Lubricator skid
		33	30" Casing Shoe Joint	0.90	62	High Pressure Pump
		24	Helifuel Tank Empty	0.94	63	Control Line Spooler
					64	Chemical Injection Spooler
					65	Compressor
					67	surge tank
					68	internal subsea test tree
					75	Riser Slip Joint
					78	Xmas Tree + Frame + Wellhead
					79	BOP
					84	36" Casing
					85	36" Casing Shoe Joint

Table 4-4: Items That Could Cause Damage to Subsea Equipment (25kJ Resistance)

No Damage Expected (Prob = 0)		Potential Damage (0<prob<1)			Expected Damage (Prob = 1)	
Item #	Item Name	Item #	Item Name	Probability	Item #	Item Name
38	9 5/8" Casing	41	5 7/8" Drill Pipe	0.06		All other items
39	9 5/8" Casing Shoe Joint	36	13 3/8" Casing	0.21		
		37	13 3/8" Casing Shoe Joint	0.21		
		35	16" Casing Shoe Joint	0.67		
		6	H/H Container empty	0.75		
		16	Basket empty	0.84		

Table 4-5: Items That Could Cause Damage to Subsea Equipment (5kJ Resistance)

4.6 Results

Table 4-6 shows the impact frequency on each target for each stage of the drilling programme.

Target	Impact Frequency From Drilling Well Number								Total	Annualised
	1	2	3	4	5	6	2013 extras	2014 extras		
1		6.47E-06	2.91E-05	1.54E-05	5.02E-06	4.26E-06			**6.02E-05**	**3.66E-05**
2	2.02E-04	3.87E-06	8.96E-06	8.67E-06	3.11E-06	2.86E-06	3.99E-08	3.88E-08	**2.30E-04**	**1.41E-04**
3		6.33E-06	1.92E-05	1.78E-05	5.64E-06	5.07E-06			**5.41E-05**	**3.29E-05**
4		1.83E-05	1.57E-05	3.39E-04	1.69E-05	1.04E-05		1.78E-07	**4.00E-04**	**2.46E-04**
5		2.16E-05	2.33E-05	7.87E-04	1.92E-05	3.12E-05			**8.82E-04**	**5.37E-04**
6		2.16E-05	2.33E-05	7.87E-04	1.92E-05	3.12E-05			**8.82E-04**	**5.37E-04**
7		2.08E-04	4.53E-06	1.97E-04	1.13E-04	1.24E-05		4.68E-08	**5.35E-04**	**3.26E-04**
8			2.00E-04	1.03E-05	3.69E-06	3.06E-06			**2.17E-04**	**1.32E-04**
9				2.69E-04	1.02E-05	1.83E-04			**4.62E-04**	**2.81E-04**
10					1.92E-04	1.04E-05			**2.02E-04**	**1.23E-04**
11						1.52E-04			**1.52E-04**	**9.25E-05**
Totals	**2.02E-04**	**2.86E-04**	**3.24E-04**	**2.43E-03**	**3.87E-04**	**4.46E-04**	**3.99E-08**	**2.64E-07**	**4.08E-03**	**2.48E-03**

Table 4-6: Impact Frequencies (Base Case – 80%:20% Port:Starboard)

Table 4-7 shows the corresponding impairment frequency (impairment frequency = impact frequency x impairment probability) for each target for each stage of the drilling programme.

Target	Damage Frequency From Drilling Well Number								Total	Annualised
	1	2	3	4	5	6	2013 extras	2014 extras		
1		6.27E-06	2.33E-05	1.35E-05	4.88E-06	4.15E-06			**5.21E-05**	**3.17E-05**
2	6.12E-05	8.92E-07	1.96E-06	1.86E-06	7.46E-07	5.22E-07	2.85E-08	2.77E-08	**6.72E-05**	**4.17E-05**
3		1.28E-06	4.49E-06	4.24E-06	1.11E-06	8.37E-07			**1.20E-05**	**7.27E-06**
4		5.57E-06	4.57E-06	1.69E-04	5.14E-06	1.33E-06		1.27E-07	**1.86E-04**	**1.15E-04**
5		1.60E-05	1.77E-05	7.15E-04	1.43E-05	2.25E-05			**7.85E-04**	**4.78E-04**
6		7.32E-06	3.25E-06	6.45E-04	8.76E-06	4.07E-05			**7.05E-04**	**4.29E-04**
7		6.61E-05	8.22E-07	9.27E-05	2.95E-05	1.29E-06		3.33E-08	**1.90E-04**	**1.16E-04**
8			5.93E-05	2.38E-06	6.53E-07	4.44E-07			**6.28E-05**	**3.82E-05**
9				8.84E-05	2.27E-06	5.07E-05			**1.41E-04**	**8.60E-05**
10					6.39E-05	1.30E-06			**6.52E-05**	**3.96E-05**
11						5.17E-05			**5.17E-05**	**3.14E-05**
Totals	**6.12E-05**	**1.04E-04**	**1.15E-04**	**1.73E-03**	**1.31E-04**	**1.75E-04**	**2.85E-08**	**1.88E-07**	**2.32E-03**	**1.41E-03**

Table 4-7: Impairment Frequencies (Base Case – 80%:20% Port:Starboard)

The above results were based on a 20%:80% split of starboard : port crane usage. The following tables show the impact and impairment frequencies based on a 50%:50% split between usage of port and starboard cranes.

Target	Impact Frequency From Drilling Well Number								Total	Annualised
	1	2	3	4	5	6	2013 extras	2014 extras		
1		5.35E-06	2.65E-05	1.55E-05	4.05E-06	5.42E-06			**5.68E-05**	**3.46E-05**
2	2.02E-04	2.92E-06	6.99E-06	7.66E-06	2.32E-06	2.97E-06	2.49E-08	2.42E-08	**2.25E-04**	**1.38E-04**
3		5.41E-06	1.84E-05	1.77E-05	4.93E-06	5.58E-06			**5.21E-05**	**3.17E-05**
4		1.30E-05	1.11E-05	2.20E-04	1.21E-05	1.02E-05		1.12E-07	**2.66E-04**	**1.64E-04**
5		1.98E-05	2.19E-05	6.10E-04	1.75E-05	3.26E-05			**7.02E-04**	**4.27E-04**
6		1.98E-05	2.19E-05	6.10E-04	1.75E-05	3.26E-05			**7.02E-04**	**4.27E-04**
7		2.08E-04	4.68E-06	1.78E-04	1.13E-04	1.43E-05		1.17E-07	**5.18E-04**	**3.17E-04**
8			2.00E-04	1.20E-05	3.84E-06	4.04E-06			**2.20E-04**	**1.34E-04**
9				2.54E-04	7.82E-06	1.83E-04			**4.45E-04**	**2.71E-04**
10					1.92E-04	1.23E-05			**2.04E-04**	**1.24E-04**
11						1.52E-04			**1.52E-04**	**9.25E-05**
Totals	**2.02E-04**	**2.74E-04**	**3.12E-04**	**1.93E-03**	**3.75E-04**	**4.55E-04**	**2.49E-08**	**2.53E-07**	**3.54E-03**	**2.16E-03**

Table 4-8: Impact Frequencies (Sensitivity – 50%:50% Port:Starboard)

Target	Damage Frequency From Drilling Well Number								Total	Annualised
	1	2	3	4	5	6	2013 extras	2014 extras		
1		5.20E-06	2.11E-05	1.36E-05	3.94E-06	5.28E-06			**4.91E-05**	**2.99E-05**
2	6.11E-05	6.05E-07	1.40E-06	1.62E-06	5.04E-07	5.56E-07	1.78E-08	1.73E-08	**6.58E-05**	**4.05E-05**
3		9.97E-07	4.25E-06	4.20E-06	8.97E-07	9.96E-07			**1.13E-05**	**6.89E-06**
4		3.64E-06	2.98E-06	1.07E-04	3.38E-06	1.27E-06		7.96E-08	**1.19E-04**	**7.32E-05**
5		1.46E-05	1.67E-05	5.48E-04	1.30E-05	2.37E-05			**6.16E-04**	**3.75E-04**
6		6.66E-06	2.65E-06	4.34E-04	8.13E-06	4.11E-05			**4.92E-04**	**2.99E-04**
7		6.62E-05	8.67E-07	8.37E-05	2.95E-05	1.86E-06		8.32E-08	**1.82E-04**	**1.12E-04**
8			5.94E-05	2.81E-06	7.03E-07	7.39E-07			**6.36E-05**	**3.87E-05**
9				8.17E-05	1.59E-06	5.06E-05			**1.34E-04**	**8.14E-05**
10					6.39E-05	1.86E-06			**6.58E-05**	**4.00E-05**
11						5.17E-05			**5.17E-05**	**3.14E-05**
Totals	**6.11E-05**	**9.79E-05**	**1.09E-04**	**1.28E-03**	**1.26E-04**	**1.80E-04**	**1.78E-08**	**1.80E-07**	**1.85E-03**	**1.13E-03**

Table 4-9: Impairment Frequencies (Sensitivity – 50%:50% Port:Starboard)

4.7 Conclusions

The total frequency of objects being dropped during lifting operations and impacting on subsea equipment with sufficient energy as to damage the equipment and cause a loss of containment at the new SWRX Glory Hole is calculated to be 1.41E-03 per annum.

The total annualised impairment frequencies are carried forward to the MODU (for SWRX) risk assessments in Sections 5 and used as subsea release frequencies. Releases from the gas and production facilities will be treated as two separate events in the MODU risk assessment; the frequency for gas release will be the impairment frequency for targets 1, 2, 3, 5 and 8 (gas injection pipeline, manifold, central pipework and gas injection wells), whilst the remaining six targets will be combined to give the production fluid release frequency.

It should be noted that the impairment frequency for target 1 applies to each of the flowlines (they are too close together to model as separate targets). Therefore, as there are two production flowlines and two gas flowlines (one injection, one lift), the frequency for target 1 will be multiplied by 2 and included in both the production fluid release frequency and the gas release frequency. Similarly, target 5 includes one gas flowline and 2 production flowlines and the release frequencies will be included appropriately.

This gives a subsea gas release frequency of **6.27E-04 per annum** and a subsea production fluids release frequency of **1.83E-03 per annum**. These figures are carried forward to the MODU risk assessment in Section 5.

It can be seen from the above results that the damage frequency due to objects dropped by the DSV is almost negligible compared to the MODU results. This is due to the low number of lifts conducted. The total DSV damage frequency is **3.16E-06 per annum** (annualised based on 25 days of activities). This value is carried forward to the DSV risk assessment in Section 6.

It should be remembered that this assessment is conservative as it assumes that items dropped onto subsea equipment with sufficient impact energy to cause damage will result in a release of hydrocarbons from the equipment – this may not necessarily be the case, but represents a worst case scenario. Further, releases from the water injection well are conservatively treated as a release of production fluids.

Husky has advised that it is likely that the DSV lifts will not actually be performed directly over the SWRX glory hole as modelled here. Rather, the vessel will lift the structures overboard away from the glory hole and then transit to the glory hole with the structures no more than 10m above the seabed. This will avoid lifting over Subsea assets and minimise the potential for objects to be dropped onto and cause damage to other items in the glory hole. Whilst this operating procedure would clearly reduce the risks of impact on subsea targets, it will not be remodelled here, as the loss of containment risks from the DSV lifted items are very low and remodelling this would only serve to make negligible risks even lower.

5. MODU Risk Assessment

The analysis presented here is based upon the use of a semi-submersible MODU for planned development drilling and completion activities. This assessment has identified hazards to which MODU personnel will be exposed during the well operations in the SWRX project. The analysis has assessed the potential consequences of such hazards and subsequently determined the associated risk to personnel.

The assessment has been based upon the use of the Global Santa Fe (GSF) Grand Banks. This MODU has its own Safety Plan in place [18] which has been supported by QRA [17] and has previously conducted operations at the White Rose field. Further QRA analysis for the MODU operating at the White Rose field has also been completed [1,3,4]. This section of the report is largely the same as the previous assessment [4], but using the results of the revised dropped objects study.

As discussed in Section 4.3, Husky has not yet selected the MODU that will be used for the SWRX project. A number of MODUs are under consideration, including the GSF Grand Banks. Once the MODU to be used has been selected, this study can be revisited and updated where necessary to reflect the details of the actual MODU to be used.

This assessment therefore focuses on the risks or hazards that are different as a result of the operations on SWRX. Details on those risks or hazards that would be the same, irrespective of where the MODU is operating, are not discussed in detail here but reference is given to the previous studies.

The scope of the analysis focuses on risks to MODU personnel only. With respect to personnel on the SeaRose FPSO, the Southern drill centre is located approximately 2km from the FPSO and the new SWRX glory hole will be located a further 4km from the SDC. Consequence analysis, conducted previously for the White Rose project, has shown that there are no hydrocarbon events, originating from any of the new or existing drill centres, which could impact the FPSO.

The analysis presented in this report aims to identify the major threats to life and to quantify them as risks expressed as:

TRIF: Temporary Refuge Impairment Frequency (per annum) - the annual frequency with which the TR will be impaired within a specified time period. Within the MODU Safety Case [18], the specified time period is set as 60mins as it is considered that this would be sufficient time to conduct a controlled evacuation.

PLL: Potential Loss of Life (per annum) - number of expected fatalities per year on the installation;

IRPA: Individual Risk Per Annum - the annual probability of fatality of an individual member of an employment category.

The TR on the Global Santa Fe (GSF) Grand Banks is comprised of the accommodation module, however, the TR should not be considered as a box but as a system. In this respect, the following are all given consideration:

- availability of escape routes to the TR;

- availability of the TR in terms of structural support, integrity of containment and survivability of occupants in its internal environment;
- availability of evacuation routes from the TR and the evacuation facilities.

The risk parameters calculated have been broken down into the contributions made by each accident type to enable the major risk contributors to be identified.

The IRPA is calculated for four employment categories (drill crew, deck/maintenance crew, motorman, and catering/administration crew) which cover the range of activities on the installation.

This assessment has been based on the previous risk assessment [3] carried for the MODU operating in the White Rose field. It is assumed that the consequences of the events previously identified (e.g. blowouts, accommodation fires, subsea releases) will be identical for corresponding events at SWRX, but that the frequency of occurrence of each hydrocarbon event may be different and this is assessed in more detail next.

5.1 Hydrocarbon Events

Hydrocarbon releases that occur as a result of operations on SWRX can be broadly grouped into:

- Blowouts that may occur during drilling operations;
- Subsea releases from live process equipment adjacent to the well being drilled;
- Events that are specific to the MODU.

The likelihood and consequences of blowouts were discussed previously in Section 3. Those subsea process releases and MODU specific events that may occur are described next.

5.1.1 Subsea Process Events

Releases from subsea processing equipment may occur as a result of:

- releases from the subsea manifold and equipment,
- releases from subsea flowlines and flexible jumpers.

Releases from these equipment items can occur as a result of equipment failures or through impact events (e.g. dropped objects, fishing trawl net impact).

5.1.2 Equipment Failures

The release frequency from subsea equipment/manifold was derived by tabulating the equipment items contained within each section using process and instrumentation information.

The output of this equipment count was a data input sheet for each section detailing the number and dimensions of all equipment for that section, an example of which is shown in Figure 5-1. Failure rate data for each equipment item identified has been drawn from [19] to allow overall failure frequencies to be generated.

Equipment Description		Number of Components	Small	Medium	Large
Reciprocating Compressors					
Centrifugal Compressors					
Reciprocating Pump					
Centrifugal Pump (double seal)					
Pressure Vessels					
Shell & Tube Heat Exchangers (3)	Shell				
Shell & Tube Heat Exchangers (3)	Tubing				
Shell & Tube Heat Exchangers (3)	Combined				
Small Process Piping (/m)	< 3 inch				
Process Piping (/m)	4 inch				
Process Piping (/m)	6 inch				
Process Piping (/m)	8 inch				
Process Piping (/m)	10 inch	50	1.30E-03	3.56E-04	1.47E-04
Process Piping (/m)	11 inch				
Large Process Piping (/m)	> 12 inch				
Flange	<3 inch	12	1.02E-03	3.03E-05	3.45E-06
Flange	4 inch				
Flange	6 inch	36	3.05E-03	4.55E-05	7.69E-05
Flange	8 inch				
Flange	10 inch	1	8.46E-05	1.26E-06	2.14E-06
Flange	11 inch				
Flange	> 12 inch				
Valve	<3 inch	12	2.61E-03	1.31E-04	1.49E-05
Valve	4 inch				
Valve	6 inch	20	4.17E-03	2.44E-04	1.85E-04
Valve	8 inch				
Valve	10 inch	1	2.09E-04	1.22E-05	9.25E-06
Valve	11 inch				
Valve	> 12 inch				
Small bore fitting (2)		4	1.88E-03		
Total Leak Frequency (/yr) for Isolated Section			1.43E-02	8.21E-04	4.39E-04

Figure 5-1: Sample Failure Rate Input Sheet

This process has been repeated for each of the subsea events identified. Total release frequencies (per annum) for each set of subsea equipment is summarised in Table 5-1 below.

Event ID	Description	Leak Frequency (/yr)		
		Small	Medium	Large
8	Subsea Release from SWRX production manifold and wells	8.96E-03	3.45E-04	2.23E-04
9	Subsea release from SWRX gas injection manifold and wells	7.08E-03	3.09E-04	1.77E-04

Table 5-1: Equipment Failure Rates for Subsea Manifolds and Wellheads

For subsea flowlines and flexible jumpers the latest PARLOC release frequency data [20] (see Table 5-2) has been applied.

	10mm	50mm	Full Bore	Total
Steel Pipeline	4.07E-04	9.90E-05	2.09E-04	7.15E-04
Flexible Pipeline	8.85E-04	1.40E-04	2.79E-04	1.30E-03

Table 5-2: Base Parloc 2001 [20] Pipeline Release Frequency Data

The above data is based upon a length of flowline equivalent to 500m (typical safety zone). The flowlines to be installed at the SWRX Glory Hole are expected to be flexible.

Since not all of the flowline releases will be sufficiently close to the MODU to impact the rig, the results of the consequence analysis conducted and presented in Appendix B, have been used to determine the proportion of the flowline releases which can impact the rig.

These are presented in Table 5-3 below.

Type of Flowline	Proportion of Releases Applicable		
	10mm	50mm	FB
Production Flowline	-	5%	25%
Gas Lift Flowline	-	5%	10%
Gas Injection Flowline	5%	5%	10%

Table 5-3: Proportion of Flowline Releases Capable of Impacting the MODU

Flexible jumpers for the gas lift equipment are located between the manifolds and the wellheads therefore releases from these sections would be expected to be directly below the MODU when the MODU was on location. However the flexible line release frequencies reported in Table 5-2 above have not been factored to account for the estimated length of flexible line at each location which has been estimated to be around 50m, and therefore the frequencies need to be factored here. Gas lift releases and gas injection releases have been combined as the consequences would be very similar.

Overall pipeline and flexible flowline release frequencies for each subsea event are calculated and the results are presented in Table 5-4.

Event ID	Description	Leak Frequency (/yr)		
		10mm	50mm	FB
8	Release from SDC Production Flowlines	-	1.40E-05	1.40E-04
9	Release from SDC Gas Lift / Injection Flowlines	1.33E-04	2.59E-05	7.68E-05

Table 5-4: Release Frequencies for Subsea Flowlines and Flexible Jumpers

Finally, subsea equipment failure rates and subsea flowline failure rates for each event have been summated. These failure rates are annual and therefore assume that the MODU is present for one full year of operations. The risks for the proportion of the year that the MODU shall spend at the SWRX Glory Hole shall also be reviewed in this assessment.

Equipment failure release frequencies for each event are presented in Table 5-5 below.

Event ID	Description	Leak Frequency (/yr)		
		10mm	50mm	FB
8	Subsea Release from SWRX Production Facilities	8.96E-03	5.58E-04	3.62E-04
9	Subsea Release from SWRX Gas Injection Facilities	7.21E-03	3.35E-04	2.54E-04

Table 5-5: Total Equipment Failure Subsea Hydrocarbon Events Release Frequencies

5.1.3 Dropped Objects

Loss of containment incidents could occur as a result of dropped objects from the MODU impacting subsea facilities (wellheads, manifolds etc.). The dropped object frequency was assessed previously in Section 4. It was determined that the frequency of dropped object incidents resulting in damage or release, whilst the MODU is located at SWRX, has been calculated to be:

- SWRX Production Facilities 1.83E-03 per annum;
- SWRX Gas Injection Facilities 6.27E-04 per annum.

Each of the above frequencies is based upon; the MODU being on location at that drill centre for the entire year; equal usage of the port and starboard cranes and the MODU being located directly over each well slot.

If, however, it is assumed that such incidents are most likely to result in a large hydrocarbon release and if each release frequency is split evenly between the subsea hydrocarbon events at that drill centre, the following release frequencies, to be added to calculated release frequencies in Table 5-5, result.

Event ID	Description	Leak Frequency (/yr)		
		10mm	50mm	FB
8	Subsea Release from SWRX Production Facilities	-	-	1.83E-03
9	Subsea Release from SWRX Gas Injection Facilities	-	-	6.27E-04

Table 5-6: Subsea Hydrocarbon Events Release Frequencies as a Result of Dropped Object Incidents

5.1.3.1 Fishing Impacts

The threat of impact to subsea pipelines as a result of fishing activities at the White Rose field was previously examined in [21], during the Project phase.

This analysis concluded that there was a risk of fishing vessels operating in the White Rose region and damaging subsea pipelines as a result.

However, whilst it is recognised that subsea equipment (pipelines, wellheads etc.) could be damaged as a result of impact by fishing vessels trawl gear, the consequences for personnel on the MODU itself will be limited.

This is due to the fact that the area around the installation will be monitored for shipping movements in order to identify potential collision events as soon as possible. In addition exclusion zones around the MODU and the FPSO will be enforced by the standby vessel which should prevent any vessels including fishing vessels from operating close to either unit. There is also a constraint on how close trawl gear can get to the MODU location as a result of the anchor lines which do not touch down on the seabed until some distance out from the MODU. Thus in the unlikely event that damage did occur and a release of hydrocarbons resulted, the release would not impact either the MODU or the FPSO.

5.1.3.2 Overall Release Frequencies

Bringing together the equipment failure rates calculated in Section 5.1.2 and dropped object failure rates presented in Section 5.1.3, overall hydrocarbon release frequencies for subsea events are presented in Table 5-7 below.

Event ID	Description	Leak Frequency (/yr)		
		10mm	50mm	FB
8	Subsea Release from SWRX Production Facilities	8.96E-03	3.58E-04	2.20E-03
9	Subsea Release from SWRX Gas Injection Facilities	7.21E-03	3.35E-04	8.811E-04

Table 5-7: Overall Hydrocarbon Events Release Frequencies

5.1.3.3 Ignition Probabilities and Consequences

The ignition and explosion probabilities used in this QRA (other than for blowout events) are based on the UKOOA ignition model. This model is based on naturally ventilated modules and is therefore appropriate for use for the MODU. The ignition probabilities are calculated based on the type, size and location of release.

Ignition probabilities for each release size are presented in Table 5-8 below.

Event ID	Description	Leak Frequency (/yr)		
		10mm	50mm	FB
8	Subsea Release from SWRX Production Facilities	0.016	0.025	0.1
9	Subsea Release from SWRX Gas Lift Facilities	0.007	0.025	0.1

Table 5-8: Ignition Probabilities for Subsea Releases

The fire sizes and durations from the SWRX production flowlines are of insufficient size and / or duration to result in loss of the MODU integrity. The main threat to personnel on the MODU is therefore from the immediate effects of any fire on the sea surface that may result in high thermal radiation levels at the deck level.

Releases from the gas injection flowline may result in a sea fire of sufficient duration to cause impairment of the MODU TR. There is also the potential (though very low) for unignited gas to be drawn into the TR, resulting in impairment.

Releases from the SWRX production and gas injection equipment have been included in the QRA model used previously for the MODU [3] to determine the risks to the MODU and personnel as a result of SWRX operations.

5.1.4 MODU Specific Hazards

Hazards that are specific to operations on the MODU include:

- Fire / Explosion In Mud Pit Room;
- Fire / Explosion in Shale Shaker House;
- Engine Room Fire;
- Helifuel Fire During Refuelling;
- Accommodation Fire.

These hazards were assessed in the MODU Safety Plan [18] and QRA [17] prepared previously. As they are not anticipated to change as a result of SWRX operations then they are not discussed in detail here. However, they have been included in the risk assessment to ensure that all of the risks on the MODU during SWRX operations are taken into account.

5.2 Non-Hydrocarbon Events

The following events have also been included in the assessment of SWRX MODU risks:

- Ship Collision
- Iceberg Collision
- Helicopter Travel
- Towing Incident
- Dropped Objects onto MODU
- Structural Failure
- Mooring Failure
- Extreme Weather
- Loss of Stability
- Occupational Risks

In a similar manner to the MODU Specific Hazards, a number of the non-hydrocarbon hazards have previously been assessed in the MODU Safety Plan [18] and QRA [17] reports.

Whilst all of the above hazards have been included in the risk assessment, only those hazards that may change as a result of operations at SWRX have been described here in detail.

5.2.1 Helicopter Travel

Helicopter movements can be considered to generate two potential hazards. Firstly, the risk to personnel on board the helicopter if it crashes or ditches at sea and secondly the risk to the installation if the helicopter impacts it. Historically, helicopter risks have been dominated by fatalities amongst those on board the helicopter.

The transport risks are calculated on the basis that rig personnel working a three week on – three week off shift pattern will take 16 flights per year between the MODU and the shore base each year, and that each flight will last 2 hours.

Based on an analysis of the annual accident rates published up to 2007 from the UK Civil Aviation Authority (CAA) [22], the following accident rates are applicable:

Risk of fatality during take-off/landing = 1.83E-07 per flight stage

Risk of fatality during flight = 2.11E-06 per hour flown

Based on the above data, the individual risk and PLL due to helicopter travel has been derived as follows:

IRPA = number of flights per year x (frequency of crash per hour x fatality fraction x flight duration + frequency of crash per take-off/landing x fatality fraction)

= 7.04E-05 per annum

PLL = Number of personnel {number of flights per year x (frequency of crash per hour x fatality fraction x flight duration + frequency of crash per take-off/landing x fatality fraction)}/average offshore occupancy

= 1.32E-02 fatalities per annum

Helicopter crash onto the helideck is likely to result in significant damage to the helicopter and may result in the release of helifuel onto the helideck. The helideck is equipped with local fire fighting equipment and therefore the potential for such an event to escalate and result in failure of the TR integrity is considered to be low. Similar, should the helicopter crash onto another area of the MODU, the potential for the event to escalate to the extent where the TR integrity is threatened is considered to be low.

5.2.2 Occupational Risk

The occupational risks relate to the hazards associated with performing work offshore, e.g. hazards such as falls, crushing, mechanical impacts, electrocution, etc. The Fatal Accident Rates (FAR) used in the QRA are based on information presented in [23]. These FARs exclude marine, diving and helicopter risks.

Worker Group	Occupational FAR (per 10^8 working hours)
Drill Crew	5
Deck Crew	8.5
Motorman	5.7
Catering / Admin Crew	-
Divers	12.7

Table 5-9: Occupational Fatal Accident Rates (FAR)

There are no divers on the MODU, however their occupational risk is presented here for completeness and used in the DSV assessment shown in Section 6. The FAR values are converted to individual risk per annum (IRPA) by taking into account the actual time each year that members of each employment category are exposed to the hazards at the workplace. For all employment categories, it is assumed that each individual spends 50% of their time offshore with 50% of his/her time at the workplace and the remaining 50% of the time in the accommodation. Assuming that an individual is only exposed during his/her time at the workplace offshore, the FARs when converted to IRPAs are calculated to be:

- drill crew 1.10E-04 per annum;
- deck crew 1.86E-04 per annum;
- motorman 1.25E-04 per annum;
- catering negligible;
- divers. 2.74E-04 per annum;

5.2.3 Ship Collision

There are a number of potential sources of vessel collision hazard to which the MODU could be exposed. These are:

- attendant vessels (supply boat, standby boats, shuttle tanker);
- errant vessels.

During the units period of operation at the SWRX Glory Hole, there will be standby and supply vessels in close proximity to the MODU. Supply boats will clearly be at most risk of colliding with the unit when it is alongside, either offloading or backloading equipment and supplies. Collision or contact is an ever present threat during such operations.

The standby boat could also collide with the MODU, although it will not normally be required to operate in close proximity to the unit. Attendant vessels will regularly approach the MODU and the threat of collision and subsequent damage should be considered. Husky intends to conduct an OSV (Offshore Support Vessel) risk assessment and the results of this study will then be incorporated into the MODU risk assessment.

The potential for powered 3rd party vessels, including fishing boats, to collide with and damage the MODU depends upon the frequency of vessel movements in the vicinity of the White Rose field and upon the types of shipping traffic prevalent. Mitigating measures exist to prevent a collision by a powered or drifting vessel. These primarily involve the monitoring of shipping movements in order to identify any potential collision events as soon as possible together with means for alerting and intervening, if necessary, to avert a collision.

There shall be an exclusion zone extending 50m from the MODU anchor pattern that fishing vessels are not permitted to fish within. In addition, as long as vessels contact the FPSO to inform them of their position, they may still pass through the White Rose field. As a result, if a vessel is on a converging course with the MODU and these measures fail then a collision could occur. As an emergency measure the MODU can also move off-station if an approaching vessel poses a threat of collision.

In the absence of site specific data the most comprehensive source of ship collision data for worldwide oil & gas activities is found in the Worldwide Offshore Accident Database [24].

This dataset has been used to determine the MODU ship collision risk as reported within the MODU Safety Case [18]. However, the same data set was also used for the SeaRose FPSO

Safety Plan [25] following a more detailed review of the source data. For consistency, the data from the Safety Plan has been used in this assessment rather than the MODU Safety Case [18] information.

The frequency of severe or total loss ship collisions is therefore taken to be 5.32E-05 per annum.

For MODU operations at the SWRX Glory Hole the resulting risk to personnel is presented in Table 5-10 below.

Event	PLL	IRPA			
		Drill	Maintenance/ Deck	Motorman	Catering
Ship Collision	1.63E-03	8.68E-06	8.68E-06	8.68E-06	8.68E-06

Table 5-10: Ship Collision Societal and Individual Risk Levels

These frequencies are generic and therefore it is recommended that a ship collision study for the SWRX Glory Hole be conducted to determine more accurately the risks to the MODU from vessel collision.

The ship collision frequencies that are included here are assumed to result in total loss or severe damage to the MODU to the extent where failure occurs relatively quickly and most likely within one hour. Ship impacts that result in damage to the MODU pontoons or legs to cause gradual loss of stability are assumed to be included within the Loss of Stability risks.

5.2.4 Iceberg Collision

As the White Rose field is located off the coast of Newfoundland, there is the possibility of the MODU being struck by an iceberg with the consequences of such an impact potentially severe.

The iceberg threat to the FPSO and subsea flowlines has been previously examined within [26] and [21]. Within these analyses the return period for large icebergs in the White Rose area was found to be 465 years. The event tree presented in Figure 5-2 demonstrates how the risk to the MODU of iceberg collision has been considered within this analysis.

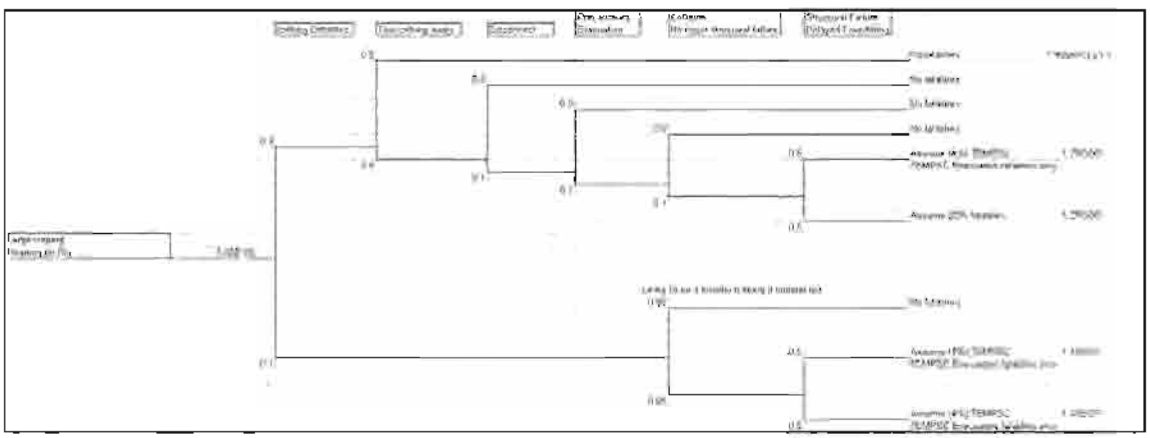


Figure 5-2: Iceberg Collision Event Tree

The frequency of hazardous outcomes and the potential fatality fraction following an iceberg collision are presented in Table 5-11.

Event	Frequency (per year)	Fatality Fraction
Iceberg collision resulting in rapid collapse	1.27E-08	0.2
Iceberg collision resulting in delayed foundering	2.96E-07	0.04

Table 5-11: Iceberg Collision Frequency and Fatality Fraction

For MODU operations at the SWRX Glory Hole the resulting risk to personnel is presented in Table 5-12 below.

Event	PLL	IRPA			
		Drill	Maintenance/ Deck	Motorman	Catering
Iceberg Collision	1.35E-06	7.19E-09	7.19E-09	7.19E-09	7.19E-09

Table 5-12: Iceberg Collision Societal and Individual Risk Levels

The frequency of iceberg impact, and resulting risk, is calculated on the basis that the potential for impact at the SWRX Glory Hole is the same as it shall be for any other location in the White Rose field. It is recommendation of this study that this assumption be reviewed in more detail to ensure that their potential for collision at SWRX is not significantly higher than at other locations in the field and that the collision management procedures still apply. Iceberg impacts considered within this section are assumed to result in loss of the TR integrity within the one hour endurance period of the MODU.

5.3 Personnel Distribution

The MODU has a typical POB of 94 during drilling operations with members of the rig crew operating on a three week rotation schedule. The personnel categories used to calculate Individual Risks are drill crew, maintenance/deck crew, motorman and catering/admin staff.

5.4 Results

The RISKMODEL summary output sheet is presented in Figure 5-3 next.

RESULTS SUMMARY SHEET

TR Impairment Frequency within 1 hr	-	**6.80E-05**	**Highest IRPA Total**	-	**4.53E-04 Motorman Crew**
TR Impairment Frequency	-	**1.01E-04**	**Hydrocarbon IRPA**	-	**2.21E-04**
Hydrocarbon PLL	-	**1.77E-02**	**Non Hydrocarbon IRPA**	-	**2.32E-04**
Non Hydrocarbon PLL	-	**3.31E-02**	**Freq. HC Release**	-	**0.181413817**
Total PLL	-	**5.08E-02**	**Freq. Ignited Events**	-	**0.003516981**

		TR Impairment Freq (TRIF) within 1 hr		Total TR Impairment Frequency (TRIF)		Potential Loss Of Life (PLL)		Drill		Maintenance / Deck		Motorman		Catering	
		TRIF (/Annum)	%	TRIF (/Annum)	%	PLL (Fats /a)	%	IRPA	%	IRPA	%	IRPA	%	IRPA	%
TR Impairment Mechanisms :															
	Derrick Collapse & Thermal	4.52E-06	6 7%	9.05E-06	9.0%										
	Thermal Breach	7.42E-06	10.9%	7.42E-06	7 3%										
	RainOut	5.97E-08	0.1%	5.97E-08	0.1%										
	Unignited Blowout			1 88E-07	0.2%										
	Sea Fire	3.85E-05	56.7%	6.24E-05	61.7%										
	HVAC Failure - Smoke	4 50E-06	6.6%	8 99E-06	8.9%										
Calculated PLL :															
Hydrocarbon	Immediate					7 28E-03	14.3%	4.51E-05	14.6%			1.71E-04	37.8%		
	Muster														
	TR Fatalities					7.69E-03	15.1%	4 06E-05	13 1%	4 16E-05	11.6%	3.86E-05	8.5%	4 16E-05	26.6%
	Evacuation Fatalities					1.33E-03	2 6%	7 08E-06	2 3%	7.12E-06	2 0%	6.92E-06	1 5%	7.12E-06	4.6%
Hydrocarbon - Rig Specific	Fire/Explosion in Mud Pit Room	4.41E-10	0.0%	4.41E-10	0.0%	7.13E-07	0.0%	9 79E-10	0.0%	9.79E-10	0.0%	1.75E-08	0.0%	9.79E-10	0 0%
	Fire/Explosion in Shale Shaker House	1.99E-08	0 0%	1.99E-08	0.0%	1.79E-04	0.4%	3.65E-07	0.1%	3.65E-07	0 1%	3 82E-06	0.8%	3.65E-07	0.2%
	Fire - Engine Room	1.57E-08	0 0%	1.57E-08	0.0%	9 23E-05	0.2%	4.17E-07	0 1%	4.17E-07	0 1%	8 52E-07	0.2%	4.17E-07	0.3%
	Fire - Helicopter Fuel	1.43E-06	2 1%	1 43E-06	1.4%	1 16E-03	2.3%			1.58E-05	4 4%				
Non Hydrocarbon	Helicopter Travel					1 32E-02	26 1%	7.04E-05	22 8%	7.04E-05	19.7%	7.04E-05	15.6%	7.04E-05	45.0%
	Occupational					1 28E-02	25.3%	1.10E-04	35.4%	1.86E-04	52.0%	1.25E-04	27.6%		
	Loss of Stability					1.05E-03	2.1%	5.43E-06	1.8%	5.43E-06	1 5%	5.69E-06	1.3%	5.69E-06	3.6%
	Mooring Failure					5.89E-05	0.1%	3.06E-07	0 1%	3 06E-07	0.1%	3.17E-07	0.1%	3.17E-07	0.2%
	Loss of Tow					7.33E-05	0.1%	3.90E-07	0.1%	3.90E-07	0.1%	3.90E-07	0 1%	3.90E-07	0.2%
	Structural Failure					3.77E-03	7.4%	1.97E-05	6 4%	1 97E-05	5.5%	2 03E-05	4.5%	2.03E-05	13.0%
	Mechanical Failure - Lifting Equipment					3.96E-05	0.1%	6 18E-07	0 2%	6 18E-07	0.2%				
	Extreme Weather					3.28E-04	0.6%	6 33E-07	0.2%	7 35E-07	0.2%	7 35E-07	0 2%	7 35E-07	0 5%
	Ship Collision					1 63E-03	3.2%	8 68E-06	2 8%	8 68E-06	2 4%	8 68E-06	1 9%	8.68E-06	5.5%
	Iceberg Collision					1.35E-06	0.0%	7 19E-09	0.0%	7.19E-09	0 0%	7.19E-09	0 0%	7 19E-09	0.0%
	Fire - Accommodation	1 15E-05	16.9%	1 15E-05	11.4%	5 24E-05	0.1%	2.56E-07	0 1%	2.56E-07	0.1%	2.56E-07	0.1%	3 02E-07	0.2%
Hydrocarbon Total						1.77E-02	34.9%	9.35E-05	30.2%	6.54E-05	18.3%	2.21E-04	48.9%	4.95E-05	31.7%
Non Hydrocarbon Total						3.31E-02	65.1%	2.16E-04	69.8%	2.93E-04	81.7%	2.32E-04	51.1%	1.07E-04	68.3%
Totals		6.80E-05	100 0%	1.01E-04	100.0%	5.08E-02	100.0%	3.10E-04	100.0%	3.58E-04	100.0%	4.53E-04	100 0%	1.56E-04	100.0%

Figure 5-3: MODU Risk Model Results

5.4.1 TR Impairment Frequency (TRIF)

Two values of TRIF are calculated and presented in the results. Firstly the TRIF caused by hydrocarbon events which occur within the 1 hour endurance period of the TR are presented. The hydrocarbon events considered under this category are the very rapid impairments caused by failure of the HVAC system, sea fire events (which could occur as a result of subsea blowouts during drilling operations) which lead to fire impingement on unprotected steel supports for the TR, and events where the drill tower collapses causing a direct breach of the TR fabric. The Total MODU TRIF within 1 hour for the SWRX Project is 6.80E-05 per annum.

The total hydrocarbon TRIF is also presented which includes all events including those which occur after 1 hour. A time period of 1 hour is considered to be sufficient to allow a controlled evacuation of the MODU to take place. The Total Hydrocarbon MODU TRIF for the SWRX Project is 1.01E-04 per annum.

The calculated TRIF for the representative impairment parameters are presented in Table 5-13.

Source	Within 1 Hour		Total	
	TRIF (per annum)	%	TRIF (per annum)	%
Derrick Collapse & Thermal	4.52E-06	7%	9.05E-06	9%
Thermal Breach	7.42E-06	11%	7.42E-06	7%
RainOut	5.97E-08	0%	5.97E-08	0%
Unignited Blowout	0.00E+00	0%	1.86E-07	0%
Sea Fire	3.85E-05	57%	6.24E-05	62%
HVAC Failure - Smoke	4.50E-06	7%	8.99E-06	9%
Fire/Explosion in Mud Pit Room	4.41E-10	0%	4.41E-10	0%
Fire/Explosion in Shale Shaker House	1.99E-08	0%	1.99E-08	0%
Fire - Engine Room	1.57E-08	0%	1.57E-08	0%
Fire - Helicopter Fuel	1.43E-06	2%	1.43E-06	1%
Fire - Accommodation	1.15E-05	17%	1.15E-05	11%
	6.80E-05	**100%**	**1.01E-04**	**100%**

Table 5-13: Hydrocarbon TRIF Results for the Base Case

Table 5-14 below shows the contribution from each of the fire and explosion events to the overall hydrocarbon TR impairment frequency within one hour.

Event ID	Description	TRIF <1Hr	%
1	Mud Room Fire	4.41E-10	0.0%
2	Shaker Room Fire	1.99E-08	0.0%
3	Helifuel Fire	1.43E-06	2.1%
4	Engine Room Fire	1.57E-08	0.0%
5	Acommodation Fire	1.15E-05	16.9%
6	Subsea Release from SWRX Production Facilities	0.00E+00	0.0%
7	Subsea Release from SWRX Gas Injection Facilities	2.08E-05	30.6%
8	Subsea Blowouts at SWRX - From Gas Wells	1.24E-05	18.3%
9	Subsea Blowouts at SWRX - From Oil Wells	1.28E-05	18.8%
10	Drillfloor Blowouts at SWRX - From Gas Wells	3.47E-06	5.1%
11	Drillfloor Blowouts at SWRX - From Oil Wells	5.55E-06	8.2%
	Total	**6.80E-05**	**100.0%**

Table 5-14: TR Impairment Frequency Contribution from Fire and Explosion Events

The results show that the main contributors are blowout events, either subsea or on the drill floor. These account for a total of 50% of the TRIF within 1 hour. Subsea releases from the gas injection facilities account for 31% and accommodation fires for a further 17% of the TRIF.

Husky has defined impairment-based criteria to distinguish between accidental events that have the potential to cause high-fatality accidents, and those which do not. High-fatality accidents are those where the consequences are sufficiently severe that they have the potential to escalate and cause fatalities to personnel other than those in the immediate vicinity of the incident.

Loss of integrity of the TR is defined as having occurred if, within 1 hour, there is:

- failure of external walls, allowing entry of fire and/or smoke.
- fire within the TR;
- deterioration of physical conditions within the TR which render it uninhabitable, that is, if there loss of breathable atmosphere, or intolerable heat build-up, etc.; and
- list, trim or heel in excess of 15 degrees.

The criteria applied to the impairment based TR integrity are:

- no single major accident hazard should result in failure of the integrity of the TR with a frequency higher than 1E-04 per annum;
- the total frequency of failure of the integrity of the TR should not exceed 1E-03 per annum for all major accident hazards.

The impairment based TR integrity is shown next for all events on the MODU that may cause loss integrity within the one hour endurance period.

Event ID	Description	Impairment Based TR Integrity (per annum)	%
1	Mud Room Fire	4.41E-10	0.0%
2	Shaker Room Fire	1.99E-08	0.0%
3	Helifuel Fire	1.43E-06	0.4%
4	Engine Room Fire	1.57E-08	0.0%
5	Acommodation Fire	1.15E-05	3.4%
6	Subsea Release from SWRX Production Facilities	0.00E+00	0.0%
7	Subsea Release from SWRX Gas Injection Facilities	2.08E-05	6.1%
8	Subsea Blowouts at SWRX - From Gas Wells	1.24E-05	3.7%
9	Subsea Blowouts at SWRX - From Oil Wells	1.28E-05	3.8%
10	Drillfloor Blowouts at SWRX - From Gas Wells	3.47E-06	1.0%
11	Drillfloor Blowouts at SWRX - From Oil Wells	5.55E-06	1.6%
12	Mooring Failure	1.85E-06	0.5%
13	Loss of Tow	1.50E-05	4.4%
14	Structural Failure	1.01E-04	29.8%
15	Extreme Weather	1.00E-04	29.5%
16	Ship Collision	5.32E-05	15.7%
17	Iceberg Collision	3.08E-07	0.1%
	Total	**3.39E-04**	**100.0%**

Table 5-15: MODU Impairment Based TR Integrity Frequency Contribution

It can be seen from Table 5-15 that the overall frequency of impairment of the TR integrity is below 1E-03 per annum. However, the frequency of structural failure exceeds the 1E-04 per annum frequency, although it is marginal and considered not to be an issue for this assessment.

Subsea blowout frequencies are based on historical, generic information. As the MODU has been conducting well operations at the White Rose field for a number of years now, it could be argued that the drill crew on board will have a good knowledge of the reservoirs and therefore the historical values are likely to be conservative. Established procedures that are on place on the MODU for conducting well operations should also ensure that the risk of a subsea blowout occurring during SWRX operations is low.

5.4.2 Potential Loss of Life (PLL)

The total PLL for the MODU is 5.08E-02 fatalities per annum, of which 35% can be attributed to hydrocarbon events and 65% to non-hydrocarbon events.

The total PLL for the actual duration (600 days) of the SWRX project is 8.35E-02 fatalities.

The different types of fatalities which make up the total PLL are shown in Table 5-16, and discussed below.

Source	PLL per Annum	%
Immediate Hydrocarbon	7.28E-03	14%
Delayed Hydrocarbon	9.02E-03	18%
Occupational	1.28E-02	25%
Helicopter Travel	1.32E-02	26%
Structural Failure	3.77E-03	7%
Hydrocarbon - Rig Specific	1.44E-03	3%
Ship Collision	1.63E-03	3%
Loss of Stability	1.05E-03	2%
Extreme Weather	3.28E-04	1%
Loss of Tow	7.33E-05	0.1%
Mooring Failure	5.89E-05	0.1%
Fire - Accommodation	5.24E-05	0.1%
Mechanical Failure - Lifting Equipment	3.96E-05	0.1%
Iceberg Collision	1.35E-06	0.0%
Total	**5.08E-02**	**100%**

Table 5-16: Potential Loss of Life (PLL) for SWRX Project

The PLL due to immediate fatalities accounts for 14% of the total PLL. The largest contributors to the immediate fatalities are those fatalities among essential personnel who would stay on the drill floor attempting to control a well incident. Other significant contributors to immediate fatalities are explosions in the shaker room and the mud pit area where an event can occur rapidly and cause fatalities in the immediate vicinity.

Delayed fatalities, which account for 18% of the total PLL, are either those associated with the need for TEMPSC usage if the TR is impaired or where a blowout has occurred, or are those associated with both the TR and the TEMPSC both being impaired leaving only tertiary means of escape available.

The greatest contributors to non-hydrocarbon risks involve the risks associated with offshore working. These are the helicopter travel between the shore and the MODU and the occupational (working) risks, which together amount to 51% of the overall PLL. Control of these hazards is not considered further in this analysis. The occupational risks (working accidents) for this installation are also high due to the high number of drill crew who traditionally have a high occupational risk associated with their jobs.

5.4.3 Individual Risk Per Annum (IRPA)

The risks to individual personnel on the MODU is dependent on worker category.

For the Drill Crew, the IRPA is 3.10E-04 per annum, for Maintenance/Deck Crew it is 3.58E-04 per annum. The Motorman Crew has an IRPA of 4.53E-04 per annum and the lowest risk group is the Catering/Admin Crew, whose IRPA is 1.56E-04 per annum.

The breakdown of contributors to the IRPAs for the main worker categories on the MODU are presented below in Table 5-17.

Source	Drill Crew	%	Maintenance / Deck	%	Motorman	%	Catering	%
Immediate Hydrocarbon	4.51E-05	14.6%	0.00E+00	0.0%	1.71E-04	37.8%	0.00E+00	0.0%
Delayed Hydrocarbon	4.77E-05	15.4%	4.87E-05	13.6%	4.55E-05	10.1%	4.87E-05	31.2%
Hydrocarbon - Rig Specific	7.83E-07	0.3%	1.67E-05	4.7%	4.69E-06	1.0%	7.83E-07	0.5%
Helicopter Travel	7.04E-05	22.8%	7.04E-05	19.7%	7.04E-05	15.6%	7.04E-05	45.0%
Occupational	1.10E-04	35.4%	1.86E-04	52.0%	1.25E-04	27.6%	0.00E+00	0.0%
Loss of Stability	5.43E-06	1.8%	5.43E-06	1.5%	5.69E-06	1.3%	5.69E-06	3.6%
Mooring Failure	3.06E-07	0.1%	3.06E-07	0.1%	3.17E-07	0.1%	3.17E-07	0.2%
Loss of Tow	3.90E-07	0.1%	3.90E-07	0.1%	3.90E-07	0.1%	3.90E-07	0.2%
Structural Failure	1.97E-05	6.4%	1.97E-05	5.5%	2.03E-05	4.5%	2.03E-05	13.0%
Mechanical Failure - Lifting Equipment	6.18E-07	0.2%	6.18E-07	0.2%	0.00E+00	0.0%	0.00E+00	0.0%
Extreme Weather	6.33E-07	0.2%	7.35E-07	0.2%	7.35E-07	0.2%	7.35E-07	0.5%
Ship Collision	8.68E-06	2.8%	8.68E-06	2.4%	8.68E-06	1.9%	8.68E-06	5.5%
Iceberg Collision	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%
Fire - Accommodation	2.56E-07	0.1%	2.56E-07	0.1%	2.56E-07	0.1%	3.02E-07	0.2%
Totals	**3.10E-04**	**100.00%**	**3.58E-04**	**100.0%**	**4.53E-04**	**100.0%**	**1.56E-04**	**100.0%**

Table 5-17: MODU IRPA Results for the SWRX Project

It can be seen that the IRPA for the Drill Crew or Motorman is much higher than that for the catering / administration staff. This is due to the immediate fatality risk which arises as a result of the time spent on the main deck, the drill floor or in other areas where hydrocarbon inventories are present.

The second effect is that associated with the occupational (working) risks associated with each worker group, with the deck crew having the highest contribution from this source due to their historical exposure as discussed above.

The other risk contributions follow the patterns discussed in for the PLL.

It should be noted that none of the individual risk levels for any of the worker groups examined exceed the individual risk Target Level of Safety of 5E-04 per annum (for new operations [27]).

5.5 Conclusions

The risk levels for the MODU carrying out the drilling activities for the South White Rose Extension Project have been assessed and are below the Target Levels of Safety for TR impairment (1E-03 per annum) and for IRPA (5E-04 per annum).

The frequency of hydrocarbon TR impairment is 6.80E-05 per annum, or once every 14,700 years. The impairment based TR integrity frequency is calculated to be 3.39E-04 per annum, and includes all events capable of failing the integrity of the TR. There are no hydrocarbon events causing failure of the TR integrity that exceed Husky's 1E-04 per annum criteria for a single major accident hazard.

The total PLL is 5.08E-02 fatalities per annum or one fatality every 20 years. The highest risk worker category is the Motorman Crew, with an IRPA of 4.53E-04 per annum, this is relatively close to, but still below, Husky's Target Level of Safety for new operations (5E-04 per annum) [27].

6. DSV Risk Assessment

The DSV risk assessment investigates the risks to personnel on board the DSV whilst it is on-station at the new SWRX Glory Hole to install supporting items such as manifolds. There shall be a requirement for a DSV and/or a construction vessel to complete the installation of subsea equipment at SWRX Glory Hole. However, for simplicity within this assessment, it is assumed that the DSV will be performing all operations.

The DSV risk assessment has been carried out in exactly the same way as the MODU risk assessment, but with non-applicable risks removed. Again, the DSV or construction vessel would have a Safety Plan in place before commencement of operations. This review has therefore focussed on the specific hazards and risks introduced through operation on the SWRX project.

The consequences, in terms of effects on personnel (immediate / delayed fatalities) and on TR impairment mechanisms (fires, smoke etc.) are assumed to be the same for events occurring on the DSV as for those occurring on the MODU.

6.1 Hydrocarbon Events

The events of interest in this study are the subsea releases from the live facilities at the SWRX Drill Centre, fires in the Engine Room and the Accommodation. There are no drilling activities to be carried out by the DSV and therefore no drillfloor blowout events are considered in this assessment. Similarly, there can be no Mud Pit Room or Shaker Room hazards as these areas are specific to a MODU. However, as the SWRX gas injection well will be live during some DSV activities, a subsea production blowout from this well has been included.

The impairment frequency of the subsea equipment at SWRX due to objects dropped by the DSV (as determined in Section 4) has been incorporated into the release frequencies for the live gas injection facilities – these results have been annualised based on the DSV being on station at the SWRX glory hole for 25 days. It should be noted that the DSV will conduct activities at SWRX during 2013 before any of the subsea facilities are live and further activities during 2014, when the gas injection well will be live. For conservatism, these two sets of activities have been combined into one – this is conservative because there will be no live facilities beneath the DSV during the first set of activities, but it will be assumed that during all DSV activities at SWRX, there will be the potential for a hydrocarbon release to occur beneath the vessel. Similarly, the subsea production blowout consequences have been applied to the entire period of DSV activity at SWRX, although the well will only be live during one portion of the activities.

Table 6-1 shows the list of hydrocarbon events considered in the DSV Risk Assessment for the SWRX operations and the release frequencies.

Event	**Frequency (per annum)**		
	10mm	**50mm**	**FB**
Engine Room Fire			2.78E-04
Accommodation Fire			4.40E-04
Subsea Release from SWRX Gas Injection Facilities	1.20E-03	5.58E-05	1.70E-04
Subsea Production Blowout from SWRX Gas Injection well	-	-	1.80E-05

Table 6-1: Hydrocarbon Events – DSV Risk Assessment

As there will only be one live well and a portion of the subsea equipment installed and live during the DSV's work period, the subsea release frequency from the SWRX gas injection facilities has been assumed to be 1/6 of that estimated for the MODU (whose frequency was based on 6 live wells). The dropped object damage frequency of 1.40E-06 per annum (calculated in Section 4) is added to the large release from the gas injection facilities.

The closer proximity of the engine room to the DSV accommodation means that the likelihood of impairing the TR has been increased over the value assumed for the MODU. For the DSV, it is assumed that 1% of all engine fires may result in impairment of the TR. This provides an impairment frequency similar to that calculated for the SeaRose FPSO [25].

6.2 Non-Hydrocarbon Events

The following events have been included in the SWRX DSV Risk Assessment, with information taken from the MODU Risk Assessment section:

- Ship Collision
- Iceberg Collision
- Extreme Weather
- Structural Failure
- Occupational Risks

Mooring Failure, Towing Incidents and Loss of Stability events have been removed from the DSV risk assessment as they do not apply to the DSV. It is also assumed that there shall be no helicopter transport risks as the vessel will return to shore during the period of operations. In reality, there may be a requirement to perform a small number of helicopter transits during the period of operations. However, these are not expected to significantly affect any of the risk levels reported here.

6.3 Personnel Distribution

The DSV has a typical POB of 90 during operations. The personnel categories used to calculate Individual Risks are divers, maintenance/deck crew and catering/admin staff.

6.4 Risk Assessment Results

Figure 6-1 below shows the results of the DSV risk assessment for the SWRX project. Note that these risks have been annualised.

TR Impairment Frequency within 1 hr	-	1.82E-05	Highest IRPA Total	-	2.95E-04 Maintenance / Deck Crew
TR Impairment Frequency	-	1.98E-05	Hydrocarbon IRPA	-	1.84E-06
Hydrocarbon PLL	-	3.31E-04	Non Hydrocarbon IRPA	-	2.93E-04
Non Hydrocarbon PLL	-	3.23E-02	Freq. HC Release	-	0.159806169
Total PLL	-	3.26E-02	Freq. Ignited Events	-	0.000748921

		TR Impairment Freq. (TRIF) within 1 hr		Total TR Impairment Frequency (TRIF)		Potential Loss Of Life (PLL)		Divers		Maintenance / Deck		Catering/Admin	
		TRIF (/Annum)	%	TRIF (/Annum)	%	PLL (Fats /a)	%	IRPA	%	IRPA	%	IRPA	%
TR Impairment Mechanisms :													
	HVAC Failure - Gas	1.08E-06	5.9%	1.08E-06	5.4%								
	HVAC Failure - Smoke	5 18E-10	0.0%	5.18E-10	0.0%								
	RainOut												
	Sea Fire	2.88E-06	15.8%	3.09E-06	15.6%								
	Unignited Blowout			1 39E-06	7 0%								
Calculated PLL :													
Hydrocarbon	immediate												
	Muster												
	TR Fatalities					3 14E-04	1 0%	1.75E-06	0 8%	1.75E-06	0 6%	1.75E-06	1 6%
	Evacuation Fatalities					1.80E-05	0.0%	8.91E-08	0.0%	8 91E-08	0.0%	8.91E-08	0.1%
Hydrocarbon - DSV Specific	Fire - Engine Room	2 78E-06	15 2%	2.78E-06	14.0%	7.13E-07	0.0%	9.79E-10	0.0%	9 79E-10	0.0%	9.79E-10	0.0%
Non Hydrocarbon	Helicopter Travel					1.27E-02	38.9%	7.04E-05	32 3%	7.04E-05	23.9%	7.04E-05	64 8%
	Occupational					1.27E-02	38.9%	1.10E-04	50.3%	1.86E-04	63.2%		
	Loss of Stability					1.05E-03	3.2%	5.43E-06	2.5%	5.43E-06	1.8%	5.69E-06	5.2%
	Mooring Failure					5.89E-06	0.2%	3.06E-07	0 1%	3.06E-07	0.1%	3.17E-07	0.3%
	Loss of Tow					7.33E-05	0.2%	3.90E-07	0 2%	3.90E-07	0.1%	3 90E-07	0.4%
	Structural Failure					3.77E-03	11.6%	1 97E-05	9.0%	1 97E-05	6.7%	2.03E-05	18.7%
	Mechanical Failure - Lifting Equipment					3.96E-05	0 1%	6.18E-07	0.3%	6.18E-07	0.2%		
	Extreme Weather					3.28E-04	1 0%	6.33E-07	0.3%	7.35E-07	0.2%	7.35E-07	0.7%
	Ship Collision					1 56E-03	4 8%	8 68E-06	4.0%	8 68E-06	2.9%	8.68E-06	8 0%
	Iceberg Collision					1.29E-06	0.0%	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%
	Fire - Accommodation	1.15E-05	63.0%	1.15E-05	58 0%	5.24E-05	0.2%	2.56E-07	0 1%	2.56E-07	0.1%	3.02E-07	0 3%
Hydrocarbon Total						3.31E-04	1.0%	1.84E-06	0 8%	1.84E-06	0.6%	1.84E-06	1.7%
Non Hydrocarbon Total						3.23E-02	99.0%	2.16E-04	99.2%	2.93E-04	99 4%	1 07E-04	98.3%
Totals		1.82E-05	100.0%	1 98E-05	100 0%	3.26E-02	100.0%	2.18E-04	100.0%	2.95E-04	100.0%	1.09E-04	100.0%

Figure 6-1: DSV Risk Assessment Results

6.4.1 DSV TR Impairment Frequency (TRIF)

There are very few contributors to TR impairment – the total hydrocarbon TRIF is just 1.82E-05 per annum, all of which are assessed to occur within one hour. Fires in the Accommodation (63%), sea fires from a subsea production blowout (16%), unignited gas ingress from subsea releases (6%) and fires in the Engine Room (15%) account for 100% of the TRIF.

The TRIF for the actual duration of the SWRX project activities will be significantly lower, as the DSV will only be on-station for 25 days to carry out these activities. The actual duration TRIF is 2.39E-06.

In a similar manner to the MODU risks, the DSV impairment based TR integrity frequency has also been calculated and is shown in Table 6-2.

Event ID	Description	Impairment Based TR Integrity (per annum)	%
1	Subsea Release from SWRX Gas Injection Facilities	3.75E-06	1.3%
2	Production Blowout at SWRX - From Gas Injection Well	1.81E-06	0.6%
3	Fire - Engine Room	2.78E-06	1.0%
4	Fire - Accommodation	1.15E-05	3.9%
5	Mooring Failure	1.85E-06	0.6%
6	Loss of Tow	1.50E-05	5.2%
7	Structural Failure	1.01E-04	34.7%
8	Extreme Weather	1.00E-04	34.3%
9	Ship Collision	5.32E-05	18.3%
10	Iceberg Collision	3.08E-07	0.1%
	Total	**2.91E-04**	**100.0%**

Table 6-2: DSV Impairment Based TR Integrity Frequency Contribution

The total impairment frequency is below the impairment based criteria of 1E-03 per annum for all major accident events. In a similar manner to the MODU, the frequency of structural damage exceeds the 1E-04 per annum limit placed on individual major accident hazards, although in this case it is marginal.

6.4.2 DSV Potential Loss of Life (PLL)

The total PLL for the DSV is 3.26E-02 fatalities per annum, of which 1% can be attributed to hydrocarbon events and 99% to non-hydrocarbon events.

The total PLL for the actual duration of the SWRX project is 2.23E-03.

The different types of fatalities which make up the total PLL are shown in

Table 6-3 and discussed below.

Source	PLL per Annum	%
Immediate Hydrocarbon	0.00E+00	0%
Delayed Hydrocarbon	3.29E-04	1%
Occupational	1.27E-02	39%
Helicopter Travel	1.27E-02	39%
Structural Failure	3.77E-03	12%
Hydrocarbon - Rig Specific	7.13E-07	0%
Ship Collision	1.56E-03	5%
Loss of Stability	1.05E-03	3%
Extreme Weather	3.28E-04	1%
Loss of Tow	7.33E-05	0.2%
Mooring Failure	5.89E-05	0.2%
Fire - Accommodation	5.24E-05	0.2%
Mechanical Failure - Lifting Equipment	3.96E-05	0.1%
Iceberg Collision	1.29E-06	0.0%
Total	**3.26E-02**	**100%**

Table 6-3: Potential Loss of Life (PLL) on DSV for SWRX Project

The greatest contributors to the PLL are the non-hydrocarbon risks associated with offshore working and primarily occupational (working) risks and helicopter transfer risks, which each account for 39% of the overall PLL. Control of these hazards is not considered further in this analysis.

6.4.3 DSV Individual Risk Per Annum (IRPA)

The Individual Risk Per Annum (IRPA) to personnel on the DSV is dependent on worker category.

For the Dive Crew, the IRPA is 2.18E-04 per annum, for Maintenance/Deck Crew it is 2.95E-04 per annum whilst the lowest risk group is the Catering/Admin Crew, whose IRPA is 1.09E-04 per annum.

The breakdown of contributors to the IRPAs for the main worker categories on the DSV are presented below in Table 5-17.

Source	Divers	%	Maintenance / Deck	%	Catering	%
Immediate Hydrocarbon	0.00E+00	0.0%	0.00E+00	0.0%	0.00E+00	0.0%
Delayed Hydrocarbon	1.83E-06	0.8%	1.83E-06	0.6%	1.83E-06	1.7%
Hydrocarbon - Rig Specific	9.79E-10	0.0%	9.79E-10	0.0%	9.79E-10	0.0%
Helicopter Travel	7.04E-05	32.3%	7.04E-05	23.9%	7.04E-05	64.8%
Occupational	1.10E-04	50.3%	1.86E-04	63.2%	0.00E+00	0.0%
Loss of Stability	5.43E-06	2.5%	5.43E-06	1.8%	5.69E-06	5.2%
Mooring Failure	3.06E-07	0.1%	3.06E-07	0.1%	3.17E-07	0.3%
Loss of Tow	3.90E-07	0.2%	3.90E-07	0.1%	3.90E-07	0.4%
Structural Failure	1.97E-05	9.0%	1.97E-05	6.7%	2.03E-05	18.7%
Mechanical Failure - Lifting Equipment	6.18E-07	0.3%	6.18E-07	0.2%	0.00E+00	0.0%
Extreme Weather	6.33E-07	0.3%	7.35E-07	0.2%	7.35E-07	0.7%
Ship Collision	8.68E-06	4.0%	8.68E-06	2.9%	8.68E-06	8.0%
Iceberg Collision	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%
Fire - Accommodation	2.56E-07	0.1%	2.56E-07	0.1%	3.02E-07	0.3%
Totals	**2.18E-04**	**100.00%**	**2.95E-04**	**100.0%**	**1.09E-04**	**100.0%**

Table 6-4: DSV IRPA Results for the SWRX Project

The other risk contributions follow the patterns discussed in for the PLL.

It should be noted that none of the individual risk levels for any of the worker groups examined exceed the individual risk Target Level of Safety of 5E-04 per annum for new operations.

6.5 Conclusions

The risk levels for the DSV carrying out the installation and hook-up activities for the South White Rose Extension Project are predicted to be low.

The frequency of hydrocarbon TR impairment is 1.82E-05 per annum, or once in 55,000 years. The impairment based TR integrity frequency is calculated to be 2.91E-04 per annum should all hazards that may impair the DSV TR be taken into account. The total PLL is 3.26E-02 per annum or one fatality every 31 years. The highest risk worker category is the Maintenance / Deck Crew, whose IRPA is calculated to be 2.95E-04 per annum.

It should be noted, however, that these risk figures assume continuous operation throughout a full year. The operations that are to be carried out by the DSV for the South White Rose Extension Project are predicted to last for just 25 days. The risks for the actual period of operation can therefore be calculated; the TRIF is predicted to be 1.25E-06 and the PLL to be 2.23E-03.

As discussed in Section 4.7, the DSV may operate in such a way as to carry out lifting activities at a distance from the glory hole, minimising the risk of an object being dropped onto the subsea equipment. However, for conservatism, the damage frequency calculated based on lifts being conducted immediately above the glory hole have been carried forward to the DSV risk assessment. However, this additional release frequency is very low and has minimal effect on the overall results. It should be noted that if you completely remove the risk of loss of containment from dropped objects from the DSV risk assessment, the overall DSV TRIF reduces by less than 0.1% and the max IRPA and PLL reduce by less than 0.01%.

7. Pipelay Vessel

As part of the SWRX project, there will be a requirement for a pipelay vessel to be used to install the new gas injection flowline between the SWRX Glory Hole and the Northern Drill Centre. However, unlike the MODU and the DSV, the pipelay vessel will not be conducting any activities that are unique to the SWRX project; it will be carrying out standard activities, similar to those it performs all year round. The pipelay vessel will conduct limited activities over live hydrocarbon equipment and therefore there are few field specific risks to assess. Further, the vessel will be able to move off-station immediately in the event of an emergency and is unlikely to be affected by any SWRX project related incident. Therefore, the risks to the pipelay vessel and the personnel working on it have not been quantitatively assessed.

8. Review of FPSO Modifications

8.1 SWRX Production Fluid Tie-in

The arrangements for the tie-back of the SWRX fluids to the FPSO have not yet been finalised. If the SWRX fluids are to be tied back to the FPSO via existing flowlines, then it would be expected that there would be no requirement for any topsides changes to the SeaRose FPSO. If new, SWRX dedicated risers are to be installed, then modifications to the FPSO would be required.

Once the tie-back arrangements are finalised, the potential impacts on the SeaRose FPSO will be reviewed.

8.2 Gas Injection Extension

An additional 16km of gas injection pipeline is to be installed between the Northern drill centre and the SWRX drill centre. The location of the new line is shown in Figure 2-1. The potential consequences of extended fire durations etc. as a result of the additional high pressure gas inventory has been assessed.

The current flowline configuration (i.e. GI to NDC only) includes a 5.5" internal diameter riser, which is approximately 300m in length and an 8.5" internal diameter flowline, which is close to 9000m in length. This equates to a volume of approximately 330m^3, and a mass of approximately 100,000kg assuming that the density of the gas at 40MPa is around 300kg/m^3.

Rupture of this flowline would cause loss of the entire gas inventory over a period in excess of 2 hours, assuming no contribution from the injection wells.

The probability of discharge of the entire flowline gas inventory in the event of a breach is conservatively estimated at 100%, although this would be reduced substantially if the flowline is depressurised by venting the gas through the flare.

The gas inventory in the GI flowline will be affected by the proposed extension to SWRX. The proposed flowline has a gas volume of approximately 916m^3 and a gas mass of approximately 275,000kg. This is based on a 5.5" internal diameter riser, which is 300m in length and an 8.5" internal diameter flowline, which is 30,000m in length. Again, it is assumed that the density of the gas at 40MPa is around 300kg/m^3.

A comparison of the riser release rates and fire size results has been made been made between the existing gas injection case (to NDC only) and the extended case to SWRX. The release of gas from the flowline has been modelled using the time dependant blowdown model included in Atkins' PIFL model [28] as per the current QRA. Results are presented in Table 8-1 to Table 8-4.

	Release Size	Release Rate (kgs^{-1}) with Time (mins)									
		0mins	0.5	1	2	5	10	20	30	60	120
Current Configuration (to NDC only)	10mm	3.4	3.4	3.4	3.4	3.4	3.3	3.3	3.2	3.0	2.7
	50mm	85.6	63.1	54.3	38.5	36.4	29.9	23.4	18.4	8.8	2.0
	Full Bore	1113.2	62.6	53.0	39.2	37.1	30.5	23.1	17.5	7.6	1.5
Base Case (NDC to SWRX)	10mm	3.4	3.4	3.4	3.4	3.4	3.4	3.3	3.3	3.2	3.1
	50mm	85.6	63.1	54.3	38.5	36.4	29.9	24.4	21.5	17.3	12.3
	Full Bore	1113.2	62.6	53.0	39.2	37.1	30.5	24.8	21.8	17.4	12.1

Table 8-1: Time Dependent Release Rate

	Release Size	Jet Fire Length (m) with Time (mins)									
		0mins	0.5	1	2	5	10	20	30	60	120
Current Configuration (to NDC only)	10mm	26	26	26	26	26	26	26	25	25	24
	50mm	95	84	79	69	67	62	56	51	38	21
	Full Bore	265	84	78	69	68	63	56	50	36	19
Base Case (NDC to SWRX)	10mm	26	26	26	26	26	26	26	26	26	25
	50mm	95	84	79	69	67	62	57	55	50	44
	Full Bore	265	84	78	69	68	63	58	55	50	43

Table 8-2: Time Dependent Jet Fire Flame Length

	Release Size	Fireball Diameter (m) with Time (mins)									
		0mins	0.5	1	2	5	10	20	30	60	120
Current Configuration (to NDC only)	10mm	10	10	10	10	10	10	10	10	9	9
	50mm	36	31	30	26	25	23	21	19	14	8
	Full Bore	99	31	29	26	25	24	21	19	13	7
Base Case (NDC to SWRX)	10mm	10	10	10	10	10	10	10	10	10	9
	50mm	36	31	30	26	25	23	22	20	19	16
	Full Bore	99	31	29	26	25	24	22	21	19	16

Table 8-3: Time Dependent Fireball Diameter

	Release Size	Pool Fire Diameter (m) with Time (mins)									
		0mins	0.5	1	2	5	10	20	30	60	120
Current Configuration (to NDC only)	10mm	24	24	24	24	24	24	24	24	24	9
	50mm	36	31	30	26	25	24	24	24	24	8
	Full Bore	99	31	29	26	25	24	24	24	24	7
Base Case (NDC to SWRX)	10mm	24	24	24	24	24	24	24	24	24	24
	50mm	36	31	30	26	25	24	24	24	24	24
	Full Bore	99	31	29	26	25	24	24	24	24	24

Table 8-4: Time Dependent Sea Surface Pool Fire Diameter

As can be seen, the additional inventories involved in the proposed flowline extension means that the release rates and fire sizes beyond 30 minutes are greater than for the current configuration. However, it should be noted that all releases for the current configuration last in excess of 2 hours and therefore, this additional inventory is unlikely to increase the risk to personnel or the asset. The risks assessed in the QRA will therefore be unaffected by the additional inventory.

9. Conclusions & Recommendations

9.1 Conclusions

The conclusions of this Safety Assessment of the South White Rose Extension Project are as follows:

1) The annual frequency of blowouts during the drilling and completion of the six new wells for the SWRX project is predicted to be 4.68E-03 per annum.
2) The frequency of objects being dropped during lifting operations on the MODU and impacting on subsea equipment with sufficient energy as to damage the equipment and cause a loss of containment is relatively low. The impairment frequency at the new SWRX Glory Hole is 1.41E-03 per annum for objects dropped from the MODU and 2.68E-06 per annum for objects dropped from the DSV.
3) The hydrocarbon TR Impairment Frequency for the MODU is 6.80E-05 per annum, or once every 14,700 years. The total PLL is 5.08E-02 fatalities per annum or one fatality every 20 years. The IRPA for the highest risk worker category (the Drill Crew) is 4.53E-04 per annum.
4) The impairment based TR integrity frequency for the MODU is calculated to be 3.39E-04 per annum. The highest contributor to this frequency is from structural failure and extreme weather, which contribute approximately 1E-04 per annum each.
5) In all cases, however, the TR impairment frequency and IRPA values are below Husky's Target Levels of Safety
6) The risk levels for the DSV carrying out the installation and hook-up activities for the South White Rose Extension Project are predicted to be low. The frequency of hydrocarbon TR impairment is 1.82E-05 per annum, or once in 54,800 years. The total PLL is 3.26E-02 per annum or one fatality every 31 years. The highest risk worker category is the Maintenance / Deck Crew, whose IRPA is calculated to be 2.95E-04 per annum.
7) As for the MODU, the TRIF and IRPA values for the DSV are significantly below Husky's Target Levels of Safety (1E-03 per annum).

9.2 Recommendations

1) As the SWRX Project progresses it is recommended that this safety assessment is updated to reflect any changes that may occur to the design. It is particularly important that assumptions made within this study are reviewed and updated to ensure that the conclusions drawn remain valid.
2) The potential frequency and consequence of an impact between the MODU and visiting OSVs (Offshore Supply Vessel) should be reviewed by Husky and the results incorporated into a later revision of the MODU risk assessment.
3) This report should be revisited and updated once the actual MODU to be used has been selected and once the glory hole layout and SWRX tie-back arrangements have been finalised.

The following recommendations were made in the previous review of SWRX activities; Husky should confirm that these have been reviewed and closed out where appropriate.

1) A review of the traffic management procedures at the White Rose field should be undertaken by Husky to ensure that there are sufficient measures in place to protect the SWRX equipment, and any MODU working at the SWRX Glory Hole, from vessels passing through the field.
2) A White Rose specific field traffic survey should be undertaken to provide a better understanding of the vessels that may pass through the field. The results of this study should be used to develop a ship collision

assessment that determines the collision risk to the FPSO as well as any MODU that may be operating in the field.

3) Husky should also review in more detail the potential for icebergs to damage or scour equipment in the SWRX Glory Hole or flowlines. The review should include Ice Management procedures to ensure that the SWRX equipment is protected to a similar level as existing subsea equipment.

4) The potential for MODU mooring chains to damage the flowlines or umbilicals has previously been assessed by the White Rose project. However, the potential damage that drifting anchors could cause to the flowlines or umbilical has not been assessed and should be reviewed to ensure that the potential frequency of damage is acceptable.

10. References

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Appendix A – Impact Frequency Plots

The following plots show the frequency of impact of dropped objects onto the subsea equipment at the SWRX or Southern Glory Holes. The following Frequency Key shows the colours that are used in the plots to represent various impact frequencies. Note that the frequencies shown in the plots represent the frequency of the objects hitting the subsea equipment but takes no account of the probability of damage or loss of containment occurring.

Frequency Key
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08

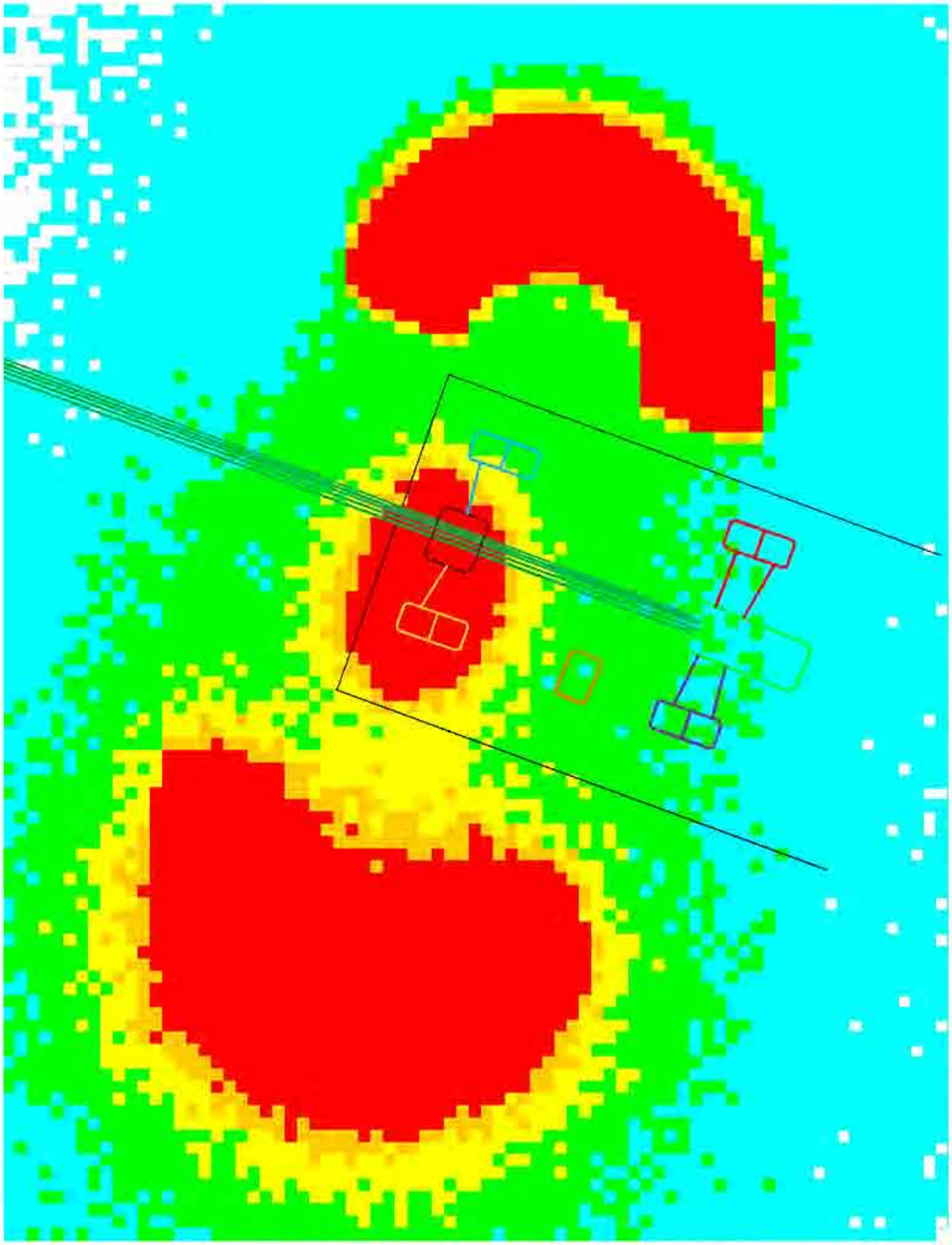

Figure A1: Impact Frequency Plot for Drilling Well 1

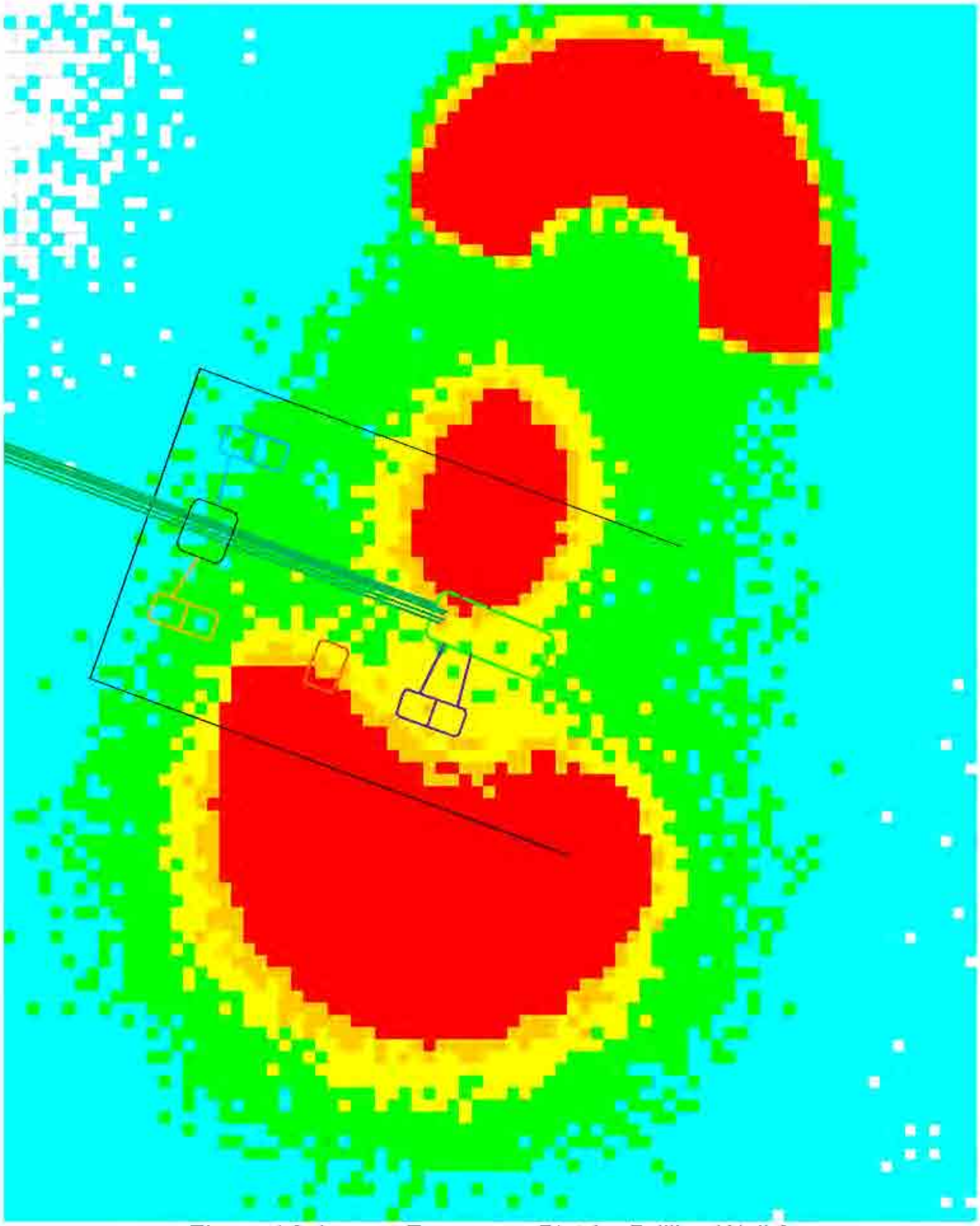

Figure A2: Impact Frequency Plot for Drilling Well 2

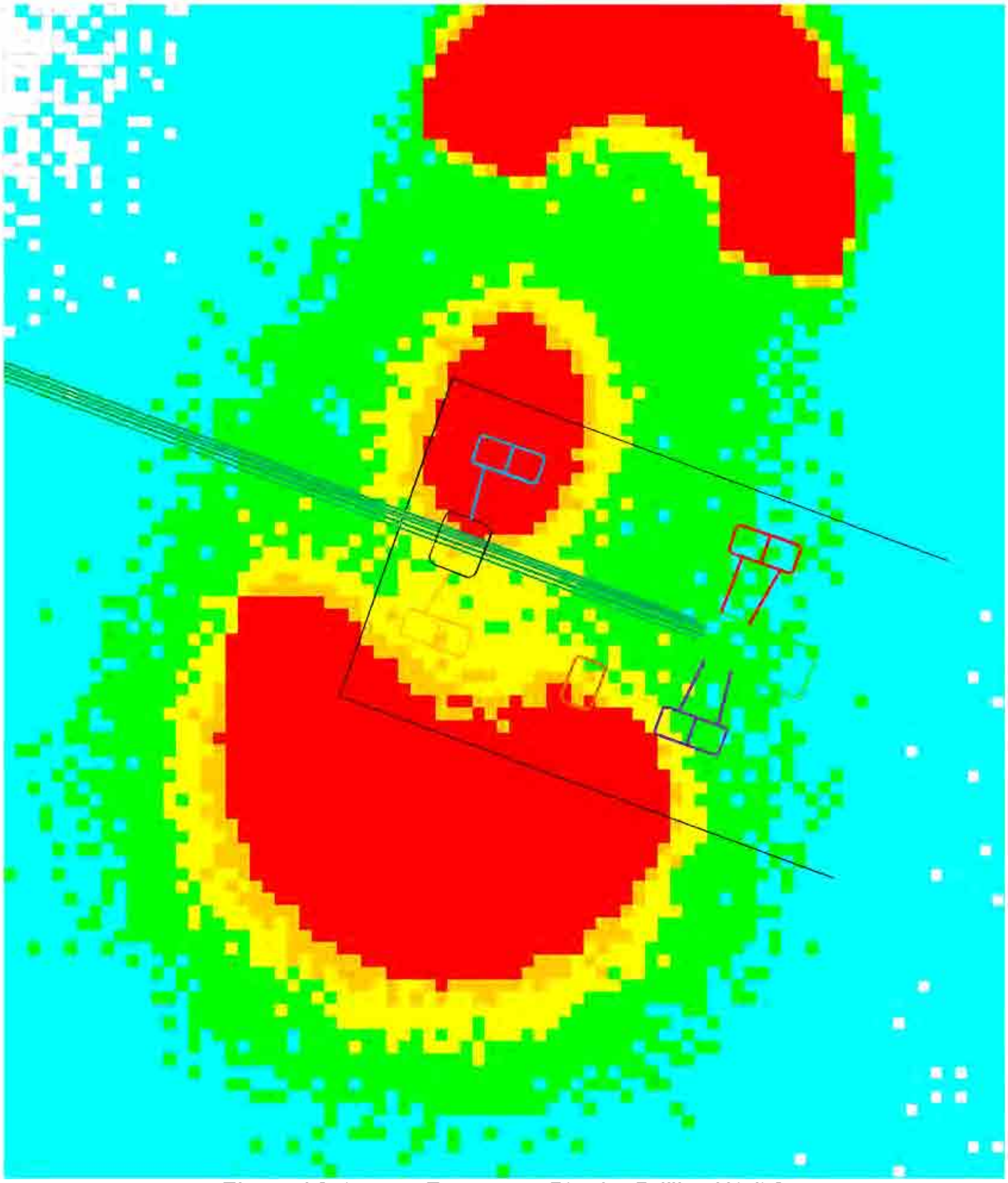
Figure A3: Impact Frequency Plot for Drilling Well 3

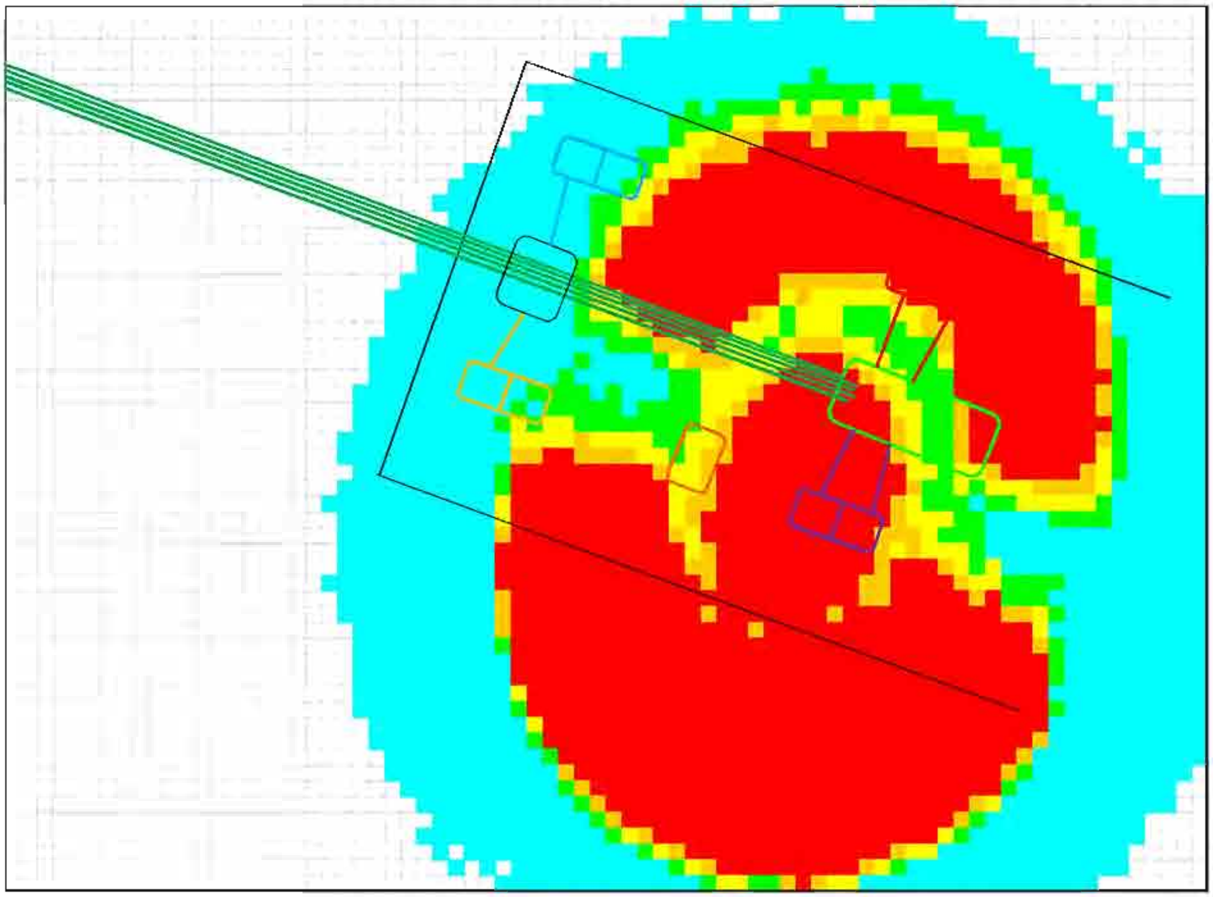

Figure A4: Impact Frequency Plot for Drilling Well 4

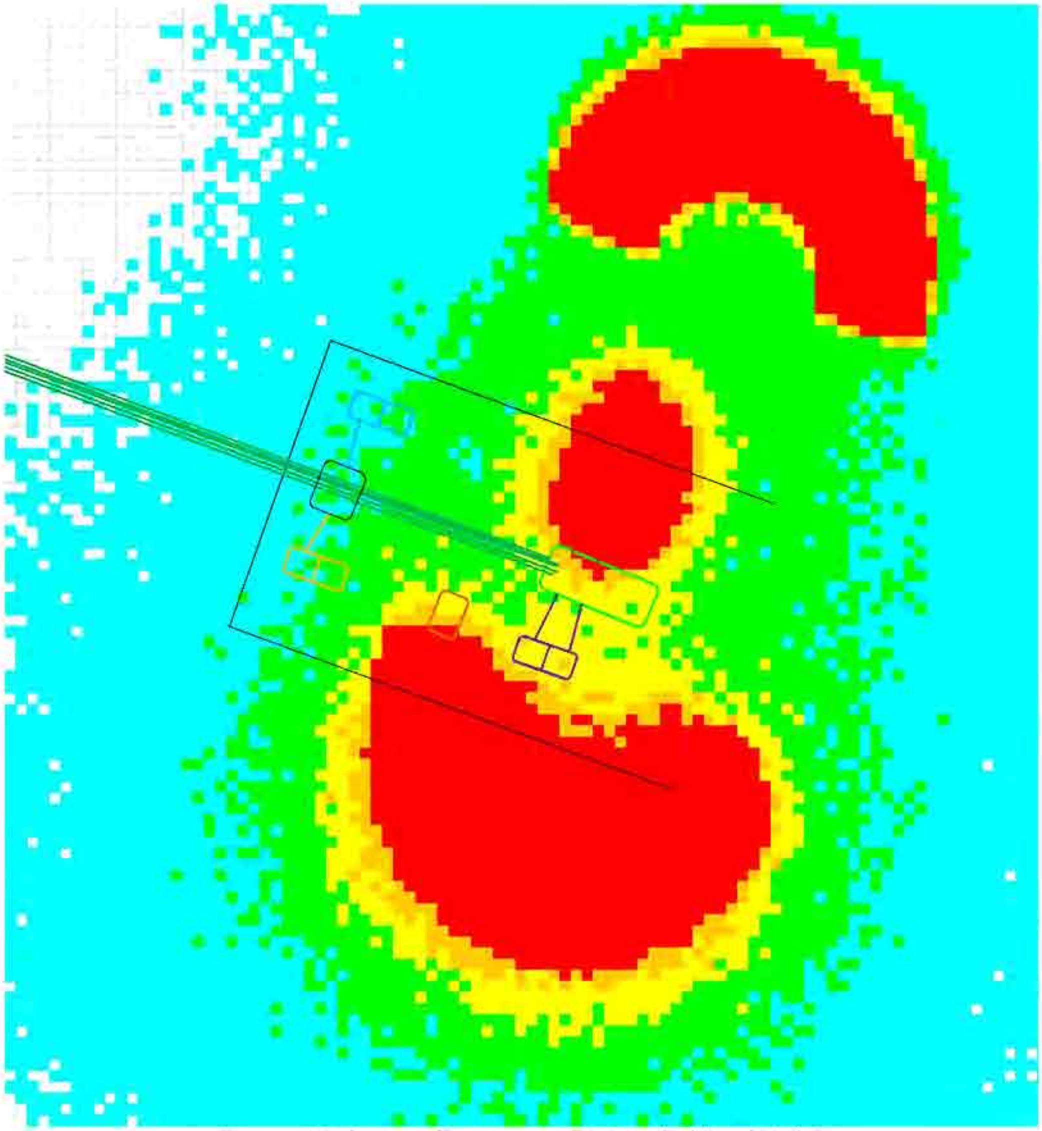

Figure A5: Impact Frequency Plot for Drilling Well 5

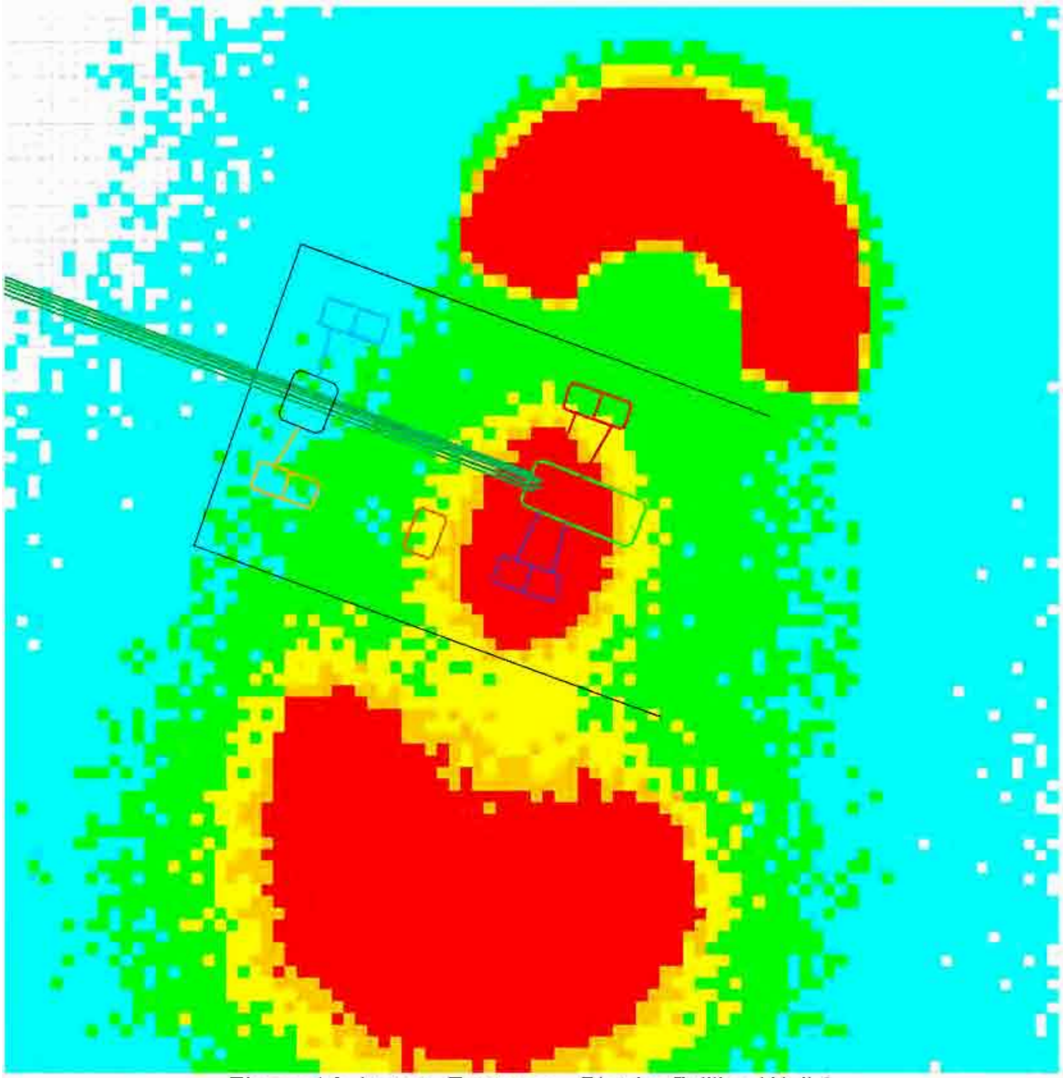

Figure A6: Impact Frequency Plot for Drilling Well 6

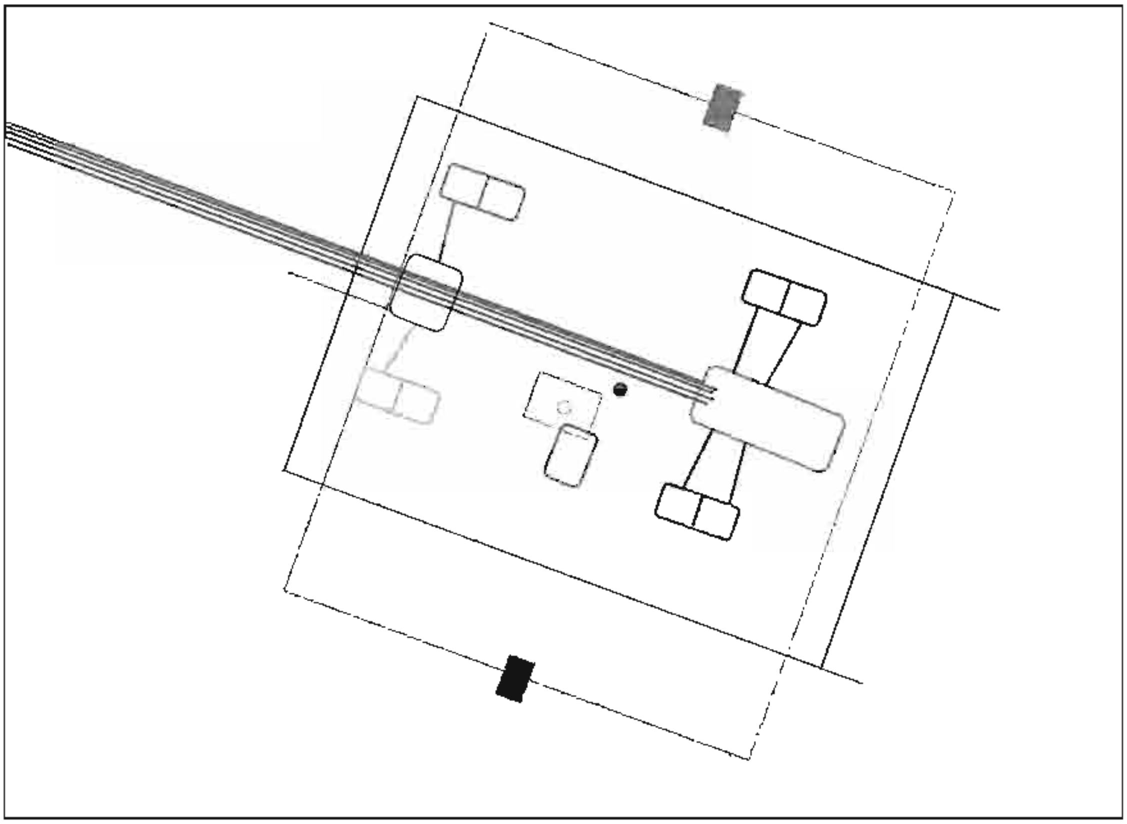

Figure A7: Impact Frequency Plot for Installing Additional Items

Appendix B Blowout Consequence Analysis

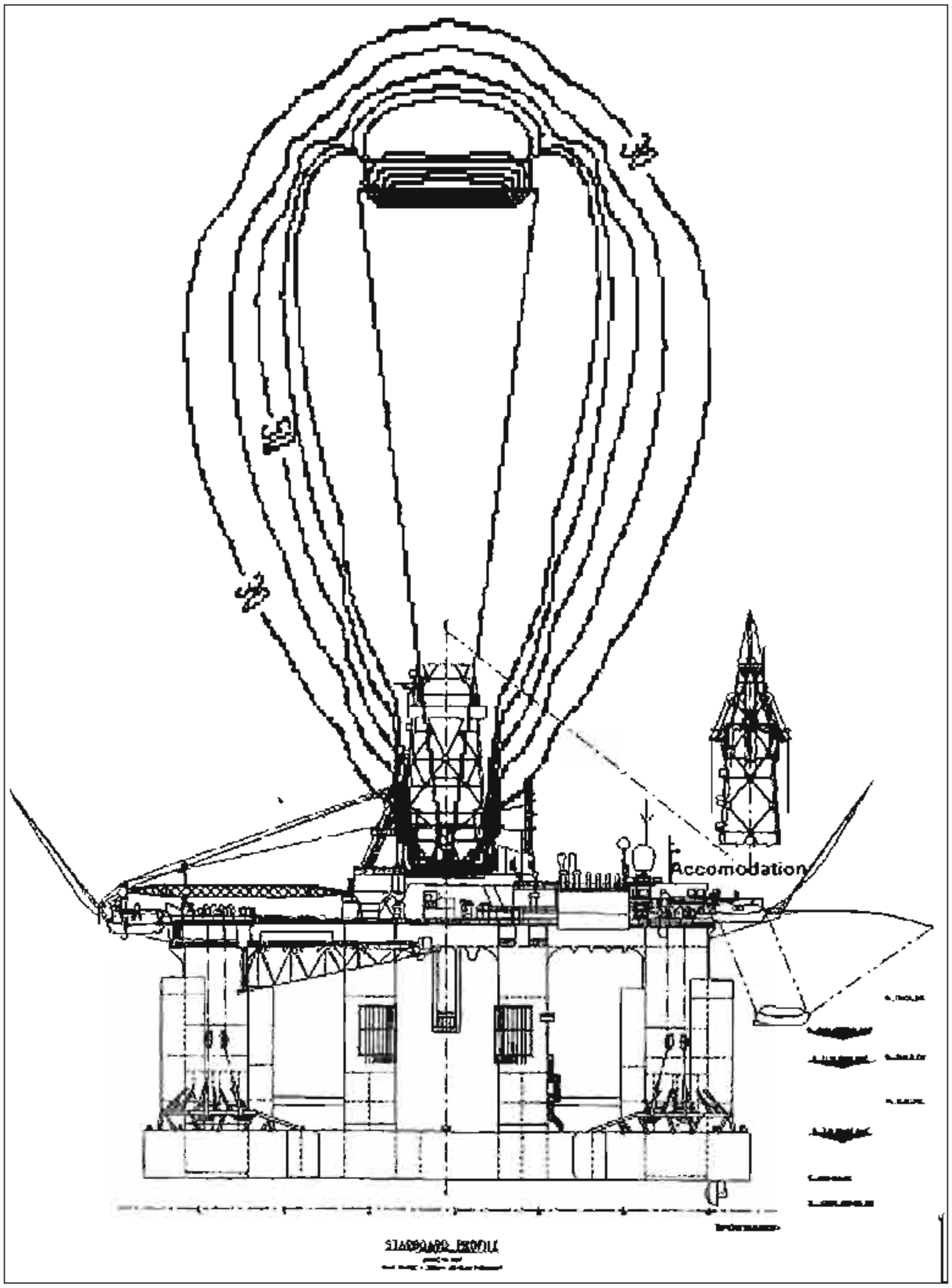

Figure A1: 50kg/s Vertical Drillfloor Blowout with 0m/s Wind (Contours in kW/m²)

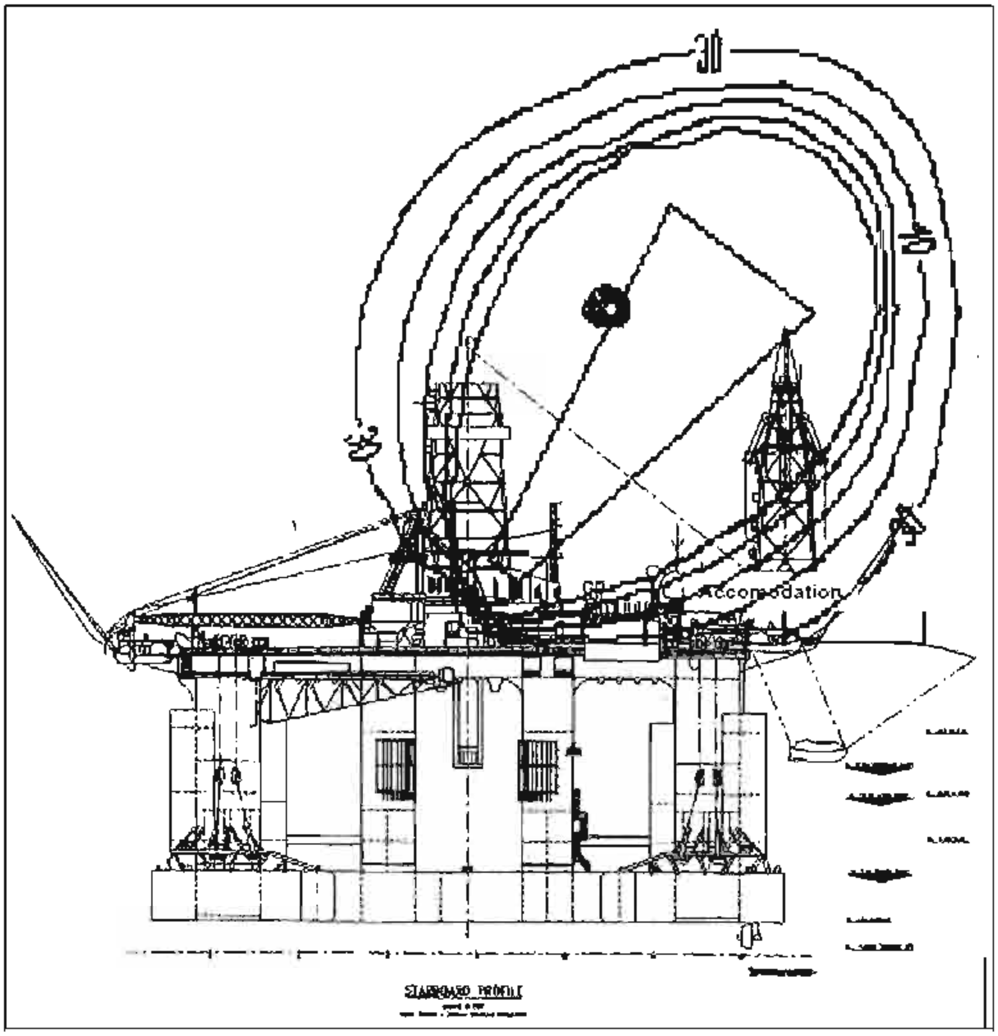

Figure A2: 50kg/s Vertical Drillfloor Blowout with 5m/s Wind Towards Accommodation (Contours in kW/m^2)

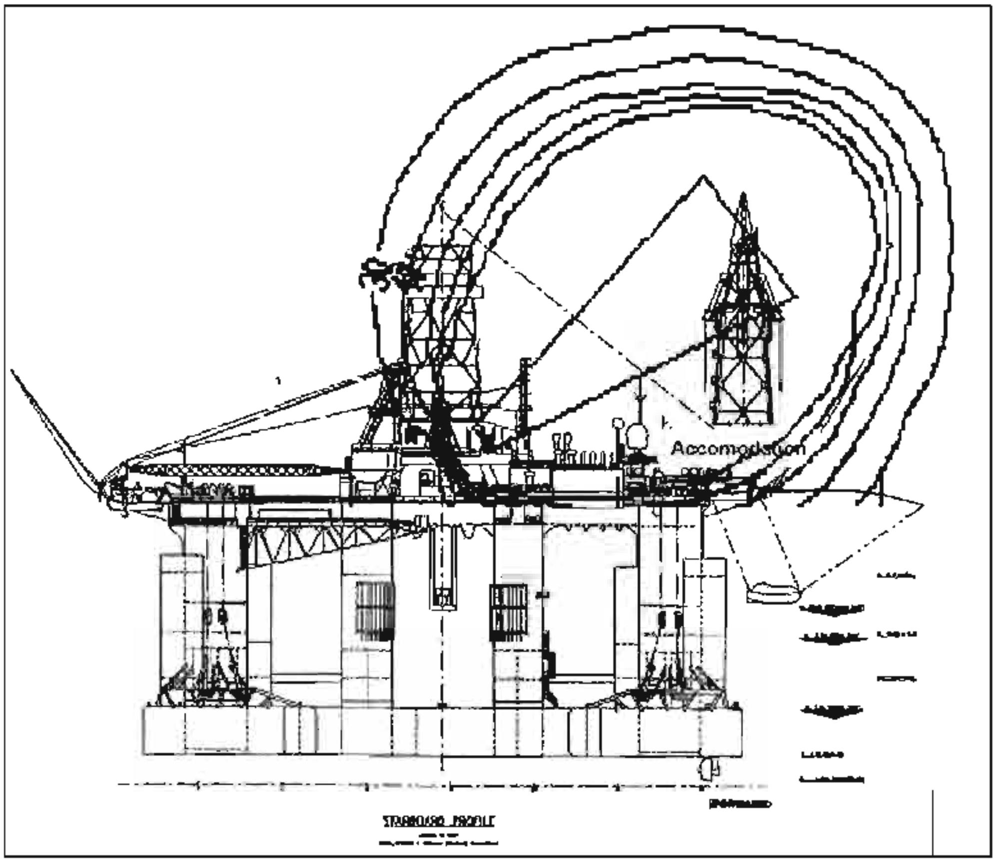

Figure A3: 50kg/s Vertical Drillfloor Blowout with 10m/s Wind Towards Accommodation (Contours in kW/m^2)

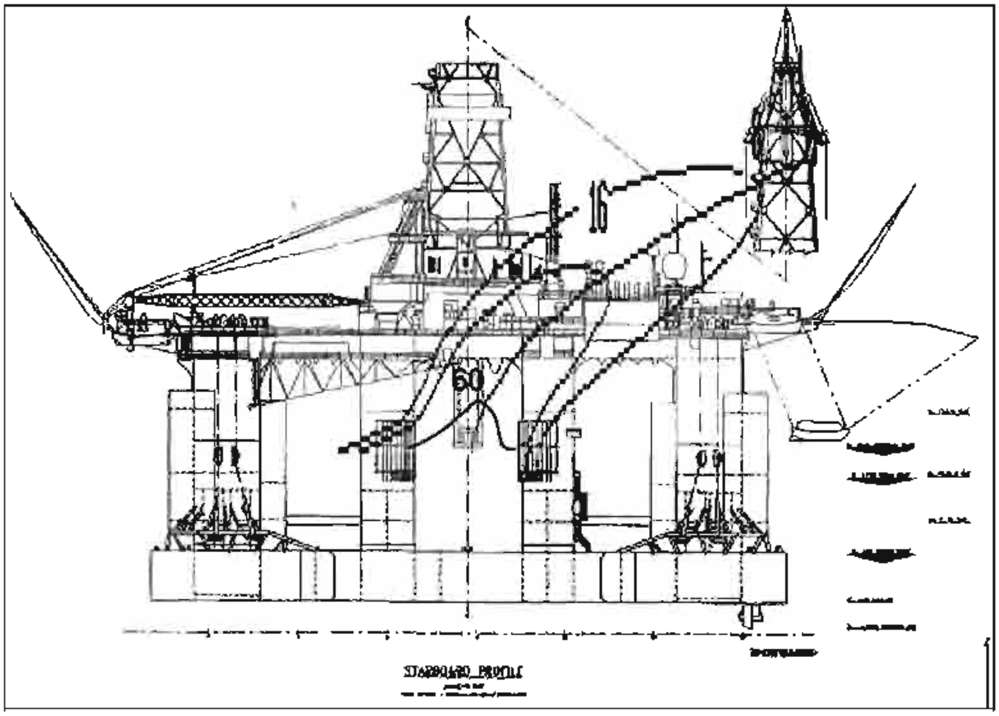

Figure A4: Deep Reservoir Blowout Sea Surface Fire Smoke Dispersion, 5m/s Wind Towards Accommodation, MODU at Operational Draft

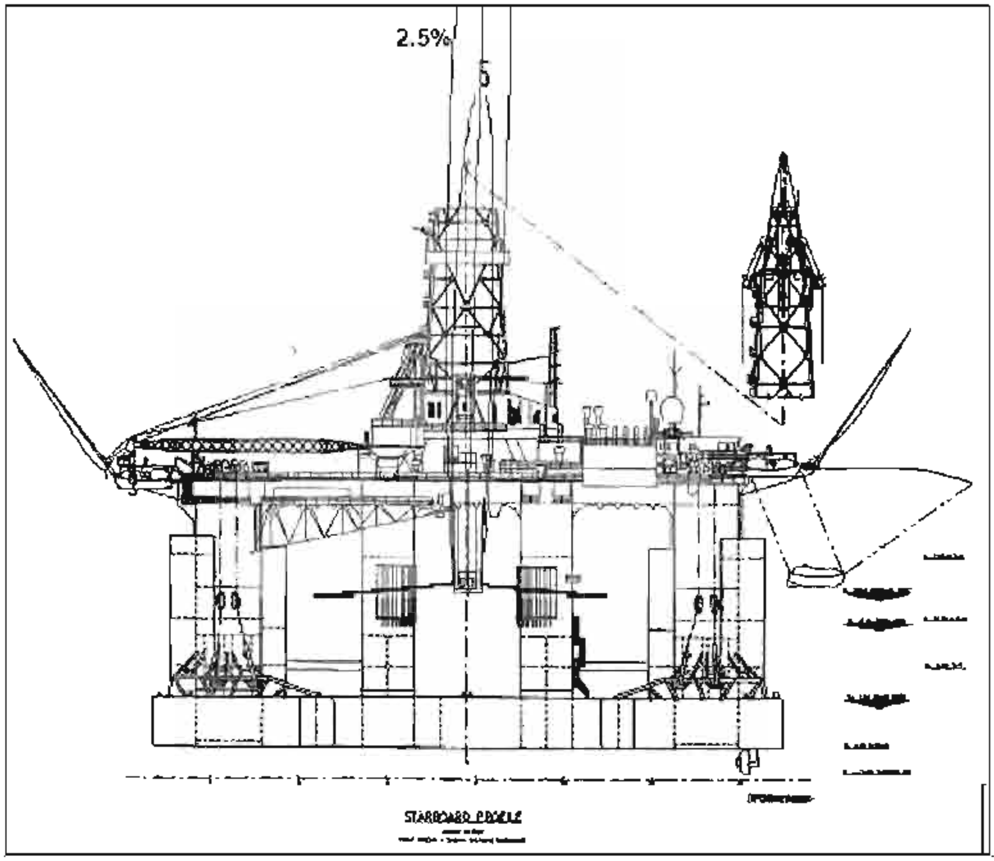

Figure A5: Shallow Gas Blowout Sea Surface Gas Dispersion, 0m/s Wind Towards Accommodation, MODU at Operational Draft

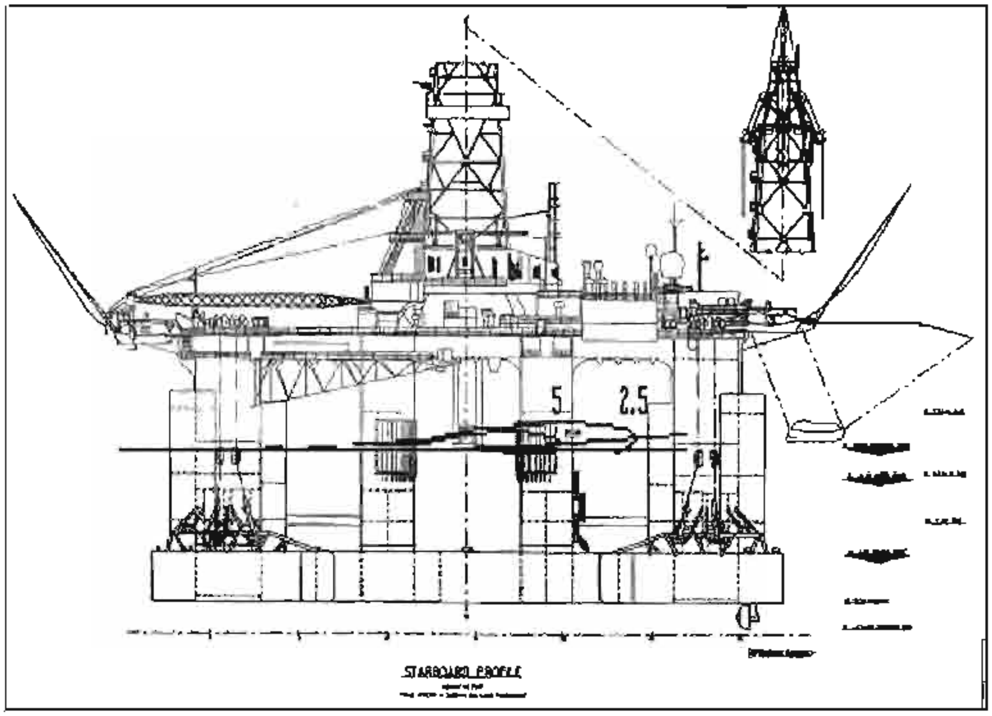

Figure A6: Shallow Gas Blowout Sea Surface Gas Dispersion, 5m/s Wind Towards Accommodation, MODU at Operational Draft

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