Husky Energy REPORT

REPORT TITLE

SeaRose Tieback Project Concept Safety Assessment

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SeaRose Tieback Project Concept Safety Assessment

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ABBREVIATIONS

BOP	Blowout Preventor
bopd	Barrels of oil per day
CGH	Central Glory Hole
CO	Carbon Monoxide
C-NLOPB	Canada - Newfoundland and Labrador Offshore Petroleum Board
DSV	Dive Support Vessel
ESD	Emergency Shutdown
FE	Finite Element
FPSO	Floating Production, Storage and Offloading Vessel
IRPA	Individual Risk Per Annum
MMSCFD	Million Standard Cubic Feet Per Day
MODU	Mobile Offshore Drilling Unit
NADC	North Amethyst Drill Centre
PLL	Potential Loss of Life
QRA	Quantitative Risk Analysis
ROV	Remotely Operated Vehicle
SDC	South Drill Centre
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
WWRX	West White Rose Extension Project

S1 SUMMARY

Husky Oil Operations Ltd (Husky) is considering the extension of the White Rose Field and the addition of the North Amethyst Field to incorporate three additional drill centres – South White Rose Extension (SWRX), West White Rose Extension (WWRX) and North Amethyst Field (NADC). This will involve the construction of three new glory holes. The base case considers that SWRX and WWRX drill centres will be tied back to the FPSO via the existing Southern and Central Drill Centres respectively, whilst the NADC flowlines will be tied back directly to the FPSO.

As part of the development, Husky is intending to submit to the C-NLOPB a Development Plan for North Amethyst and Development Plan Amendments for the White Rose field extensions. To support these applications, Husky has requested that Atkins assess the potential impact of the new development on existing White Rose safety studies.

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 tiebacks. The studies which have been identified as requiring review are:

- The White Rose Quantitative Risk model which was used to generate a number of studies including the QRA [1], FRA [2], and TRIA [3].
- MODU Blowout Risk Assessment (WR-HSE-RP-0015) [4];
- MODU Dropped Object Analysis (WR-HSE-RP-0028) [5];
- MODU Risk Assessment (WR-HSE-RP-0020) [6].

In addition, this report details the hazards and risks associated with Diving Support Vessel (DSV) operations, as this was not specifically addressed within the studies listed above.

S1.1 Tieback To SeaRose FPSO

The construction of new drill centres for the Tieback project may have an effect on the overall risk levels on the SeaRose FPSO. The SWRX and WWRX drill centres are tied back through existing drill centres and will therefore have minimal effects on the FPSO risk levels. However, the North Amethyst drill centre is to be tied back directly to the FPSO, resulting in three additional hydrocarbon risers and flowlines being installed on the SeaRose. In total, two production risers, one gas lift line and one water injection riser will be tied back to the SeaRose from the NADC. Additionally, Husky wishes to consider the option of having the WWRX drill centre tied back directly to the FPSO in a similar manner to North Amethyst.

The tie-back of the North Amethyst field directly to the SeaRose FPSO is predicted to result in an increase of 2% (relative to the risk levels in the most recent revision of the SeaRose FPSO QRA [1]) in the hydrocarbon-only TRIF, to 1.83E-04 per annum. The TRIF for all hazards increases by around 1% to 2.95E-04 per annum. The PLL is expected to rise by 2% to 4.08E-02 per annum and the maximum IRPA by 2% to 2.55E-04 (the maximum value remains for the Process Crew).

The tie-back of the WWRX pool directly to the FPSO will be via risers containing fluids from both WWRX and CDC. The arrival pressure of these new risers is lower than previously considered for the original CDC risers and therefore the risk levels will

reduce. TRIF will reduce to 1.75E-04 per annum, the PLL to 3.91E-02 per annum and the maximum IRPA to 2.41E-04 per annum.

Although the risk levels are predicted to increase as a result of the installation of new risers to tie-back the North Amethyst field, the risk levels remain well below Husky's Target Levels of Safety.

S1.2 Blowout Risk Assessment

A review of the blowout risk assessment has indicated that there is an increase in the blowout frequency (for each of the new drill centres compared to the initial White Rose development) simply as a result of the increased number of well operations being carried out over the period of each of the new developments.

The consequences of a blowout at each location were reviewed and considered to be the same as blowouts during the development of the White Rose field.

S1.3 Dropped Object Risk Assessment

The dropped object study was also reviewed to determine the potential for damaging subsea equipment as a result of SWRX, North Amethyst and WWRX development and installation activities. The assessment concluded that the frequency of damage to subsea equipment at each of the new drill centres was of a similar order. It was assumed that damage to the xmas trees and the associated flowlines and manifolds could only result in a loss of hydrocarbon containment if the wells were live following completion.

S1.4 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, WWRX and North Amethyst projects. The analysis has assessed the potential consequences of such hazards and subsequently determined the associated risk to personnel.

The assessment is based on the Global Santa Fe (GSF) Grand Banks as this MODU has performed operations at the White Rose field. Should there be a requirement for a different MODU to perform the tieback project operations then this assessment shall be reviewed and updated to ensure that the specific MODU risks are included.

The assessment has determined that the loss of TR integrity frequency (TRIF) for the MODU whilst conducting SWRX operations is **1.93E-04** per annum. For North Amethyst, the TRIF was found to be **1.92E-04** per annum and at WWRX it is **1.85E-04** per annum.

Whilst each of these values lie below Husky's defined criteria of **1E-03** per annum for all major accident hazards, subsea blowouts contribute approximately **1.4E-04** per annum to the total in each case. This exceeds Husky's defined criteria of **1E-04** per annum for a single major accident hazard. However, it should be remembered that the MODU has been operating in the White Rose field for a number of years and, in combination with the established procedures in place, should therefore mean that the generic, historical blowout frequency used here is likely to be conservative. The subsea blowout frequency also exceeded 1E-04 per annum for the original White Rose Development.

The individual risk levels for various MODU worker groups have also been assessed within this study. The maximum risk level has been assessed as being for the Drill Crew, whose IRPA is **5.49E-04** per annum at SWRX, **5.43E-04** per annum at North Amethyst and **5.34E-04** per annum at WWRX. Again, these values are all below Husky's defined criteria of **1E-03** per annum**.**

S1.4.1 MODU Risk Results Discussion

The TRIF for the MODU carrying out the drilling activities for the SWRX, WWRX and North Amethyst projects are each predicted to be slightly higher than the previously assessed risks for the MODU operating in the White Rose field during the development phase [6].

The main cause of the increased risks is the higher number of wells to be drilled and completed. Previously, the risks relating to the year with the highest planned drilling activities were included – this was predicted to be 2005, where the equivalent of 4 wells were to be drilled and 7 completed (see Section 4.2). The SWRX development involves the drilling and completion of 5 wells in an 11.6 month period – equivalent to 5.2 in a year, for the Base Case at North Amethyst, ten wells are to be drilled and completed in 23.6 months (5.1 per year) and at WWRX there will be 12 wells drilled and completed in 29.6 months (4.9 wells per year). The blowout frequency associated with the drilling of wells is higher than that for well completion and therefore the overall risks associated with blowouts has increased.

Overall, although the TRIF for the SWRX, North Amethyst and WWRX projects are all higher than those previously calculated for the MODU operating in the White Rose field, they remain significantly lower than Husky's Target Levels of Safety (TLS) of 1E-03 per annum.

As the design progresses then the risks associated with the operations shall be reviewed and updated as necessary to reflect any changes. Any assumptions made in this assessment shall also be reviewed to ensure that they reflect the latest design for the Project.

S1.5 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. The DSV risk assessment investigates the risks to personnel on board the DSV whilst it is on-station at the Southern Drill Centre, to allow modifications relating to the SWRX project to be carried out. It has been assumed that the risks to the DSV will be identical when on-station at the Central Drill Centre carrying out activities relating to the WWRX project.

The conclusions of the DSV risk assessment are that the TR integrity frequency is within Husky's criteria at **1.49E-04** per annum. The highest risk worker category is the Dive Crew, whose IRPA is calculated to be **7.07E-04** per annum.

These risk figures assume continuous operation throughout a full year. The operations that are to be carried out by the DSV and constructions vessel for the South White Rose Extension Project are predicted to last for approximately 48 days and will therefore be lower than shown here.

S1.6 General Conclusion

The overall risks associated with the MODU are higher for the SWRX, North Amethyst and WWRX projects than previously calculated for the MODU operating at the three original drill centres; this is primarily due to the increased risks associated with blowouts as a result of the additional wells being drilled over the period of one year. However, it should be noted that the hazards associated with operations at the new drill centres are considered to be the same as those for similar drilling operations elsewhere on the White Rose field.

In all cases, however, the TRIF and IRPA values associated with the South White Rose Extension Project remain significantly below Husky's Target Levels of Safety (1E-03 per annum).

S1.7 Recommendations

1) As the SeaRose Tieback 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) 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 new subsea equipment, and any MODU working at the new Glory Holes, from vessels passing through the field.
3) 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.
4) Husky should also review in more detail the potential for icebergs to cause damage or scouring of equipment in the new glory holes or flowlines. This review should also include the Ice Management procedures to ensure that the new equipment can be protected to a similar level as existing subsea equipment.
5) The project should review the impact on blowdown rates for the SDC production / test and gas lift lines as a result of the inclusion of the SWRX pool. Similarly, the impact of the WWRX pool on the CDC flowlines should be considered. Any increase in the blowdown rates and time may affect the time taken to release the riser buoy via the QCDC system in the turret during a controlled disconnect operation;
6) The ESD shut down times for the new facilities should also be reviewed to ensure that the time to close valves is optimised and does not prolong the period of packing that may occur at the FPSO after the riser ESD valves have closed in the turret;
7) 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 umbilicals in the expanded field area has not been assessed in this report and should be reviewed to ensure that the potential frequency of damage is acceptable.

1 INTRODUCTION

Husky Oil Operations Ltd (Husky) is considering the extension of the White Rose Field. Three new drill centres are to be developed; the South White Rose Extension (SWRX), the West White Rose Extension (WWRX) and the North Amethyst Drill Centre (NADC). The projects will each involve the drilling of new wells and the installation of subsea equipment. The base case assumes that the SWRX and WWRX drill centres will be tied back to the FPSO via the Southern and Central Glory Holes respectively and therefore the developments will have minimal impact on the risk levels on the FPSO itself. The base case also assumes that the North Amethyst Drill Centre will be tied-back directly to the SeaRose and therefore there will be an impact on the FPSO risk levels as a result of the installation of additional risers and flowlines.

As part of the development, Husky is intending to submit to the C-NLOPB a Development Plan for North Amethyst and Development Plan Amendments for the White Rose field extensions. To support these applications, Husky has requested that Atkins assess the potential impact of each of the new developments on existing White Rose safety studies. This report has been prepared as an ancillary document for these applications and reflects the current stage of the SeaRose Tieback Project designs.

Figure 1-1 shows the proposed layout of the White Rose field.

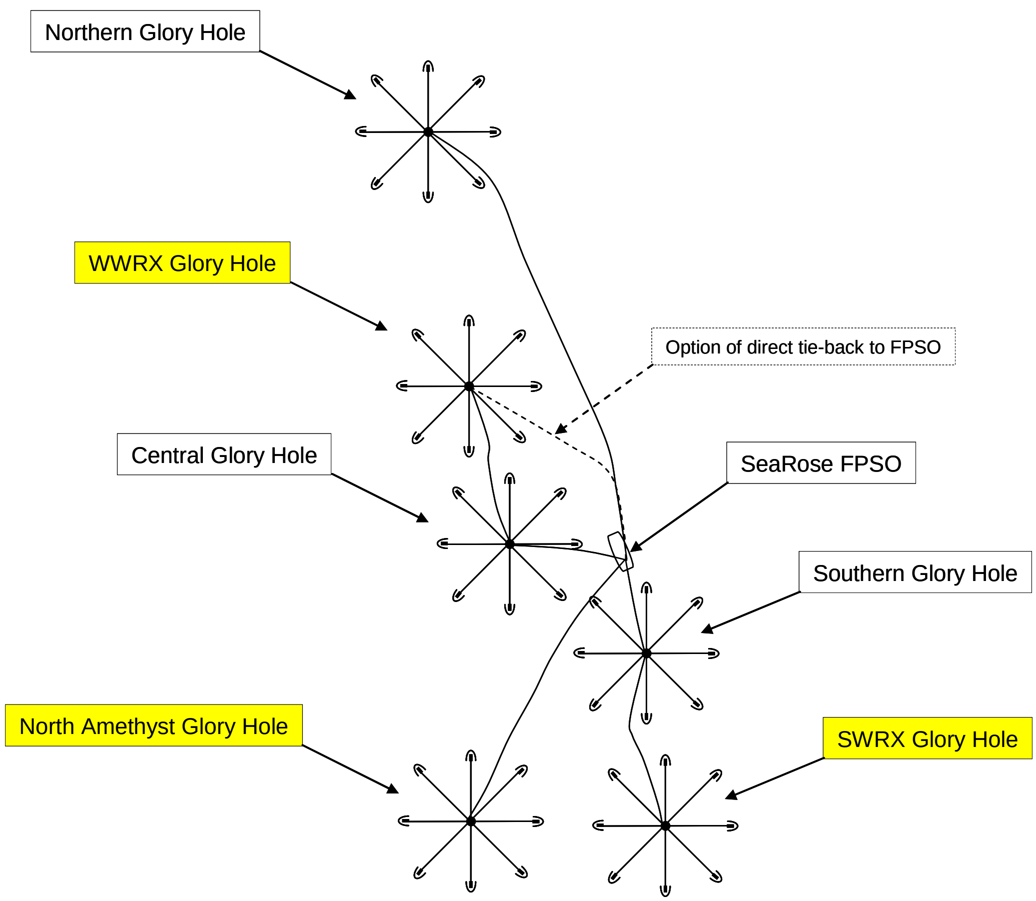

Figure 1-1: White Rose Field Layout

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 extension developments. The safety studies which have been identified as requiring review are:

- The White Rose Quantitative Risk model which was used to generate a number of studies including the QRA [1], FRA [2], and TRIA [3] – Reviewed in Section 3.
- MODU Blowout Risk Assessment (WR-HSE-RP-0015) [4] – Reviewed in Section 4;
- MODU Dropped Object Analysis (WR-HSE-RP-0028) [5] – Reviewed in Section 5;
- MODU Risk Assessment (WR-HSE-RP-0020) [6] – Reviewed in Section 6.

In addition, Section 7 of this report details the hazards and risks associated with Diving Support Vessel (DSV) operations, as this was not specifically addressed within the studies listed above.

The SWRX project has already been considered in depth in report SX-HSE-RP-0001 [7], Issued by Husky in October 2006. This report combines the analysis previously performed for SWRX with the new analyses of WWRX and North Amethyst. This allows the overall risk picture, where all three new drill centres are tied back to the FPSO, in addition to the topsides and riser modifications, to be examined.

The risks to the environment from the White Rose Extension Developments have not been considered in this report. Since the White Rose Development Application was submitted, Husky has determined that environmental risk is more appropriately defined through a qualitative, rather than quantitative, assessment. The qualitative assessment provides a number of environmental objectives and provides protection measures to ensure these objectives are met.

1.2 Report Structure

Section 2 of the report gives details of the SeaRose Tiebacks, including diagrams representing the new equipment layouts.

Section 3 assesses the potential impact that each of the tiebacks may have on the SeaRose FPSO.

For each of the three drill centres, the changes to the frequency of blowouts and impairment from dropped objects have been identified within Sections 4 and 5 and the revised frequencies are carried into sections 6 and 7 to establish the subsequent change in risk levels. Any direct changes to the Risk Assessments are also discussed in sections 6 and 7.

2 SEAROSE TIEBACKS

2.1 South White Rose Extension

This area is located approximately 4km south of the current Southern Glory Hole (SGH), as shown in Figure 2-1, in approximately 120m of water. The SWRX development will require a new glory hole to be constructed with facilities for production, gas lift and water injection and the associated flowlines tied back to the existing SGH. In addition, at the SGH, it will be necessary to carry out some modifications to allow the new wells to be tied back to the existing facilities.

Within the new glory hole, one new drill centre will be constructed with wells tied back and into the SGH manifolds. The SWRX drill centre will comprise three horizontal production wells and two horizontal water injection wells with expansion capacity for eight wells. The total predicted recoverable oil from SWRX is 24.4 million bbl.

As SWRX facilities will be routed to and from the SeaRose FPSO via the SGH, there shall be minimum requirement to make modification to the FPSO and therefore this assessment concentrates primarily on the subsea activities.

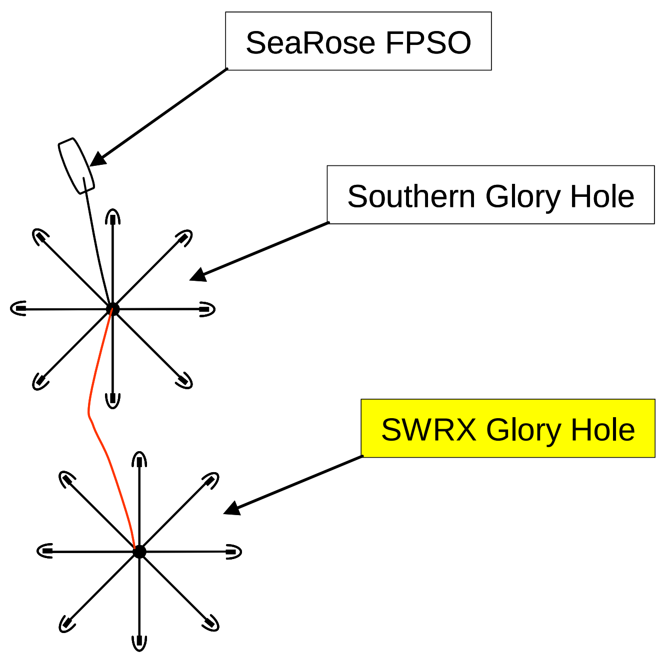

Figure 2-1: SWRX Tieback to the SGH

2.2 North Amethyst Field

The North Amethyst area is located approximately 7km South-West of the SeaRose FPSO, as shown in Figure 2-2, in approximately 120m of water. The North Amethyst development will require a new glory hole to be constructed with facilities for production, gas lift and water injection and the associated flowlines tied back to the FPSO. The project will involve the drilling of ten new wells (4 production and 6 water injection) at the North Amethyst area and the installation of subsea facilities. In addition, at the Central Glory Hole, it will be necessary to carry out some modifications to allow for the installation of control umbilicals routed from the FPSO to North Amethyst via the CGH. A contingency has been made for an additional 2 production and 1 water injection wells, giving a total of 13 wells. As the North Amethyst facilities will be routed directly to and from the SeaRose FPSO, the risk levels on the FPSO have been re-assessed to account for three additional hydrocarbon risers (two production and one gas lift) being installed on the FPSO, as discussed in Section 3.3.

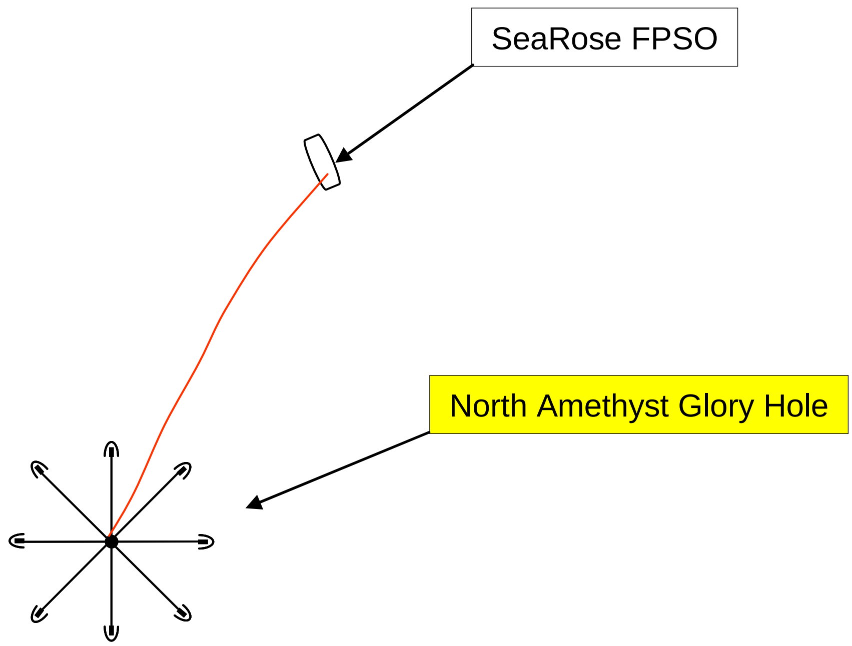

Figure 2-2: North Amethyst Tieback to the SeaRose FPSO

2.3 West White Rose Extension

This area is located approximately 6km North-North-West of the current Central Glory Hole (CGH), as shown in Figure 2-3, in approximately 120m of water. The WWRX development will require a new glory hole to be constructed with facilities for production, gas lift and water injection and the associated flowlines tied back to the existing CGH (per the base case). The project will involve the drilling of twelve new wells (5 production and 7 water injection) at the WWRX area and the installation of subsea facilities. In addition, at the CGH, it will be necessary to carry out some modifications to allow the new wells to be tied back to the existing facilities. A contingency has been made for an additional 2 production and 1 water injection wells, giving a total of 15 wells. As WWRX facilities will be routed to and from the SeaRose FPSO via the CGH (in the base case), there shall be minimal requirement to make modifications to the FPSO and therefore this assessment concentrates primarily on the subsea activities. However, a sensitivity will be considered where the flowlines are tied back directly to the FPSO and therefore the risk levels on the SeaRose have been re-assessed to account for risers (two production and one gas lift) being routed from WWRX to the FPSO, as discussed in Section 3.3.

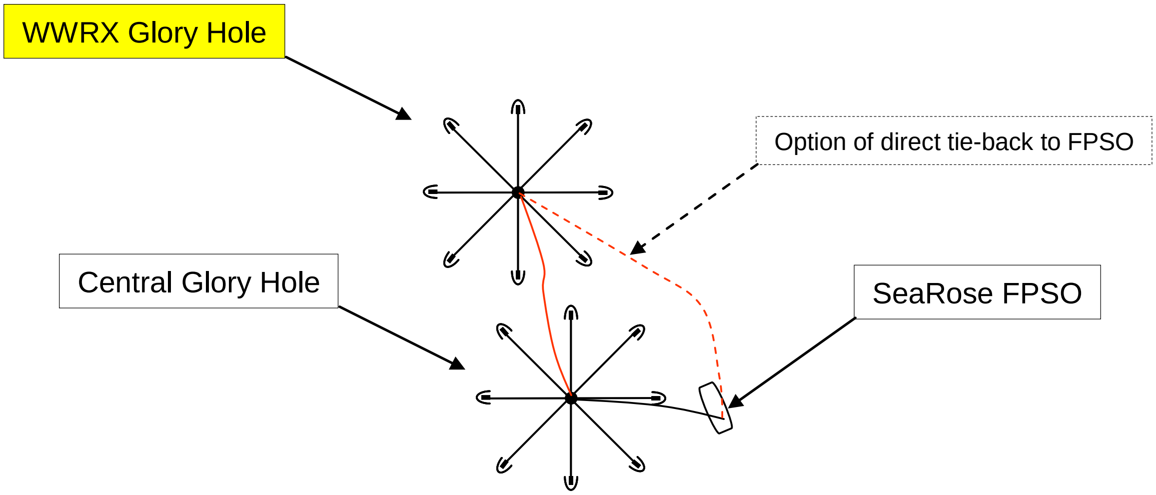

Figure 2-3: WWRX Tieback to the CGH or to SeaRose FPSO

2.3.1 Glory Hole Construction

The glory holes needed to support establishment of the drill centres will each be excavated to a maximum of 9-11m below existing seabed level with a maximum "floor" dimension of 70m by 70m and graded sloped sides as required for stability and the flowline ramps. The greater dimensions of the glory hole result from lessons learned during the original White Rose Development. Specifically:

- Increased depth will allow equipment to be installed on purpose made blocks to decrease exposure of wellheads and associated equipment to irregularities in excavation and sedimentation in the bottom of the glory hole;
- A larger size will facilitate unimpeded movement of ROVs, easier equipment installation, and to allow for possible installation of a universal subsea tree structure currently being assessed; and
- Graded slope ramps will facilitate placement of flow lines and may enhance removal or movement of sediment out of the glory hole through increased current flow.

The proposed glory hole layouts are indicated in Figure 2-4 - Figure 2-6.

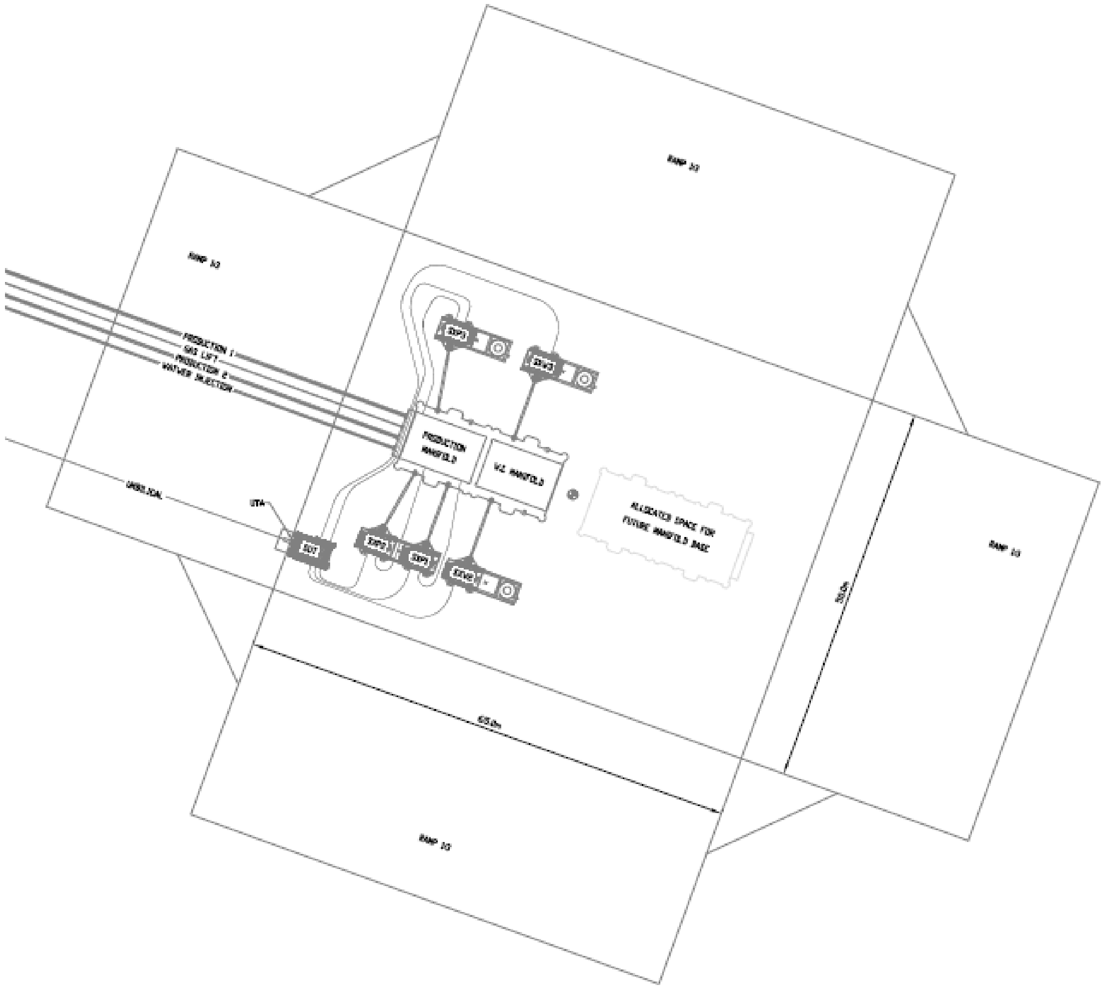

Figure 2-4: Proposed SWRX Glory Hole Layout

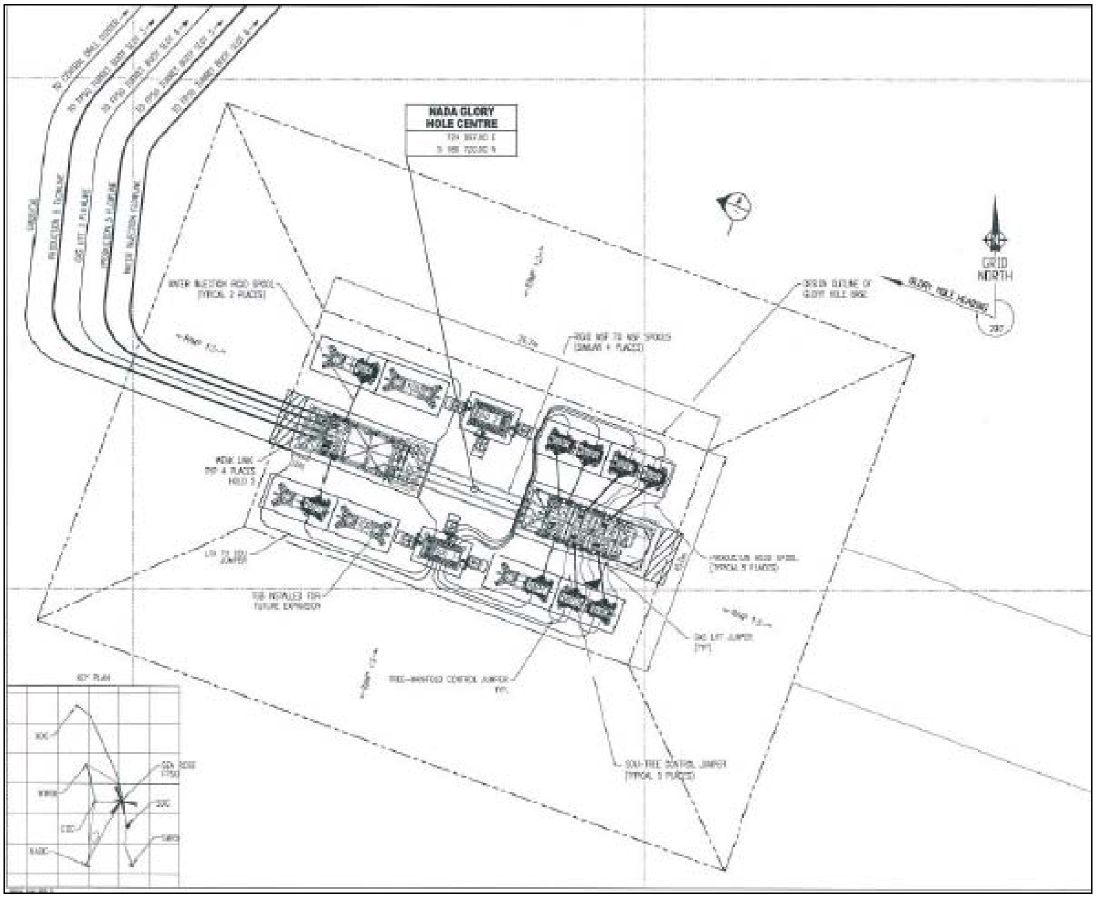

Figure 2-5: Proposed North Amethyst Glory Hole Layout

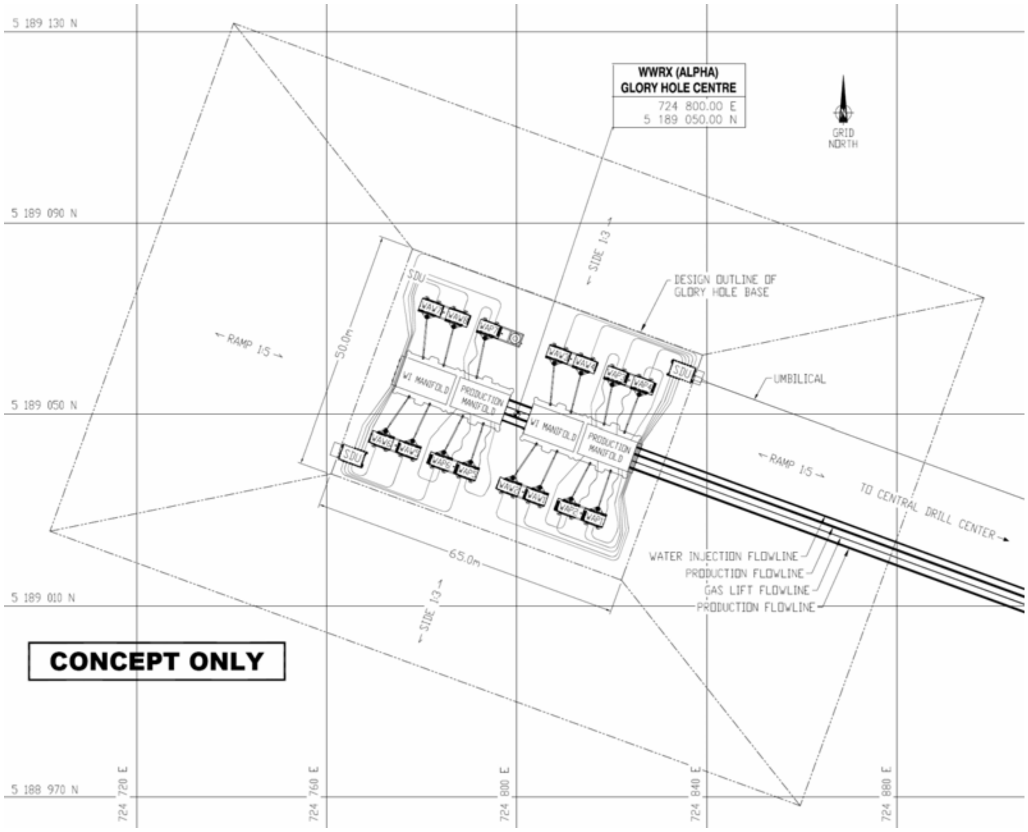

Figure 2-6: Proposed WWRX Glory Hole Layout

2.3.2 Subsea Equipment

The subsea facilities at each of the drill centres will include all equipment necessary for the safe and efficient operation and control of the subsea wells and transportation of production and injection fluids. No changes to existing flowlines, risers or umbilicals are anticipated.

3 REVIEW OF FPSO MODIFICATIONS

3.1 Previous QRA Modifications for Increased Throughput

In November 2006, the SeaRose QRA [1] was revised to consider an increase in the production throughput from 100k bopd to 140k bopd 'dry oil'. This involved changes to a number of process stream flowrates and operating conditions of some equipment.

At this point, the opportunity was taken to make a number of additional changes to the SeaRose risk model;

- a one minute time delay between gas detection and shutdown initiation was incorporated.
- the leak frequency database that is used in the assessment was changed from the E&P Forum [28] to the OIR12 database [8], which is the current industry standard database for hydrocarbon release frequencies.
- The ignition model used was also changed, from Cox, Lees & Ang's [33] methodology to the UKOOA model [31,32] – again this is the current industry standard for the calculation of ignition probabilities.
- Finally, the occupational risk levels were revised in line with data reporting accidents for the 25 year period to 2005.

Overall, compared to the 2005 Safety Plan figures, the TRIF reduced by 9% to 2.91E-04 per annum and the Process Crew IRPA reduced by 32% to 2.49E-04 per annum. The main contributor to the reduction in the IRPA was the change in occupational risks and the reduction in TRIF was predominantly as a result of the change in ignition probability model.

3.2 SeaRose Topsides Modifications for Increased Throughput

Modifications to the SeaRose FPSO are to be made in order to accommodate a throughput of 140k bopd 'wet oil' production will bring about some changes to the FPSO topsides and the process. The impact on risk levels is considered for 3 main changes to the FPSO topsides:

1) Increased diameter of the HP Separator from 4.15m to 4.8m;
2) Installation of additional fuel gas turbine main power generator;
3) Use revised Heat & Mass Balance – new '140k wet oil' case with higher overall flowrates and a higher water cut than the '140k dry oil' case used in the current QRA. Some operating pressures have changed slightly.

There are no major knock-on effects from these modifications which are mainly in place to allow debottlenecking of the process. As a result of the revised heat and mass balance, new flow rates and stream compositions have been used in the QRA model. This has a negligible impact on the overall risk levels. Updated pressures, however, have a small influence on the risk results. The revised pressures in the '140k wet oil' heat & mass balance for gas compression trains are the main contributors to the minor changes in risk levels.

3.2.1 Fire Sizes and Durations

Although there are a number of minor differences between the initial fire sizes and the fire durations for the dry oil and wet oil cases, none of the changes are significant enough to alter the consequences of the fire; there are no events which were previously deemed to be too small or of too short a duration to cause TR impairment (either directly or through escalation to another inventory) that are now considered to be large enough / of long enough duration.

The topsides modifications only affect events P5G, P5L (gas / liquid release from the HP Separator) and P20 (gas release from HP Fuel gas distribution). For a pool fire following a release from the larger HP separator, the duration would increase by approximately 30-34%; this is true for the dry oil case and for the wet oil case. However, the pool fire from the smaller separator lasted over 9 hours for a small release and over 80minutes for the medium and large releases. The consequences of a 13hour / 110minute fire are not considered to be any more severe and therefore the increased fire pool duration has no effect on the QRA results.

The increased separator size also results in longer duration jet-fires if a hydrocarbon release occurs from the gas side of the vessel. As for the pool fires, none of the changes is significant enough to alter the consequences of the jet-fire. J30 PFP will protect the separators against escalation for 40 minutes.

3.2.2 Explosions

The increased gas inventories for in the HP separator and gas turbine inventories could result in an increased gas volume being released, resulting in higher predicted overpressures and greater potential for TR impairment.

The maximum gas concentrations expected after the modifications have been carried out were found to be slightly increased and therefore the fraction of the module filled with a stoichiometric cloud could also increase. However, although with the modifications in place the cloud volumes are slightly higher, the difference is not sufficient to cause the predicted overpressure to be higher. Therefore the probability that an explosion event will result in TR impairment is not affected by the topsides modifications and the QRA results will not be affected.

3.2.3 Ignition Probabilities

Using the UKOOA ignition model, the ignition probability is dependent on the hydrocarbon outflow rates. The topsides modifications do not result in any changes to the operating pressures and therefore the initial outflow rates do not change – therefore the ignition probabilities are unaffected. However, the change from using the H&MB for the dry oil case to the wet oil case has resulted in slightly different ignition probabilities – the overall ignited event frequency has increased from 0.0104 to 0.0105 per annum.

3.2.4 QRA Results

Increasing the size of the HP separator and installing an additional turbine has no effect on the QRA results.

Changing from the dry oil case to the wet oil case has a minimal effect on the risk level. The slight increase in the ignited event frequency carries through the risk model and the risks associated with each event are changed very slightly.

The slightly increased risk results from these topsides changes are used as the basis for the reassessment of FPSO risk in response to the SWRX, NADC and WWRX Projects.

3.3 Tie-Back Modifications

The addition of new drill centres for the Tie-back project may have an effect on the overall risks on the SeaRose FPSO. The SWRX and WWRX drill centres are tied back through existing drill centres and will therefore have minimal effects on the FPSO risk levels. However, the North Amethyst drill centre is to be tied back directly to the FPSO, resulting in three additional risers and flowlines being installed on the SeaRose. The impact of the installation of these risers has been considered within this section. Additionally, Husky wishes to consider the option of having the WWRX drill centre tied back directly to the FPSO in a similar manner to North Amethyst. This section of the report looks at the impact each of the individual tiebacks has on the FPSO risks and also determines the overall risk picture once all three drill centres have been constructed and tied-back.

3.3.1 SWRX

The SWRX project shall result in minimal topsides changes to the SeaRose FPSO. However, the tie-in of the SWRX flowlines to the SDC production manifold may result in additional SWRX flowlines inventory being released at the FPSO if an accidental release occurred from the SDC production flowlines.

The additional 5.1km of SWRX flowline inventory has been included in the SDC flowline inventory that was modelled in the White Rose Fire Risk Analysis [9] and the hydrocarbon release rates, fire sizes and durations re-assessed.

The results are shown in Table 3-1 in terms of jet flame length versus release time. The release from the SDC flowline including the SWRX inventory is modelled as event R1A, the SDC flowline on its own is modelled as R2A. For comparison, a release from the gas injection riser is also shown as event R7A.

Riser ID	Riser Description	Release Size	Jet Fire Length (m) with Time (mins)									
			0mins	0.5	1	2	5	10	15	20	30	60
R1A	Above Sea Releases from 10" Production/Test	10mm	50	50	50	50	50	50	49	49	49	49
	#1 from SDC	50mm	218	215	214	209	208	200	194	187	174	141
	2 PHASE	Full Bore	1232	489	441	358	346	299	259	224	151	71
R2A	Above Sea Releases from 10" Production/Test	10mm	50	50	50	49	49	49	49	49	48	47
	#2 from SDC	50mm	218	215	212	198	193	172	153	136	108	54
	2 PHASE	Full Bore	1232	489	441	266	225	99				
R7A	Above Sea Releases from 5.5" Gas Injection to	10mm	26	26	26	26	26	26	26	26	26	25
	NDC	50mm	95	83	78	69	67	62	59	57	52	40
	GAS	Full Bore	265	88	83	71	69	64	60	57	52	38

Table 3-1: Comparison of Riser Fire Sizes and Durations

It can be seen that the inclusion of the SWRX flowline inventory has resulted in large flames lengths being sustained for longer. The jet flame lengths shown here are based on free field conditions and the flame would actually behave more like a fire ball due to the confinement within the turret. Irrespective of the flame behaviour, all releases from the SDC riser within the turret are of sufficient size and duration to cause structural damage, even without the additional SWRX inventory.

Whilst the consequences of a riser release within the turret are clearly severe, the potential frequency of a fire event occurring in the turret from a riser release is very low, approximately once every 50,000 years per riser.

3.3.2 WWRX

3.3.2.1 Option 1 – Tieback via CDC

As for the SWRX project, the flowlines from the WWRX pool are tied back to the FPSO via an existing drill centre, in this case the Central Drill Centre (CDC), and therefore has a minimal impact on the activities on the SeaRose FPSO.

However, since there is no isolation provided on the flowline from the WWRX to the CDC an additional 5.8km of riser inventory can be included in the White Rose Fire Risk Analysis [9]. The hydrocarbon release rates, fire sizes and durations must be re-assessed as a result of this and incorporated into the QRA.

The results are shown in Table 3-2 in terms of jet flame length versus release time. The release from the CDC flowline including the WWRX inventory is modelled as event R4A, the CDC flowline on its own is modelled as R3A. For comparison, a release from the gas injection riser is also shown as event R7A.

Riser ID	Riser Description	Release Size	**Jet Fire Length (m) with Time (mins)**									
			0mins	0.5	1	2	5	10	15	20	30	60
R3A	Above Sea Releases from Production/Test #3	10mm	50	50	50	49	49	49	49	49	48	47
	from CDC	50mm	218	215	212	198	193	172	153	136	108	54
	2 PHASE	Full Bore	1232	489	441	266	225	99				
R4A	Above Sea Releases from Production/Test #4	10mm	50	50	50	50	50	50	49	49	49	49
	from CDC	50mm	218	215	214	209	208	201	195	189	177	146
	2 PHASE	Full Bore	1232	489	441	358	346	304	268	236	183	88
R7A		10mm	26	26	26	26	26	26	26	26	26	25
	Above Sea Releases from Gas Injection to NDC	50mm	95	83	78	69	67	62	59	57	52	40
	GAS	Full Bore	265	88	83	71	69	64	60	57	52	38

Table 3-2: Comparison of Riser Fire Sizes and Durations

As for SWRX, it can be seen that the inclusion of the WWRX flowline inventory has resulted in large flames lengths being sustained for longer. The jet flame lengths shown here are based on free field conditions and the flame would actually behave more like a fire ball due to the confinement within the turret. Irrespective of the flame behaviour, all releases from the CDC riser within the turret are of sufficient size and duration to cause structural damage, even without the additional WWRX inventory.

Again, although the consequences of a riser release within the turret are clearly severe, the potential frequency of a fire event occurring in the turret from a riser release is very small.

3.3.2.2 Option 2 – Tieback Directly to FPSO

Husky is considering the option of tying the WWRX pool back directly to the SeaRose FPSO and therefore it is necessary to examine the risk to the FPSO presented by the installation of additional risers in the turret.

The tie-back of the WWRX pool will involve the installation of two 9” production risers and one 4.25” gas lift riser. The production risers will have associated flowlines running through the turret, connecting the risers to the production manifold in module M01. The gas lift manifold is located in the lower turret and therefore no additional flowline is required other than a new branch from the existing manifold.

There are a fixed number of potential riser connections to the FPSO. Because the tie-in of the NADC risers will use up all of the available spare slots, the direct connection of WWRX risers would require that a number of existing risers and flowlines are re-routed in-field. Therefore the total number of flowlines entering the FPSO will not be greater than for the base case. The leak frequency from each of the new risers and flowlines is assumed to be as per the corresponding existing risers from the South and Central White Rose Drill centres and therefore there is no change to the overall release frequency.

The operating arrival conditions for the direct WWRX flowlines would be different than for the combined WWRX & CDC arrival conditions. The new risers containing production fluids from CDC and WWRX have an arrival pressure of 29 bar and temperature of 65^{o}C, whereas the CDC flowlines have been modelled at an arrival pressure of 125bar and temperature of 80^{o}C.

The WWRX flowlines are 10” in diameter and 5.5km in length; the CDC flowlines are also 10” but only 2.1km long. The gas lift riser is 4.25” in diameter and 5.5km in length (again only 2.1 km at CDC); the departure pressure is 261bar and temperature is 70^{o}C, these conditions are the same as for the CDC gas lift flowline. Note that these operating conditions are preliminary estimates and may be subject to change as the project progresses.

The ignition probabilities for releases from the WWRX production risers and flowlines will be lower than for the equivalent CDC releases as a result of the lower arrival pressure.

Table 3-3 shows the fire sizes and durations for the existing CDC risers and for the new risers from WWRX.

Riser ID	Riser Description	Release Size	Jet Fire Length (m) with Time (mins)									
			0mins	0.5	1	2	5	10	15	20	30	60
R3A	Above Sea Releases from Production/Test #3	10mm	50	50	50	49	49	49	49	49	48	47
	from CDC	50mm	218	215	212	198	193	172	153	136	108	54
	2 PHASE	Full Bore	1232	489	441	266	225	99				
R4A	Above Sea Releases from Production/Test #4	10mm	50	50	50	49	49	49	49	49	48	47
	from CDC	50mm	218	215	212	198	193	172	153	136	108	54
	2 PHASE	Full Bore	1232	489	441	266	225	99				
R6A		10mm	22	22	22	21	21	19	18	17	15	10
	Above Sea Releases from Gas Lift #2 CDC	50mm	80	60	54	27	21	6				
	GAS	Full Bore	181	55	47	19	13					
R12A	Above Sea Release from WWRX Production	10mm	27	27	27	27	27	27	27	27	27	27
	Riser 1	50mm	98	97	96	94	93	90	86	83	77	61
	2 PHASE	Full Bore	442	193	178	150	128	123	102	84	57	
R13A	Above Sea Release from WWRX Production	10mm	27	27	27	27	27	27	27	27	27	27
	Riser 2	50mm	98	97	96	94	93	90	86	83	77	61
	2 PHASE	Full Bore	442	193	178	150	128	123	102	84	57	
R14A		10mm	22	22	22	21	21	20	20	19	18	15
	Above Sea Release from WWRX Gas Lift Riser	50mm	79	59	55	44	41	29	21	15	8	
	GAS	Full Bore	178	56	53	42	39	27	19	13		

Table 3-3: Jet-Fire Length and Durations from WWRX Risers

It can be seen that the initial jet-fire sizes are smaller for the WWRX risers due to the lower operating pressures. The longer flowlines, however, result in longer fire durations, in particular for the gas lift riser.

The consequences of a release from the new production risers or flowlines are assumed to be the same as for the existing risers as discussed in the current QRA report, as although the fires may last longer, the consequences are not judged to be any more severe [1]. Similarly for the gas lift risers, although medium and large releases could now last up to 30 or 20 minutes respectively, the J30 PFP is judged to be sufficient to prevent inter-riser escalation.

Section 3.4 gives details of how the addition of these new risers impacts upon the overall risk levels on the SeaRose FPSO.

3.3.3 North Amethyst

The North Amethyst field is to be tied back directly to the SeaRose FPSO and therefore it is necessary to examine the risk to the FPSO presented by the installation of additional risers in the turret.

The tie-back of the NA field will involve the installation of two 9” production risers and one 4.25” gas lift riser. The production risers will have associated flowlines running through the turret, connecting the risers to the production manifold in module M01. The gas lift manifold is located in the lower turret and therefore no additional flowline is required other than a new branch from the existing manifold.

The production risers have been given the IDs R9A/B and R10A/B and the gas lift riser is R11A/B; the two production flowlines are identical and have been combined as event P32. The existing gas lift manifold event is P18; the leak frequency for this event has been modified to account for the additional riser branch from the manifold (note that only P18LT has been modified as there is no change to the existing equipment in the upper turret or in module M01).

The leak frequency from each of the new risers and flowlines is assumed to be as per the corresponding existing risers from the South and Central White Rose Drill centres. The leak frequency for the gas lift manifold event is increased by a third. Table 3-4 shows the leak frequencies for the new / affected events for the direct tie-back of North Amethyst to the SeaRose FPSO.

			Leak Frequency (/yr)			
Event ID	Location	Description	Small	Medium	Large	Total
P18LT	Lower Turret	Gas release from gas lift header and pipework	1.32E-02	9.52E-04	6.95E-04	1.48E-02
R9A	Lower Turret	Above Sea Release from North Amethyst Production Riser 1	4.04E-04	4.13E-05	7.45E-05	5.20E-04
R9B	Below Sea	Below Sea Release from North Amethyst Production Riser 1	3.66E-03	5.77E-04	1.16E-03	5.39E-03
R10A	Lower Turret	Above Sea Release from North Amethyst Production Riser 2	4.04E-04	4.13E-05	7.45E-05	5.20E-04
R10B	Below Sea	Below Sea Release from North Amethyst Production Riser 2	3.66E-03	5.77E-04	1.16E-03	5.39E-03
R11A	Lower Turret	Above Sea Release from North Amethyst Gas Lift Riser	4.04E-04	4.13E-05	7.45E-05	5.20E-04
R11B	Below Sea	Below Sea Release from North Amethyst Gas Lift Riser	3.66E-03	5.77E-04	1.16E-03	5.39E-03
P32LT	Lower Turret	Two phase release from North Amethyst Production Flowlines 1/2	1.38E-02	8.08E-04	1.01E-03	1.56E-02
P32UT	Upper Turret	Two phase release from North Amethyst Production Flowlines 1/2	5.44E-03	5.30E-04	3.02E-04	6.28E-03
P32M	M01 PD	Two phase release from North Amethyst Production Flowlines 1/2	2.02E-02	1.01E-03	1.30E-03	2.25E-02
		Overall Total	1.04E+00	6.52E-02	6.60E-02	1.17E+00
		Current FPSO Total	9.77E-01	6.06E-02	5.92E-02	1.10E+00

Table 3-4: Leak Frequency for North Amethyst Events on SeaRose FPSO

The overall leak frequency on the SeaRose FPSO has increased from 1.10 per annum to 1.17 per annum (+6.4%) as a result of the additional risers and flowlines.

The production risers have an arrival pressure of 29 bar and temperature of 50^{o}C; they are 10” in diameter and 6.5km in length. The gas lift riser is 4.25” in diameter and 6.5km in length; the departure pressure is 261bar and temperature is 70^{o}C.

Table 3-5 shows the fire sizes and durations for the new risers from North Amethyst.

Riser ID	Riser Description	Release Size	**Jet Fire Length (m) with Time (mins)**									
			0mins	0.5	1	2	5	10	15	20	30	60
R9A	Above Sea Release from North Amethyst	10mm	48	48	48	48	48	48	48	48	48	47
	Production Riser 1	50mm	174	172	171	168	167	163	158	154	145	123
	2 PHASE	Full Bore	785	342	315	266	258	231	206	184	147	76
R10A	Above Sea Release from North Amethyst	10mm	48	48	48	48	48	48	48	48	48	47
	Production Riser 2	50mm	174	172	171	168	167	163	158	154	145	123
	2 PHASE	Full Bore	785	342	315	266	258	231	206	184	147	76
R11A	Above Sea Release from North Amethyst Gas	10mm	26	26	26	26	26	25	25	24	23	21
	Lift Riser	50mm	95	72	66	56	54	44	36	30	20	6
	GAS	Full Bore	215	69	65	55	53	42	34	27	18	

Table 3-5: Jet-Fire Length and Durations from North Amethyst Risers

The consequences of a release from the new risers or flowlines are assumed to be the same as for the existing risers, as discussed in the current QRA report [2]. For the gas lift risers, although medium and large releases could now last up to 30 minutes, the J30 PFP is judged to be sufficient to prevent inter-riser escalation.

Section 3.4 gives details of how the addition of these new risers impacts upon the overall risk levels on the SeaRose FPSO.

3.4 Overall Risk Levels

Tie-back of the SWRX has no impact on the SeaRose risk levels, nor does the tieback of WWRX via the CDC. The topsides modifications and increased throughput have a minimal impact on the risk levels. Table 3-6 below shows the risk levels on the SeaRose FPSO for a number of cases:

1) Original risk levels before tieback projects and topsides modifications (as reported in latest QRA – 140k bopd dry oil case);
2) With increased throughput to 140k bopd wet oil, with topsides modifications and with SWRX and WWRX (via CDC) tied-back;
3) As case 2 with North Amethyst tied back directly to FPSO;
4) As case 2 with WWRX tied back directly to FPSO;
5) As case 2 with WWRX and North Amethyst tied back directly to FPSO.

Table 3-6 also shows Husky's Target Levels of Safety against which each of the reported risk parameters can be compared.

Risk Parameter	Target Level of Safety	Case				
		1	2	3	4	5
Leak Frequency	N/A	1.10	1.10	1.17	1.10	1.17
Ignited Event Frequency	N/A	0.0104	0.0105	0.011	0.0098	0.0103
TRIF (Hydrocarbon only)	1.00E-03	1.79E-04	1.80E-04	1.83E-04	1.75E-04	1.78E-04
TRIF (All Hazards)	1.00E-03	2.91E-04	2.92E-04	2.95E-04	2.87E-04	2.90E-04
PLL	N/A	4.01E-02	4.01E-04	4.08E-02	3.91E-02	3.98E-02
IRPA (max)	1.00E-03	2.49E-04	2.49E-04	2.55E-04	2.41E-04	2.47E-04
Frequency of >10 fatalities	1.95E-03	1.60E-04	1.60E-04	1.62E-04	1.48E-04	1.50E-04
Frequency of >50 fatalities	3.90E-04	1.38E-04	1.39E-04	1.41E-04	1.36E-04	1.38E-04
Frequency of Loss of Integrity of Primary Structures	1.00E-03	2.22E-04	2.22E-04	2.24E-04	2.17E-04	2.19E-04
Frequency of Impairment of Escape Routes	1.00E-03	1.76E-04	1.76E-04	1.76E-04	1.67E-04	1.67E-04
Frequency of Impairment of Evacuation Systems	1.00E-03	1.79E-04	1.80E-04	1.82E-04	1.78E-04	1.80E-04

Table 3-6: Overall Risk Results for SeaRose FPSO (per annum)

The ignited event frequency is lower for case 4 than for case 2 because the high pressure CGH flowlines and risers have been replaces with the lower pressure WWRX flowlines and risers.

It can be seen that, for all cases, the risk levels remain well below the Target Levels of Safety.

A summary of the contributions to each of these risk levels is given in Figure 3-1 to Figure 3-4 below for case 1 (the current QRA [1] before any extensions), case 3 (SeaRose with North Amethyst) and case 5 (SeaRose with North Amethyst and WWRX).

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TR Impairment Frequency within 2 hr	**-**	**1.79E-04**	**Highest IRPA Total**	**-**	**2.49E-04**	**Process Crew**
TR Impairment Frequency	**-**	**2.54E-04**	**Hydrocarbon IRPA**	**-**	**1.02E-04**	
TR&EER Impairment Frequency	**-**	**6.77E-05**	**Non Hydrocarbon IRPA**	**-**	**1.48E-04**	
Hydrocarbon PLL	**-**	**1.44E-02**	**Freq. HC Release**	**-**	**1.10**	
Non Hydrocarbon PLL	**-**	**2.57E-02**	**Freq. Ignited Events**	**-**	**0.0104**	
Total PLL	**-**	**4.01E-02**				

		TR Impairment Freq. (TRIF) within 2 hr		Total TR Impairment Frequency (TRIF)		Potential Loss Of Life (PLL)		Process		Marine / Deck		Maintenance		Catering/Admin	
		TRIF (/Annum)	%	TRIF (/Annum)	%	PLL (Fats /a)	%	IRPA	%	IRPA	%	IRPA	%	IRPA	%
TR Impairment Mechanisms :															
	External Explosion	2.323E-07	0.1%	2.32E-07	0.1%										
	HVAC Failure	9.543E-06	5.3%	9.54E-06	3.8%										
	Process Collapse - Explosion	5.632E-05	31.4%	5.63E-05	22.2%										
	Process Collapse - Fire			1.62E-06	0.6%										
	Pump Room Explosion	3.923E-05	21.9%	3.92E-05	15.4%										
	Sea Fire - Structural	7.787E-07	0.4%	7.79E-07	0.3%										
	Ship Deck - Explosions	1.027E-05	5.7%	1.03E-05	4.0%										
	Smoke	1.187E-05	6.6%	1.19E-05	4.7%										
	Structural - CT Fires	4.767E-05	26.6%	4.77E-05	18.8%										
	Structural Collapse - Turret Explosion	2.017E-06	1.1%	2.02E-06	0.8%										
	Structural Collapse - Turret Fire	1.539E-06	0.9%	7.46E-05	29.3%										
Calculated PLL :															
Hydrocarbon	Immediate					7.45E-03	18.6%	6.17E-05	24.8%	2.56E-05	12.0%	3.76E-05	16.8%		
	Muster					9.00E-04	2.2%	6.08E-06	2.4%	5.88E-06	2.8%	5.22E-06	2.3%		
	TR Fatalities					5.43E-03	13.5%	3.01E-05	12.1%	3.03E-05	14.2%	3.00E-05	13.4%	3.05E-05	30.2%
	Evacuation Fatalities					6.64E-04	1.7%	3.67E-06	1.5%	3.69E-06	1.7%	3.69E-06	1.6%	3.73E-06	3.7%
Non Hydrocarbon	Transport					6.40E-03	15.9%	3.17E-05	12.7%	3.17E-05	14.9%	3.17E-05	14.1%	3.17E-05	31.4%
	Occupational					1.69E-02	42.1%	1.03E-04	41.3%	1.03E-04	48.3%	1.03E-04	45.9%	2.19E-05	21.7%
	Ship Collision					1.56E-03	3.9%	8.68E-06	3.5%	8.68E-06	4.1%	8.68E-06	3.9%	8.68E-06	8.6%
	Structural					8.10E-04	2.0%	4.50E-06	1.8%	4.50E-06	2.1%	4.50E-06	2.0%	4.50E-06	4.5%
	Seismic Loading														
	Iceberg Collision					2.15E-06	0.005%	1.19E-08	0.0%	1.19E-08	0.0%	1.19E-08	0.0%	1.19E-08	0.0%
Hydrocarbon Total						1.44E-02	36.0%	1.02E-04	40.7%	6.55E-05	30.7%	7.66E-05	34.1%	3.42E-05	33.9%
Non Hydrocarbon Total						2.57E-02	64.0%	1.48E-04	59.3%	1.48E-04	69.3%	1.48E-04	65.9%	6.68E-05	66.1%
Totals		1.79E-04	100.0%	2.54E-04	100.0%	4.01E-02	100.0%	2.49E-04	100.0%	2.13E-04	100.0%	2.24E-04	100.0%	1.01E-04	100.0%

Figure 3-1: Overall Risk Summary for SeaRose FPSO, 140k bopd Case, Current QRA (Case 1)

RESULTS SUMMARY SHEET

TR Impairment Frequency within 2 hr	**-**	**1.83E-04**	**Highest IRPA Total**	**-**	**2.55E-04**	**Process Crew**
TR Impairment Frequency	**-**	**2.62E-04**	**Hydrocarbon IRPA**	**-**	**1.07E-04**	
TR&EER Impairment Frequency	**-**	**7.04E-05**	**Non Hydrocarbon IRPA**	**-**	**1.48E-04**	
Hydrocarbon PLL	**-**	**1.51E-02**	**Freq. HC Release**	**-**	**1.167**	
Non Hydrocarbon PLL	**-**	**2.57E-02**	**Freq. Ignited Events**	**-**	**0.0111**	
Total PLL	**-**	**4.08E-02**				

		TR Impairment Freq. (TRIF) within 2 hr		Total TR Impairment Frequency (TRIF)		Potential Loss Of Life (PLL)		Process		Marine / Deck		Maintenance		Catering/Admin	
		TRIF (/Annum)	%	TRIF (/Annum)	%	PLL (Fats /a)	%	IRPA	%	IRPA	%	IRPA	%	IRPA	%
TR Impairment Mechanisms :															
	External Explosion	2.525E-07	0.1%	2.53E-07	0.1%										
	HVAC Failure	1.051E-05	5.7%	1.05E-05	4.0%										
	Process Collapse - Explosion	5.751E-05	31.4%	5.75E-05	22.0%										
	Process Collapse - Fire			1.62E-06	0.6%										
	Pump Room Explosion	3.923E-05	21.4%	3.92E-05	15.0%										
	Sea Fire - Structural	1.215E-06	0.7%	1.22E-06	0.5%										
	Ship Deck - Explosions	1.132E-05	6.2%	1.13E-05	4.3%										
	Smoke	1.198E-05	6.5%	1.20E-05	4.6%										
	Structural - CT Fires	4.767E-05	26.0%	4.77E-05	18.2%										
	Structural Collapse - Turret Explosion	2.141E-06	1.2%	2.14E-06	0.8%										
	Structural Collapse - Turret Fire	1.606E-06	0.9%	7.85E-05	30.0%										
Calculated PLL :															
Hydrocarbon	Immediate					7.89E-03	19.3%	6.62E-05	25.9%	2.58E-05	12.0%	3.94E-05	17.3%		
	Muster					9.03E-04	2.2%	6.10E-06	2.4%	5.90E-06	2.7%	5.24E-06	2.3%		
	TR Fatalities					5.64E-03	13.8%	3.13E-05	12.3%	3.15E-05	14.7%	3.13E-05	13.7%	3.17E-05	31.0%
	Evacuation Fatalities					6.82E-04	1.7%	3.77E-06	1.5%	3.80E-06	1.8%	3.79E-06	1.7%	3.83E-06	3.7%
Non Hydrocarbon	Transport					6.40E-03	15.7%	3.17E-05	12.4%	3.17E-05	14.7%	3.17E-05	13.9%	3.17E-05	31.0%
	Occupational					1.69E-02	41.4%	1.03E-04	40.3%	1.03E-04	47.9%	1.03E-04	45.2%	2.19E-05	21.4%
	Ship Collision					1.56E-03	3.8%	8.68E-06	3.4%	8.68E-06	4.0%	8.68E-06	3.8%	8.68E-06	8.5%
	Structural					8.10E-04	2.0%	4.50E-06	1.8%	4.50E-06	2.1%	4.50E-06	2.0%	4.50E-06	4.4%
	Seismic Loading														
	Iceberg Collision					2.15E-06	0.005%	1.19E-08	0.0%	1.19E-08	0.0%	1.19E-08	0.0%	1.19E-08	0.0%
Hydrocarbon Total						1.51E-02	37.1%	1.07E-04	42.1%	6.70E-05	31.2%	7.97E-05	35.0%	3.55E-05	34.7%
Non Hydrocarbon Total						2.57E-02	62.9%	1.48E-04	57.9%	1.48E-04	68.8%	1.48E-04	65.0%	6.68E-05	65.3%
Totals		1.83E-04	100.0%	2.62E-04	100.0%	4.08E-02	100.0%	2.55E-04	100.0%	2.15E-04	100.0%	2.27E-04	100.0%	1.02E-04	100.0%

Figure 3-2: Overall Risk Summary for SeaRose FPSO with North Amethyst Extension (Case 3)

RESULTS SUMMARY SHEET

TR Impairment Frequency within 2 hr	**-**	**1.75E-04**	**Highest IRPA Total**	**-**	**2.41E-04 Process Crew**
TR Impairment Frequency	**-**	**2.22E-04**	**Hydrocarbon IRPA**	**-**	**9.35E-05**
TR&EER Impairment Frequency	**-**	**6.67E-05**	**Non Hydrocarbon IRPA**	**-**	**1.48E-04**
Hydrocarbon PLL	**-**	**1.34E-02**	**Freq. HC Release**	**-**	**1.105**
Non Hydrocarbon PLL	**-**	**2.57E-02**	**Freq. Ignited Events**	**-**	**0.0098**
Total PLL	**-**	**3.91E-02**			

		TR Impairment Freq. (TRIF) within 2 hr		Total TR Impairment Frequency (TRIF)		Potential Loss Of Life (PLL)		Process		Marine / Deck		Maintenance		Catering/Admin	
		TRIF (/Annum)	%	TRIF (/Annum)	%	PLL (Fats /a)	%	IRPA	%	IRPA	%	IRPA	%	IRPA	%
TR Impairment Mechanisms :															
	External Explosion	2.226E-07	0.1%	2.23E-07	0.1%										
	HVAC Failure	9.616E-06	5.5%	9.62E-06	4.3%										
	Process Collapse - Explosion	5.351E-05	30.6%	5.35E-05	24.1%										
	Process Collapse - Fire			1.61E-06	0.7%										
	Pump Room Explosion	3.923E-05	22.4%	3.92E-05	17.6%										
	Sea Fire - Structural	7.137E-07	0.4%	7.14E-07	0.3%										
	Ship Deck - Explosions	9.952E-06	5.7%	9.95E-06	4.5%										
	Smoke	1.151E-05	6.6%	1.15E-05	5.2%										
	Structural - CT Fires	4.767E-05	27.2%	4.77E-05	21.4%										
	Structural Collapse - Turret Explosion	1.586E-06	0.9%	1.59E-06	0.7%										
	Structural Collapse - Turret Fire	9.899E-07	0.6%	4.68E-05	21.0%										
Calculated PLL :															
Hydrocarbon	Immediate					6.78E-03	17.3%	5.56E-05	23.0%	2.44E-05	11.6%	3.45E-05	15.7%		
	Muster					7.69E-04	2.0%	5.19E-06	2.2%	5.02E-06	2.4%	4.46E-06	2.0%		
	TR Fatalities					5.35E-03	13.7%	2.97E-05	12.3%	2.98E-05	14.2%	2.96E-05	13.5%	3.00E-05	30.0%
	Evacuation Fatalities					5.54E-04	1.4%	3.06E-06	1.3%	3.08E-06	1.5%	3.08E-06	1.4%	3.11E-06	3.1%
Non Hydrocarbon	Transport					6.40E-03	16.3%	3.17E-05	13.1%	3.17E-05	15.1%	3.17E-05	14.4%	3.17E-05	31.7%
	Occupational					1.69E-02	43.2%	1.03E-04	42.7%	1.03E-04	49.0%	1.03E-04	46.9%	2.19E-05	21.9%
	Ship Collision					1.56E-03	4.0%	8.68E-06	3.6%	8.68E-06	4.1%	8.68E-06	4.0%	8.68E-06	8.7%
	Structural					8.10E-04	2.1%	4.50E-06	1.9%	4.50E-06	2.1%	4.50E-06	2.1%	4.50E-06	4.5%
	Seismic Loading														
	Iceberg Collision					2.15E-06	0.005%	1.19E-08	0.0%	1.19E-08	0.0%	1.19E-08	0.0%	1.19E-08	0.0%
Hydrocarbon Total						1.34E-02	34.4%	9.35E-05	38.8%	6.23E-05	29.7%	7.16E-05	32.6%	3.31E-05	33.2%
Non Hydrocarbon Total						2.57E-02	65.6%	1.48E-04	61.2%	1.48E-04	70.3%	1.48E-04	67.4%	6.68E-05	66.8%
Totals		1.75E-04	100.0%	2.22E-04	100.0%	3.91E-02	100.0%	2.41E-04	100.0%	2.10E-04	100.0%	2.19E-04	100.0%	9.99E-05	100.0%

Figure 3-3: Overall Risk Summary for SeaRose FPSO with WWRX Extension (Case 4)

RESULTS SUMMARY SHEET

TR Impairment Frequency within 2 hr	**-**	**1.78E-04**	**Highest IRPA Total**	**-**	**2.47E-04 Process Crew**
TR Impairment Frequency	**-**	**2.30E-04**	**Hydrocarbon IRPA**	**-**	**9.88E-05**
TR&EER Impairment Frequency	**-**	**6.85E-05**	**Non Hydrocarbon IRPA**	**-**	**1.48E-04**
Hydrocarbon PLL	**-**	**1.41E-02**	**Freq. HC Release**	**-**	**1.167**
Non Hydrocarbon PLL	**-**	**2.57E-02**	**Freq. Ignited Events**	**-**	**0.0103**
Total PLL	**-**	**3.98E-02**			

		TR Impairment Freq. (TRIF) within 2 hr		Total TR Impairment Frequency (TRIF)		Potential Loss Of Life (PLL)		Process		Marine / Deck		Maintenance		Catering/Admin	
		TRIF (/Annum)	%	TRIF (/Annum)	%	PLL (Fats /a)	%	IRPA	%	IRPA	%	IRPA	%	IRPA	%
TR Impairment Mechanisms :															
	External Explosion	2.265E-07	0.1%	2.26E-07	0.1%										
	HVAC Failure	1.058E-05	5.9%	1.06E-05	4.6%										
	Process Collapse - Explosion	5.461E-05	30.7%	5.46E-05	23.8%										
	Process Collapse - Fire			1.61E-06	0.7%										
	Pump Room Explosion	3.923E-05	22.0%	3.92E-05	17.1%										
	Sea Fire - Structural	1.150E-06	0.6%	1.15E-06	0.5%										
	Ship Deck - Explosions	1.024E-05	5.8%	1.02E-05	4.5%										
	Smoke	1.155E-05	6.5%	1.16E-05	5.0%										
	Structural - CT Fires	4.767E-05	26.8%	4.77E-05	20.7%										
	Structural Collapse - Turret Explosion	1.608E-06	0.9%	1.61E-06	0.7%										
	Structural Collapse - Turret Fire	1.067E-06	0.6%	5.13E-05	22.3%										
Calculated PLL :															
Hydrocarbon	Immediate					7.25E-03	18.2%	6.00E-05	24.3%	2.50E-05	11.8%	3.66E-05	16.4%		
	Muster					7.69E-04	1.9%	5.19E-06	2.1%	5.02E-06	2.4%	4.46E-06	2.0%		
	TR Fatalities					5.49E-03	13.8%	3.05E-05	12.4%	3.06E-05	14.5%	3.04E-05	13.7%	3.08E-05	30.6%
	Evacuation Fatalities					5.74E-04	1.4%	3.17E-06	1.3%	3.19E-06	1.5%	3.19E-06	1.4%	3.23E-06	3.2%
Non Hydrocarbon	Transport					6.40E-03	16.1%	3.17E-05	12.8%	3.17E-05	15.0%	3.17E-05	14.2%	3.17E-05	31.4%
	Occupational					1.69E-02	42.5%	1.03E-04	41.7%	1.03E-04	48.6%	1.03E-04	46.3%	2.19E-05	21.7%
	Ship Collision					1.56E-03	3.9%	8.68E-06	3.5%	8.68E-06	4.1%	8.68E-06	3.9%	8.68E-06	8.6%
	Structural					8.10E-04	2.0%	4.50E-06	1.8%	4.50E-06	2.1%	4.50E-06	2.0%	4.50E-06	4.5%
	Seismic Loading														
	Iceberg Collision					2.15E-06	0.005%	1.19E-08	0.0%	1.19E-08	0.0%	1.19E-08	0.0%	1.19E-08	0.0%
Hydrocarbon Total						1.41E-02	35.4%	9.88E-05	40.1%	6.38E-05	30.2%	7.46E-05	33.6%	3.40E-05	33.8%
Non Hydrocarbon Total						2.57E-02	64.6%	1.48E-04	59.9%	1.48E-04	69.8%	1.48E-04	66.4%	6.68E-05	66.2%
Totals		1.78E-04	100.0%	2.30E-04	100.0%	3.98E-02	100.0%	2.47E-04	100.0%	2.12E-04	100.0%	2.22E-04	100.0%	1.01E-04	100.0%

Figure 3-4: Overall Risk Summary for SeaRose FPSO with North Amethyst AND WWRX Extensions (Case 5)

3.5 SSIV Assessment

The Base Case design does not include a Sub-Sea Isolation Valve (SSIV) installed on any of flowlines from the three new drill centres. This would mean that an unisolated release from the riser at the FPSO would be fed by the entire inventory contained in the riser and the flowline to the respective drill centre. If an SSIV was installed near the base of the riser, the inventory available to feed a release would be significantly reduced and therefore the duration of a fire resulting from an ignited release would be shorter. Reduced fire durations may result in lower risks to personnel on the SeaRose and to the FPSO itself. A cost benefit analysis can be performed to determine whether the cost of installing SSIVs would be grossly disproportionate to the benefit gained through the reduction in risk.

It is noteworthy that the existing CDC, SDC, and NDC flowlines are not equipped with SSIVs, based on a similar assessment carried out for the White Rose Project [11]. The ESDVs at the tops of the risers in the lower turret have been equipped with fire and blast rated protection covers.

3.5.1 Fire Sizes and Durations

Table 3-7 shows, for releases from the North Amethyst production risers, how the fire size decays with time; firstly for the case where there is no SSIV and the entire inventory of the 6.5km flowline is available to feed the release and secondly where an SSIV is installed 70m from the base of the riser, giving a total flowline length of 250m (including the riser).

Riser ID	Riser Description	Release Size	**Jet Fire Length (m) with Time (mins)**									
			0mins	0.5	1	2	5	10	15	20	30	60
			WITH NO SSIV									
R9A	Above Sea Release from North Amethyst	10mm	27	27	27	27	27	27	27	27	27	27
	Production Riser 1	50mm	99	98	97	95	95	92	89	86	81	66
	2 PHASE	Full Bore	446	195	180	152	129	129	114	99	74	0
R10A	Above Sea Release from North Amethyst	10mm	27	27	27	27	27	27	27	27	27	27
	Production Riser 2	50mm	99	98	97	95	95	92	89	86	81	66
	2 PHASE	Full Bore	446	195	180	152	129	129	114	99	74	0
R11A	Above Sea Release from North Amethyst	10mm	22	22	22	22	22	21	21	20	19	17
	Gas Lift Riser	50mm	80	60	56	46	44	34	27	21	12	0
	GAS	Full Bore	181	58	54	45	43	32	22	18	10	0
			WITH SSIV INSTALLED									
R9A	Above Sea Release from North Amethyst	10mm	27	27	27	27	26	25	25	24	22	
	Production Riser 1	50mm	99	91	83	48	40					
	2 PHASE	Full Bore	446									
R10A	Above Sea Release from North Amethyst	10mm	27	27	27	27	26	25	25	24	22	
	Production Riser 2	50mm	99	91	83	48	40					
	2 PHASE	Full Bore	446									
R11A	Above Sea Release from North Amethyst	10mm	22	21	20	14	12	6	3			
	Gas Lift Riser	50mm	80	16								
	GAS	Full Bore	181									

Table 3-7: North Amethyst Riser Fire Durations – With and Without SSIV

It can be seen that the fire duration for each riser is significantly shorter with an SSIV in place. The reduced release rates mean that the fire sizes and durations are smaller and therefore the potential for escalation and TR impairment is reduced.

3.5.2 Risk Levels

The installation of an SSIV will not reduce the level of immediate fatalities, nor does it significantly reduce the explosion potential as the high operating pressure in the riser and valve closure time mean that a large gas cloud could still build up, regardless of the presence of an SSIV. All delayed risks (i.e. muster, TR and evacuation fatalities, but not immediate fatalities) associated with the North Amethyst risers have therefore been removed from the risk model in order to evaluate the maximum benefit of installing the SSIVs.

Table 3-8 shows the overall risk levels on the SeaRose FPSO with and without SSIVs on each of the North Amethyst risers.

	No SSIV	With SSIV	% Reduction
TRIF (per annum)	1.83E-04	1.82E-04	0.5%
PLL (per annum)	4.08E-02	4.06E-02	0.5%
Max IRPA	2.55E-04	2.54E-04	0.4%

Table 3-8: Change in Risk Levels with Installation of SSIV on North Amethyst Risers

3.5.3 Cost Benefit Analysis

With an SSIV fitted to each of the North Amethyst risers, the potential loss of life reduces by approximately 1.50E-04 fatalities per annum. An earlier revision of the SeaRose FPSO QRA [10] looked at the cost benefit of the installation of an SSIV on the gas injection riser and a further study [11] performed an in-depth cost benefit analysis for the installation of SSIVs at the original White Rose fields, including environmental and asset risks. Both studies also concluded that the installation of SSIVs could not be justified. Using the same analysis techniques and with the resulting negligible increase in risk to personnel, the conclusions would be the same for the new developments.

The assessment has been performed for North Amethyst, as it is located further from the FPSO than either SWRX or WWRX. The additional inventory available to feed a riser release will be greatest for North Amethyst and therefore the results of the assessment will also be applicable to SWRX and WWRX.

3.6 Conclusions

1 The consequences of a riser release, of any duration, within the turret are severe, but the potential frequency of such an event occurring is very low. Therefore, although there is additional inventory available to feed a release from risers in the turret as a result of the flowlines to the new drill centres, the additional risk to personnel on the FPSO from such a release is low.

2 The tie-back of the North Amethyst field directly to the SeaRose FPSO is predicted to result in an increase of 2% in the ‘hydrocarbon only’ TRIF, to 1.83E-03 per annum, the TRIF for all hazards increases by around 1% to 2.95E-04 per annum. The PLL is expected to rise by 2% to 4.08E-02 fatalities per annum and the maximum IRPA by 2% to 2.55E-04 (the maximum value remains for the Process Crew).

3 The tie-back of the WWRX pool directly to the FPSO will be via risers containing fluids from both WWRX and CDC. The arrival pressure of these new risers is lower than previously considered for the original CDC risers and therefore the risk levels will reduce. TRIF will reduce to 1.75E-04 per annum, the PLL to 3.91E-02 fatalities per annum and the maximum IRPA to 2.41E-04 per annum.

4 Although the risk levels are predicted to increase as a result of the installation of new risers to tie-back the North Amethyst field and WWRX pool, the risk levels remain well below Husky’s Target Levels of Safety.

5 The cost of the installation of SSIVs on the new flowlines is unlikely to be justified in

terms of the degree of reduction in risk to personnel, asset and environment that they may bring about.

3.7 Recommendations

A number of recommendations have been raised that should be reviewed in more detail by the Project as the design progresses:

1 Following on from the analysis in Section 3.3, the project should review the impact on blowdown rates for the SDC / CDC production / test and gas lift lines as a result of the inclusion of the new pools. Any increase in the blowdown rates and time may affect the time taken to release the riser buoy via the QCDC system in the turret during a controlled disconnect operation;

2 The ESD shut down times for the new subsea facilities should also be reviewed to ensure that the time to close valves is optimised and does not prolong the period of packing that may occur at the FPSO after the riser ESD valves have closed in the turret.

4 BLOWOUT ASSESSMENT

The blowout assessment [4] that was conducted for the White Rose project established 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 were taken into consideration. These included:

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

The location of the blowout, (on the drillfloor, subsea etc.), size and ignition probability is considered to be similar for drilling at each of the new drill centres as they are elsewhere on the White Rose field. A blowout occurring during the drilling of the new wells will have the same consequences as previously identified; however, the frequency of such an event occurring may change as the number of wells being drilled may be different. The frequency and consequences of blowouts during the development of the new drill centres are assessed next.

4.1 Well Operations

Well operations under consideration during this evaluation of the risk from blowout for the SWRX, WWRX and North Amethyst projects are:

- development drilling from the MODU;
- well completion.

Blowout frequency data for each well operation considered, and quoted in Table 4-1 below, has been based upon data contained in the Scandpower Model for Blowout Risk Prediction [12]. This data is based on historic data from the North Sea and US Gulf of Mexico. 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 water injection wells.

Well Operation		Base Blowout Per Operation
Development Drilling from the MODU	Shallow Gas	1.60×10^{-3}
	Reservoir Drilling	1.12×10^{-3}
Well Completion		9.20×10^{-4}

Table 4-1: Summary of the Base Blowout Frequency Data for Each Well Operation

4.1.1 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.

4.1.2 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.

4.2 Blowout Frequency

In the assessment of blowout risks conducted for the MODU during the development of the White Rose field [4], the worst case drilling year (according to the predicted drilling schedule) was assumed to be 2005, where 6 wells would be drilled and 7 wells completed. Table 4-2 shows the blowout frequencies that were therefore included in the existing MODU Blowout Risk assessment.

Year 2005	**Deep Reservoir**		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	4.37E-03	2.62E-03	5.46E-04
Subsea	3.39E-03	-	-
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	-	-	-
Subsea	-	-	6.40E-03

Table 4-2: Blowout Frequency Results from Previous Study

It should be noted that of the six wells that it was assumed would be drilled in 2005, two were new wells, two were top hole section only and two were reservoir section only. In terms of blowout frequency, this is effectively the same as four new wells being drilled (top hole and reservoir combined).

In order to determine the overall risks to the MODU associated with well drilling, the annualised blowout risks have been calculated for each of the proposed drill centres. These can then be used to give an overall risk picture based on the proportion of the year spent at each drill centre. By annualising the blowout frequencies, the results for each drill centre can be compared with the blowout frequencies in the current MODU Risk Assessment, as shown in Table 4-2.

4.2.1 Blowouts at SWRX

Information provided for the SWRX project suggests that 5 wells will be drilled and completed in a period of 354 days (11.6 months). A further 3 contingency wells may also be drilled, extending the project duration to 565 days (18.58 months) (Table 4-3 shows the blowout frequency for the SWRX project based on these well operations and the general frequency per operation shown in Table 4-1. Note that the frequencies presented in Table 4-3 are for the actual drilling period of 11.6 months, rather than for an entire year.

SWRX	**Deep Reservoir**		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	4.08E-03	2.45E-03	5.10E-04
Subsea	3.16E-03		
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor			
Subsea			8.00E-03

Table 4-3: Blowout Frequency Results for Duration of SWRX Operations (Base Case)

SWRX	**Deep Reservoir**		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	6.53E-03	3.92E-03	8.16E-04
Subsea	5.06E-03		
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor			
Subsea			1.28E-02

Table 4-4: Blowout Frequency Results for Duration of SWRX Operations (Contingency Case)

Table 4-5 shows the annualised blowout risks for the SWRX project, i.e. the equivalent of 5.2 wells, assuming that operations are being conducted continuously throughout a full year. This applies to both the Base Case and the Contingency case as the drilling schedule is such that the equivalent number of wells drilled per year is the same (5.2) for each case.

SWRX	**Deep Reservoir**		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	4.21E-03	2.53E-03	5.26E-04
Subsea	3.26E-03		
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor			
Subsea			8.25E-03

Table 4-5: Annualised Blowout Frequency Results for SWRX

4.2.2 Blowouts at North Amethyst

Information provided for the North Amethyst project suggests that, for the Base Case, 10 wells will be drilled and completed in a period of 23.6 months. The additional three contingency wells take the total number of wells to 13, which will be drilled and completed over 31 months.

Table 4-6 shows the blowout frequency for the North Amethyst project for the Base Case well operations, based on the general frequency per operation shown in Table 4-1.

Table 4-8 shows the total frequency for all wells, including contingency wells. Note that the frequencies presented in these tables are for the actual drilling period of 23.6 or 31 months, rather than for a single year.

North Amethyst	**Deep Reservoir**		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	8.16E-03	4.90E-03	1.02E-03
Subsea	6.32E-03		
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor			
Subsea			1.60E-02

Table 4-6: Blowout Frequency Results for Duration of North Amethyst Operations (Base Case)

North Amethyst	**Deep Reservoir**		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	1.06E-02	6.36E-03	1.33E-03
Subsea	8.22E-03		
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor			
Subsea			2.08E-02

Table 4-7: Blowout Frequency Results for Duration of North Amethyst Operations (Total, Including Contingency Wells)

Table 4-8 shows the annualised blowout risks for the North Amethyst project, i.e. the equivalent of drilling and completing 5 wells per year assuming that operations are being conducted continuously throughout a full year. Note that the annualised blowout frequency applies to the Base Case and to the Contingency case, as it is assumed that it will take the same length of time to drill and complete each well and therefore the number of wells drilled per year will be the same in each case.

North Amethyst	**Deep Reservoir**		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	4.11E-03	2.46E-03	5.13E-04
Subsea	3.18E-03		
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor			
Subsea			8.05E-03

Table 4-8: Annualised Blowout Frequency Results for North Amethyst

4.2.3 Blowouts at WWRX

Information provided for the WWRX project suggests that 12 wells will be drilled and completed in a period of 29.6 months. A further three contingency wells may be drilled, taking the total to 15 wells which will be drilled and completed in a period of 37 months. Table 4-9 shows the blowout frequency for the Base Case of the WWRX project based on these well operations and the general frequency per operation shown in Table 4-1. Table 4-10 shows the total frequency for all wells, including contingency wells. Note that the frequencies presented in these tables are for the actual drilling period of 29.6 or 37 months, rather than for one full year.

WWRX	**Deep Reservoir**		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	9.79E-03	5.88E-03	1.22E-03
Subsea	7.59E-03		
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor			
Subsea			1.92E-02

Table 4-9: Blowout Frequency Results for Duration of WWRX Operations (Base Case)

WWRX	**Deep Reservoir**		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	1.22E-02	7.34E-03	1.53E-03
Subsea	9.49E-03		
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor			
Subsea			2.40E-02

Table 4-10: Blowout Frequency Results for Duration of WWRX Operations (Total, Including Contingency Wells)

Table 4-11 shows the annualised blowout risks for the WWRX project, i.e. the equivalent of 4.9 wells per year assuming that operations are being conducted continuously throughout a full year. As discussed for North Amethyst, these frequencies apply to the Base Case and to the case including the contingency wells.

WWRX	**Deep Reservoir**		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	3.97E-03	2.38E-03	4.96E-04
Subsea	3.08E-03		
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor			
Subsea			7.79E-03

Table 4-11: Annualised Blowout Frequency Results for WWRX

4.3 Blowout Consequences

4.3.1 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 and at the drillfloor. The consequences of a blowout will be the same for all three drill centre locations.

4.3.1.1 Deep Reservoir Blowouts

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

- Drillpipe Blowout 50kg/s
- Annulus Blowout 100kg/s
- Unconfined Blowout 250kg/s

A more detailed assessment was completed during the Project phase to assess the potential environmental impact of deep reservoir blowout incidents from White Rose wells [13]. 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 [13] was 36kg/s (32kg/s oil and 4kg/s gas). This value will be used in the consequence analysis.

4.3.1.2 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.

4.3.2 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 wellfluids, which is not the case for the White Rose field.

Using historical data within [12], 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 report [12] 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.

4.3.3 Blowout Hazard Assessment

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

4.3.3.1 Drillfloor Blowouts

Ignited drillfloor 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 using in-house TORCH software [14] 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 4-12.

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 4-12: Heat Fluxes Caused by Vertical Blowouts with 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.

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.

4.3.3.2 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 [15] although this could potentially be an underestimate for larger releases [16]. 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 4-13.

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 4-13: 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 amount of smoke generated by a well ventilated gas pool fire in the case of a shallow gas release will be small. 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 [17]. The issue of CO from smoke is more extensively described in the SeaRose TR Integrity Analysis [3]. Table 4-14 shows the effects of different levels of CO on personnel.

Dispersion analysis has been conducted using the in-house PLUME software [18] 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 4-14: 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 [18] 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.

4.4 Blowout Assessment Conclusion

The annualised frequency of blowouts during the drilling and completion of:

- five (Base Case) or eight (contingency) new wells for the SWRX project is predicted to be **1.88E-02** per annum;
- twelve (Base Case) or fifteen (contingency) new wells for the WWRX project is predicted to be **1.77E-02** per annum;
- ten (Base Case) or thirteen (contingency) new wells for the North Amethyst project is predicted to be **1.83E-02** per annum;

This compares with a frequency of **1.73E-02** per annum for the assessment completed during the initial White Rose Project, based on the equivalent of 4 new wells being drilled.

These blowout frequencies are carried forward to the MODU Risk Assessments (Section 6). The consequences of a blowout are not dependent on the location of the drill centre.

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 affect on the frequencies and risks calculated here. This assessment should therefore be reviewed as the Tieback Projects move into the next phase of design.

5 DROPPED OBJECT RISK ASSESSMENT

As a part of the safety assessments of the new White Rose extensions, a dropped object study has been carried out for each new drill centre. These studies determine the dropped object risks associated with creating the new glory hole, drilling the new wells and installing the items of equipment required for the new Drill Centre.

For the White Rose Extension project the study investigates the potential for equipment to be dropped from the MODU during well operations or the DSV during the construction and hook-up phases of the project.

For each Glory Hole (SWRX, SGH, NADC and WWRX), the study estimates:

- 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.

5.1 Dropped Object Model

The dropped object model estimates:

- impact energies of falling objects;
- the likelihood (or probability) of dropped objects impacting on 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 1×10^{-5} per lift [19]; these values have been extracted from the best available HSE dropped object data and are consistent with the previous dropped object study conducted for Husky [5] during the field development. Further studies have established similar drop frequencies, such as [20] by DNV, which calculated a drop frequency of 1.2×10^{-5} per lift.

It has been recognised that there have already 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.

Therefore for the very heavy lifts of the xmas trees and the BOP, dropped object frequencies of 2E-04 and 1.5E-03 per lift respectively have been used [21]. However, these values are conservative as the MODU may continue to operate on the White Rose field for the remaining field life without dropping the BOP again.

5.2 Drilling Schedule

At each of the glory holes, a number of wells will be drilled as a first batch and then the heavy construction work will be carried out to install the equipment (manifolds, flowlines etc.) within the glory hole. The first batch of wells will then be connected and start producing or injecting. The MODU will then return to drill the remaining wells. As the exact order of drilling of the remaining wells has not yet been finalised, a conservative assumption has been made; the remaining wells will be drilled and connected in pairs - for every production well that is drilled, a water injection well will also be drilled (if there is an odd number, the additional water injection well will be drilled with the pair to make a batch of 3 wells). The sections below give the details of the numbers of wells and the schedule assumed in this assessment.

South White Rose

Total Number of wells = 5 (Base Case) 8 (Contingency);

First Batch = 2 (1 water injection, 1 production);

Subsea Equipment Installation and Hook-up of wells 1&2;

Remaining: 1 batch of 3 wells (2 production and 1 water injection);

Contingency: 1 further batch of 3 wells (1 production and 2 water injection).

North Amethyst

Total Number of wells = 10 (Base Case) 13 (Contingency);

First Batch = 7 (4 water injection, 3 production)

Subsea Equipment Installation and Hook-up of wells 1-7;

Remaining: 1 batch of 3 wells (1 production and 2 water injection);

Contingency: 1 further batch of 3 wells (2 production and 1 water injection).

West White Rose

Total Number of wells = 12 (Base Case) 15 (Contingency);

First Batch = 4 (2 water injection, 2 production);

Subsea Equipment Installation and Hook-up of wells 1-4;

Remaining: 2 batches of 2 wells each (1 production and 1 water injection);

1 batch of 4 wells (1 production and 3 water injection);

Contingency: 1 further batch of 3 wells (2 production and 1 water injection).

5.3 Potential for Damage or Loss of Hydrocarbon Containment

Objects dropped during the drilling or construction phases have the potential to impact on previously installed equipment, resulting in damage to the equipment or possibly, if the damage is severe, a release of hydrocarbons. This assessment has estimated the potential for damage to occur to the subsea equipment; this frequency is not used in any subsequent analysis within this study, rather it is presented to allow Husky to investigate the potential financial implications of dropped objects during the project.

The drilling schedule at the new glory holes is such that some wells are drilled, the manifolds and flowlines etc. are installed and the first batch of wells are connected; further drilling of the remaining wells will therefore take place over equipment which may contain hydrocarbons. For the purposes of this assessment, it is conservatively assumed that any objects which impact, with sufficient energy as to cause damage, on wells or the associated flowlines and manifolds which have been hooked-up and flowing will result in a release of hydrocarbons.

5.4 Crane Locations

For the Tieback Project, whilst on-station above the glory hole being installed, 60% of the MODU lifts will be performed using the port-side crane and 40% with the starboard-side, as advised by the Project. All heavy lifts are performed through the moonpool. Very heavy lifts (xmas trees 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 [5]. The Drilling and Operations Manual [22] makes reference to the MODU dropped objects analysis in relation to heavy or high risk lifts.

For the DSV lifts, it has been assumed that the lifts are split 50:50 between the port and starboard cranes and that all lifts are carried out with the DSV located above the centre of the glory hole at which it is working.

5.5 Hydrodynamic Modelling

Hydrodynamic models for 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. Again, the majority of the inputs assumed for this study are the same as those previously adopted for the existing MODU dropped object analysis [5], including sea current conditions etc.

5.6 Lift Manifests

A generic lift manifest has been created, containing items lifted at each new drill centre, to show the details of the objects to be lifted and the number of lifts made per well installed. The well operations manifest is based on the previous MODU dropped object study [5]. Table 5-1 shows the generic lift manifest containing all the items which are lifted per well installed.

Table 5-3 to Table 5-5 show additional lifts carried out by the MODU which are specific to the Glory Hole being created, and independent of the number of wells being installed. The manifest for the operations at SGH, where no wells are being drilled, is based on information provided by the project [23], and is shown in Table 5-2. Similar activities are to be carried out at CGH; the layout and dimensions of the CGH are very similar to those of the SGH and therefore this assessment has not been repeated for SGH. Section 7 of this report assesses the risks to the DSV from dropped objects at the SGH and it is assumed that the risk levels for the DSV at the CGH will be very similar.

Additionally, 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 the glory hole);
- PC represents the port-side crane (MODU located directly above the glory hole);
- MP represents a moonpool lift (MODU located directly above the glory hole);
- MP2 represents an offset moonpool lift (MODU located 60m North of the glory hole);
- SC2 represents the offset starboard-side crane (MODU located 60m North of the glory hole).

					Length	Width	Height		Usage Per Zone				
Item	Hydro Model	Lifts / Well	Drop Freq	weight (kg)	Length	Dia	Null	Type	SC	PC	MP	MP2	SC2
mini Container full	Small Container	400	0.00001	3000	1.828711	1.523926	2.438281	2	0.4	0.6			
mini Container empty	Small Container	150	0.00001	1400	1.828711	1.523926	2.438281	2	0.4	0.6			
maxi Container full	Medium Container	40	0.00001	3350	3.047851	2.438281	2.438281	2	0.4	0.6			
maxi Container empty	Medium Container	30	0.00001	1140	3.047851	2.438281	2.438281	2	0.4	0.6			
H/H Container full	Medium Container	25	0.00001	3170	3.047851	2.438281	1.219141	2	0.4	0.6			
H/H Container empty	Medium Container	15	0.00001	990	3.047851	2.438281	1.219141	2	0.4	0.6			
Tote full	Small Container	40	0.00001	6000	1.828711	1.523926	2.438281	2	0.4	0.6			
Tote empty	Small Container	20	0.00001	1200	1.828711	1.523926	2.438281	2	0.4	0.6			
Open Container full	Medium Container	50	0.00001	5070	6.095703	2.438281	2.438281	2	0.4	0.6			
Open Container empty	Medium Container	10	0.00001	1890	6.095703	2.438281	2.438281	2	0.4	0.6			
Closed Container full	Medium Container	10	0.00001	4630	6.095703	2.438281	2.438281	2	0.4	0.6			
Closed Container empty	Medium Container	5	0.00001	1910	6.095703	2.438281	2.438281	2	0.4	0.6			
Basket full	Mtbasket Data	50	0.00001	5000	3.047851	1.219141	1.219141	1	0.4	0.6			
Basket empty	Mtbasket Data	20	0.00001	2200	3.047851	1.219141	1.219141	1	0.4	0.6			
Basket full	Mtbasket Data	50	0.00001	3500	6.095703	1.219141	1.219141	1	0.4	0.6			
Basket empty	Mtbasket Data	10	0.00001	1200	6.095703	1.219141	1.219141	1	0.4	0.6			
Basket full	Mtbasket Data	56	0.00001	4000	9.143554	1.219141	1.219141	1	0.4	0.6			
Basket empty	Mtbasket Data	6	0.00001	1480	9.143554	1.219141	1.219141	1	0.4	0.6			
Basket full	Mtbasket Data	10	0.00001	3510	12.19141	1.219141	1.219141	2	0.4	0.6			
Basket empty	Mtbasket Data	10	0.00001	1850	12.19141	1.219141	1.219141	2	0.4	0.6			
Helifuel Tank Full	Medium Container	25	0.00001	6000	2.5	2.5	2.5	2	0.4	0.6			
Helifuel Tank Empty	Medium Container	25	0.00001	2500	2.5	2.5	2.5	2	0.4	0.6			
5 7/8" Drill Pipe Bundle [5]	TUBE06BNDDATA	40	0.00001	2910	9.45	0.15		3	0.4	0.6			
9 1/2" Drill Collars Bundle [5]	TUBE09BNDDATA	3	0.00001	2952	9.45	0.24		3	0.4	0.6			
8 1/4" Drill Collars Bundle [5]	TUBE09BNDDATA	3	0.00001	4218	9.45	0.21		3	0.4	0.6			
6 1/2" Drill Collars Bundle [5]	TUBE06BNDDATA	3	0.00001	6327	9.45	0.165		3	0.4	0.6			
7" Tubing	TUBE06DATA	32	0.00001	4353.75	12.5	0.179		3	0.4	0.6			
7" Liner Bundle of 9	TUBE09BNDDATA	20	0.00001	4353.75	12.5	0.179		3	0.4	0.6			
7" Liner Single Shoe Joint	TUBE06DATA	2	0.00001	4353.75	12.5	0.179		3	0.4	0.6			
30" Casing	TUBE30DATA	8	0.00001	5765	12.5	0.762		3	0.4	0.6			
30" Casing Shoe Joint	TUBE30DATA	2	0.00001	5765	12.5	0.762		3	0.4	0.6			
16" Casing	TUBE16DATA	45	0.00001	3523	12.5	0.406		3	0.4	0.6			
16" Casing Shoe Joint	TUBE16DATA	4	0.00001	1761.5	12.5	0.406		3	0.4	0.6			
13 3/8" Casing	TUBE13DATA	45	0.00001	1265	12.5	0.34		3	0.4	0.6			
13 3/8" Casing Shoe Joint	TUBE13DATA	4	0.00001	1265	12.5	0.34		3	0.4	0.6			
9 5/8" Casing	TUBE09DATA	60	0.00001	995.25	12.5	0.244		3	0.4	0.6			
9 5/8" Casing Shoe Joint	TUBE09DATA	4	0.00001	995.25	12.5	0.244		3	0.4	0.6			
5 7/8" HW Drill Pipe Joint	TUBE06DATA	10	0.00001	2531	12.5	0.15		3	0.4	0.6			
5 7/8" Drill Pipe	TUBE06DATA	32	0.00001	970	9.45	0.15		3	0.4	0.6			
Marine Riser Joint	Marine Riser Data	1	0.00001	3000	15.55	0.5334		3	0.4	0.6			
Riser Slip Joint	PINCNT	1	0.00001	18000	12.2	0.635		3	0.4	0.6			
PGB	X&SKD	2	0.00001	3000	4.1	3.9	4.1	1	0.4	0.6			
Wellhead	TUBE36DATA	4	0.00001	10000	10.67	0.914		3	0.4	0.6			
Xmas Tree	Xmas Tree	1	0.0002	37000	4.1	3.9	4.1	2					1
Xmas Tree Frame	X&SKD	1	0.00001	3000	4.1	3.9	4.1	1	0.4	0.6			
H.P.U Controls	HPU Controls	1	0.00001	4000	2	1.2	1.2	2	0.4	0.6			
Spares Workshop Container	Medium Container	1	0.00001	8000	6	2.8	2.8	2	0.4	0.6			
Container Completion Equipment	Small Container	1	0.00001	8000	6	1.2	1.2	2	0.4	0.6			
Workshop Container	Large Container	1	0.00001	8000	6	2.8	2.8	2	0.4	0.6			
Clamp Container	Medium Container	1	0.00001	4000	6	2.8	2.8	2	0.4	0.6			
Power Tong Box	Medium Container	1	0.00001	4000	3	2	2	2	0.4	0.6			
Handling Tools	Handling Tools	1	0.00001	6000	10	8	4	2	0.4	0.6			
Jumper Basket	Mtbasket Data	1	0.00001	4000	9	1.2	1.2	1	0.4	0.6			
Completion Equipment 1	Mtbasket Data	1	0.00001	10000	17	1.2	1.2	1	0.4	0.6			
Completion Equipment 2	Mtbasket Data	1	0.00001	10000	10	1.2	1.2	1	0.4	0.6			
Spare Cable Basket	Mtbasket Data	1	0.00001	6000	10	1.2	1.2	1	0.4	0.6			
Completion Basket	Mtbasket Data	1	0.00001	4000	20	4	4	1	0.4	0.6			
Choke Manifold	CTPP_MIU_TR	1	0.00001	4000	2	2	1	2	0.4	0.6			
Pipe Basket	Large Container	3	0.00001	4000	6	1.2	1.2	2	0.4	0.6			
Lubricator skid	CTPP_MIU_TR	2	0.00001	6000	5	2	2	2	0.4	0.6			
High Pressure Pump	PP_SLF_HPP_P	1	0.00001	4000	2	2	2.8	2	0.4	0.6			
Control Line Spooler	CT_I_EL	2	0.00001	3000	2	2	2	2	0.4	0.6			
Chemical Injection Spooler	PP_SLF_HPP_P	2	0.00001	5000	2	3	2	2	0.4	0.6			
Compressor	Air Compressor	3	0.00001	12000	4	2	2	2	0.4	0.6			
Methanol Tank	Medium Container	1	0.00001	2000	2	2	2	2	0.4	0.6			
surge tank	Large Container	2	0.00001	5000	7	3	3	2	0.4	0.6			
internal subsea test tree	TUBE20DATA	2	0.00001	5000	13	1.2		3	0.4	0.6			
Tubing Hangar	Marine Riser data	1	0.00001	2000	3	1.3	1.3	2	0.4	0.6			
Tubing Hangar landing string access	Medium Container	1	0.00001	1000	3	1.2	1.2	2	0.4	0.6			
Tubing Hangar landing string bundle	TUBE16BNDDATA	1	0.00001	1000	3	1.2		3	0.4	0.6			
5 7/8" HW Drill Pipe Joint	TUBE06DATA	6	0.00001	2530.612	12.5	0.15		3			1		
5 7/8" Drill Pipe	TUBE06DATA	32	0.00001	970.068	9.45	0.15		3			1		
Marine Riser Joint	Marine Riser Data	10	0.00001	3000	15.55	0.5334		3			1		
Riser Slip Joint	PINCNT	2	0.00001	18000	12.2	0.635		3			1		
9 1/2" Drill Collar	DC_9_5	4	0.00001	2952	9.45	0.24		3			1		
PGB	X&SKD	1	0.00001	3000	4.1	3.9	4.1	1			1		
Xmas Tree + Frame + Wellhead	Xmas Tree	1	0.0002	50000	4.1	3.9	4.1	2				1	
BOP	BOP	2	0.0015	200000	4.1	4.8	12.5	2				1	
30" Casing	TUBE30DATA	5	0.00001	5765	12.5	0.762		3			1		
30" Casing Shoe Joint	TUBE30DATA	1	0.00001	5765	12.5	0.762		3			1		
16" Casing	TUBE16DATA	89	0.00001	3523	12.5	0.406		3			1		
16" Casing Shoe Joint	TUBE16DATA	2	0.00001	1761.5	12.5	0.406		3			1		

Table 5-1: Generic Lift Manifest Per Well Installation Operation (from [5])

Item	Hydro Model	Lifts / Year	weight (kg)	Length (m)	Width / Dia (m)	Height (m)
30" Casing	TUBE30DATA	4	5600	12.2	0.762	0
glory hole levelling - air lift	TUBE36x2Data	2	2000	10	0.254	
installation of SDU base	Extra Large Container	1	54000	22.68	12.48	4.464
installation of SDU	Extra Large Container	1	20000	15.376	5.176	6
installation of extension manifold	Extra Large Container	1	20000	15.376	5.176	6
installation of WI expansion manifold	Extra Large Container	1	20000	15.376	5.176	6
SDC modifications, rigid spool installation	TUBE16x2Data	2	10700	40	0.43	
installation of WI tie-in spools	TUBE16x2Data	3	10700	40	0.43	
installation of WI weaklink arrangement (PBSJ) in SDC	Medium Container	2	3000	2.5	2.5	2.5

Table 5-2: Lift Manifest for DSV Operations at SGH (from [5])

It should be noted that the SGH lift manifest information provided by the project [5] includes the lifting of a 30" section of casing. This casing will be deployed by the MODU whilst it is briefly located over the SGH. All other lifts will be carried out by the DSV or construction vessel at SGH. However, for simplicity, it is assumed that all dropped objects that occur at SGH will only affect the DSV and dropped objects at the three new drill centres will only affect the MODU.

In addition to the lifts that are carried out per well as shown in Table 5-1, there will be a number of lifts performed in order to complete the construction of the glory holes. These lifts are assumed to be performed with the DSV stationed above the centre of the Glory Hole, whilst all lifts associated with drilling and completion (other than the heavy lifts which will be performed 60m off-station) will be performed with the MODU centred above the well being drilled. The manifests are based on the maximum number of wells to be drilled – i.e. including contingency wells. The following lifts are included in the dropped object analysis:

Item	Hydro Model	Lifts / Year	Drop Freq	weight (kg)	Length	Dia	Null	Type	SC	PC	MP	MP2	SC2
installation of manifold base	Extra Large Container	1	1.00E-05	54000	22.7	12.48	4.464	1	0.5	0.5			
installation of SDU base	Extra Large Container	1	1.00E-05	54000	22.7	12.48	4.464	1	0.5	0.5			
Piles	TUBE30DATA	9	1.00E-05	8000	22	0.61		3	0.5	0.5			
S280 Piling Hammer c/w Sleeve	TUBE30DATA	9	1.00E-05	26500	13.4	1		3	0.5	0.5			
Pile Follower	TUBE30DATA	9	1.00E-05	3000	7.8	0.6		3	0.5	0.5			
installation of production manifold	Extra Large Container	1	1.00E-05	20000	15.4	5.176	6	2	0.5	0.5			
Installation of SWRX WI manifold	Extra Large Container	1	1.00E-05	20000	15.4	5.176	6	2	0.5	0.5			
installation of SWRX SDU	Extra Large Container	1	1.00E-05	20000	15.4	5.176	6	2	0.5	0.5			
Rigid spool installation@WWRX to WI x-tree	TUBE16x2Data	2	1.00E-05	10700	40	0.43		3	0.5	0.5			
Rigid spool installation@WWRX to Prod x-tree	TUBE16x2Data	3	1.00E-05	10700	40	0.43		3	0.5	0.5			

Table 5-3: Additional Lift Manifest for SWRX

				Length	Width	Height		Usage Per Zone	
Item	Lifts / Yea	Drop Freq	weight (kg)		Dia	Null	Type	SC	PC
Module Support Frame	2	1.00E-05	130000	25	8	2	1	0.5	0.5
MSF Protection Structure	3	1.00E-05	5000	8	4	2	1	0.5	0.5
Piles	16	1.00E-05	10000	25	0.6		3	0.5	0.5
S280 Piling Hammer c/w Sleeve	16	1.00E-05	26500	13.4	1		3	0.5	0.5
Pile Follower	16	1.00E-05	3000	7.8	0.6		3	0.5	0.5
Production module	2	1.00E-05	55000	8	3	4	2	0.5	0.5
water injection module	2	1.00E-05	45000	8	3	4	2	0.5	0.5
MSF roof panels	4	1.00E-05	10000	12.5	8	2	2	0.5	0.5
SDU Support Frame	2	1.00E-05	40000	8	4	4	2	0.5	0.5
SDU	1	1.00E-05	25000	6.5	3	3	2	0.5	0.5
Electrical Distribution Box	1	1.00E-05	1000	1	1	1	2	0.5	0.5
Umbilical Termination Assembly	1	1.00E-05	15000	3	3	3	2	0.5	0.5
Production Spools (module to well)	6	1.00E-05	10000	20	0.3		3	0.5	0.5
Water injection spools (module to well)	7	1.00E-05	8000	20	0.3		3	0.5	0.5
production spoolpieces (between MSFs)	2	1.00E-05	6000	20	0.3		3	0.5	0.5
Water injection spoolpieces (between MSFs)	1	1.00E-05	4000	20	0.3		3	0.5	0.5

Table 5-4: Additional Lift Manifest for North Amethyst

				Length	Width	Height		Usage Per Zone	
Item	**Lifts / Yea**	**Drop Freq**	**weight (kg)**		**Dia**	**Null**	**Type**	**SC**	**PC**
Module Support Frame	2	1.00E-05	130000	25	8	2	1	0.5	0.5
MSF Protection Structure	3	1.00E-05	5000	8	4	2	1	0.5	0.5
Piles	16	1.00E-05	10000	25	0.6		3	0.5	0.5
S280 Piling Hammer c/w Sleeve	16	1.00E-05	26500	13.4	1		3	0.5	0.5
Pile Follower	16	1.00E-05	3000	7.8	0.6		3	0.5	0.5
Production module	3	1.00E-05	55000	8	3	4	2	0.5	0.5
water injection module	2	1.00E-05	45000	8	3	4	2	0.5	0.5
MSF roof panels	4	1.00E-05	10000	12.5	8	2	2	0.5	0.5
SDU Support Frame	2	1.00E-05	40000	8	4	4	2	0.5	0.5
SDU	1	1.00E-05	25000	6.5	3	3	2	0.5	0.5
Electrical Distribution Box	1	1.00E-05	1000	1	1	1	2	0.5	0.5
Umbilical Termination Assembly	1	1.00E-05	15000	3	3	3	2	0.5	0.5
Production Spools (module to well)	7	1.00E-05	10000	20	0.3		3	0.5	0.5
Water injection spools (module to well)	8	1.00E-05	8000	20	0.3		3	0.5	0.5
production spoolpieces (between MSFs)	2	1.00E-05	6000	20	0.3		3	0.5	0.5
Water injection spoolpieces (between MSFs)	1	1.00E-05	4000	20	0.3		3	0.5	0.5

Table 5-5: Additional Lift Manifest for WWRX

5.7 Additional Risks to Subsea Equipment

Failure of the MODU mooring chains may also result in the chain falling on top of the flowlines. Similarly, mooring chains that run close to the flowlines could damage flowlines or umbilicals through abrasion. However, this was reviewed during the White Rose Project [24] with the conclusion that such damage was unlikely to result in loss of containment from the flowlines or damage to the umbilicals.

One other hazard introduced by the MODU that has not been assessed to date is that of drifting anchors; it is recommend that the risk of anchor damage to the flowlines be assessed in more detail.

5.8 Subsea Equipment Targets

The equipment to be installed at each glory hole has been divided into target area as shown in the following diagrams. The frequency of impact and/or damage to each of these targets is determined separately. The SWRX Glory Hole has been divided into eleven target areas as shown in Figure 5-1.

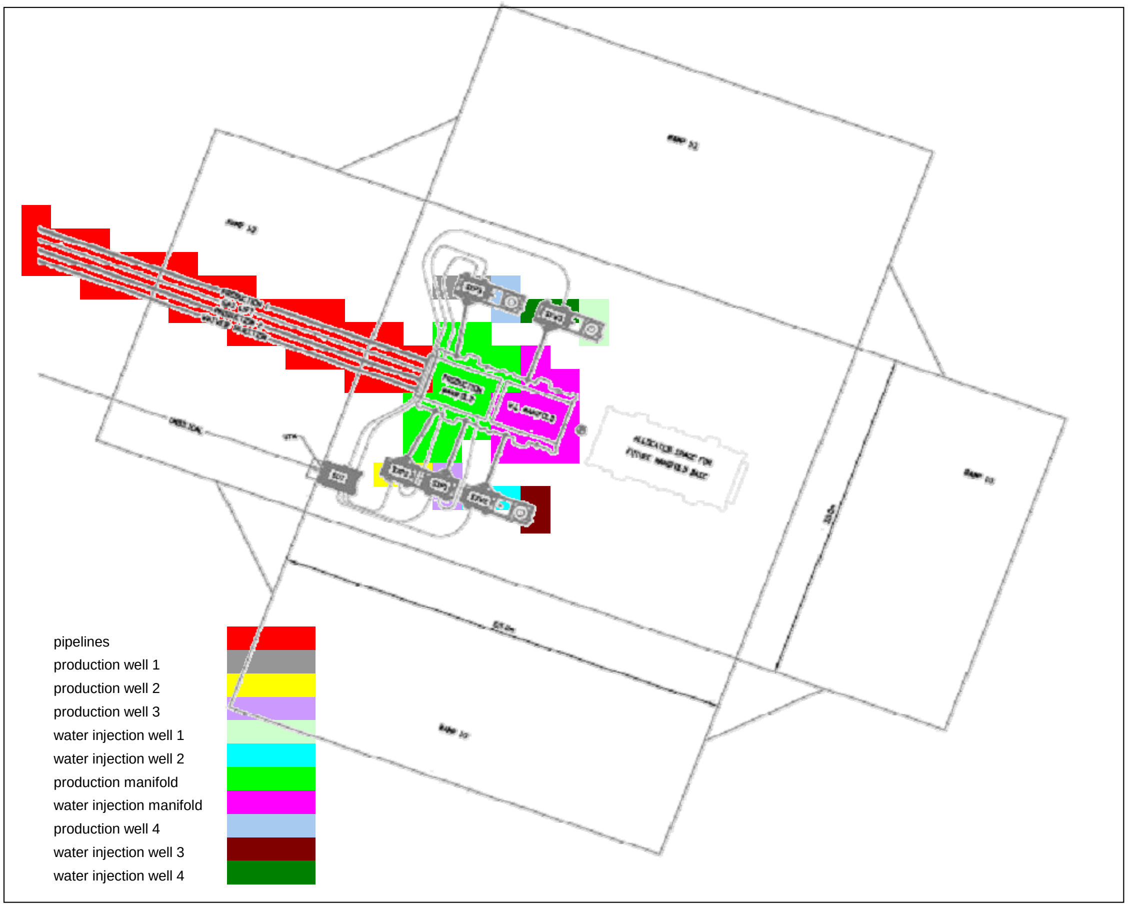


Figure 5-1: SWRX Glory Hole Subsea Equipment Targets

Similarly, the equipment at the SGH has been divided into eleven targets, as shown in Figure 5-2 below.

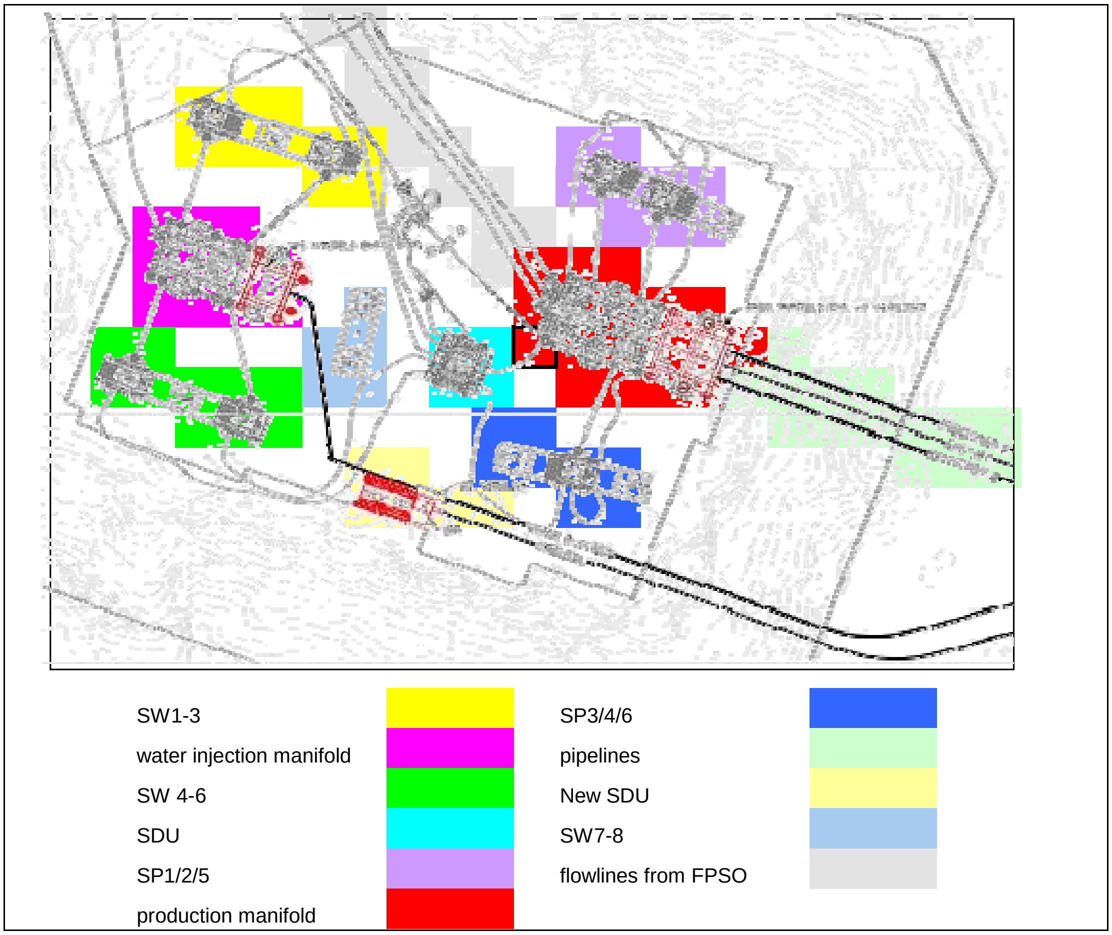


Figure 5-2: Southern Glory Hole Subsea Equipment Targets

The equipment at the NADC, for lifts carried out by the MODU, has been divided into 13 targets, as shown in Figure 5-3 below. The first ten targets represent the base case for the installation of wells. Drilling and completion of Production Wells 5 and 6 and Water Injection Well 7 are conservatively included as a contingency, should more wells be required.

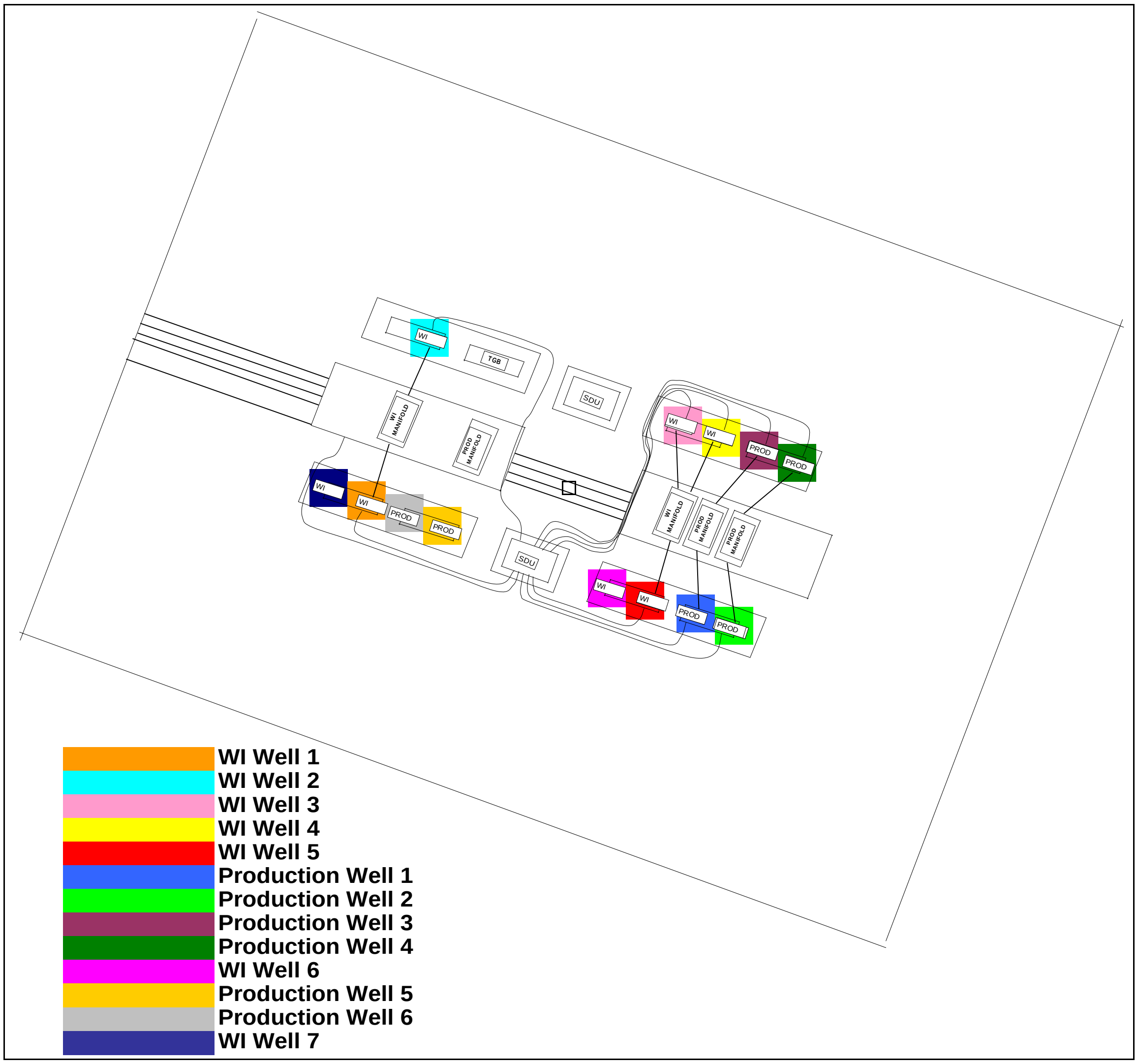


Figure 5-3: North Amethyst Glory Hole Well Targets

Six additional target areas have been identified to represent the permanent subsea equipment at NADC; these are shown in Figure 5-4 and will be installed after the first seven wells have been drilled. The first seven of the well targets in shown Figure 5-3 will also be targets during these lifts.

Figure 5-4: North Amethyst Additional Target Areas for Subsea Equipment

The 15 target areas defined for the well installation MODU lifts at WWRX are given in Figure 5-5 below. Twelve of these wells represent the base case, whilst an additional two production and one water injection wells are included in the study as a contingency.

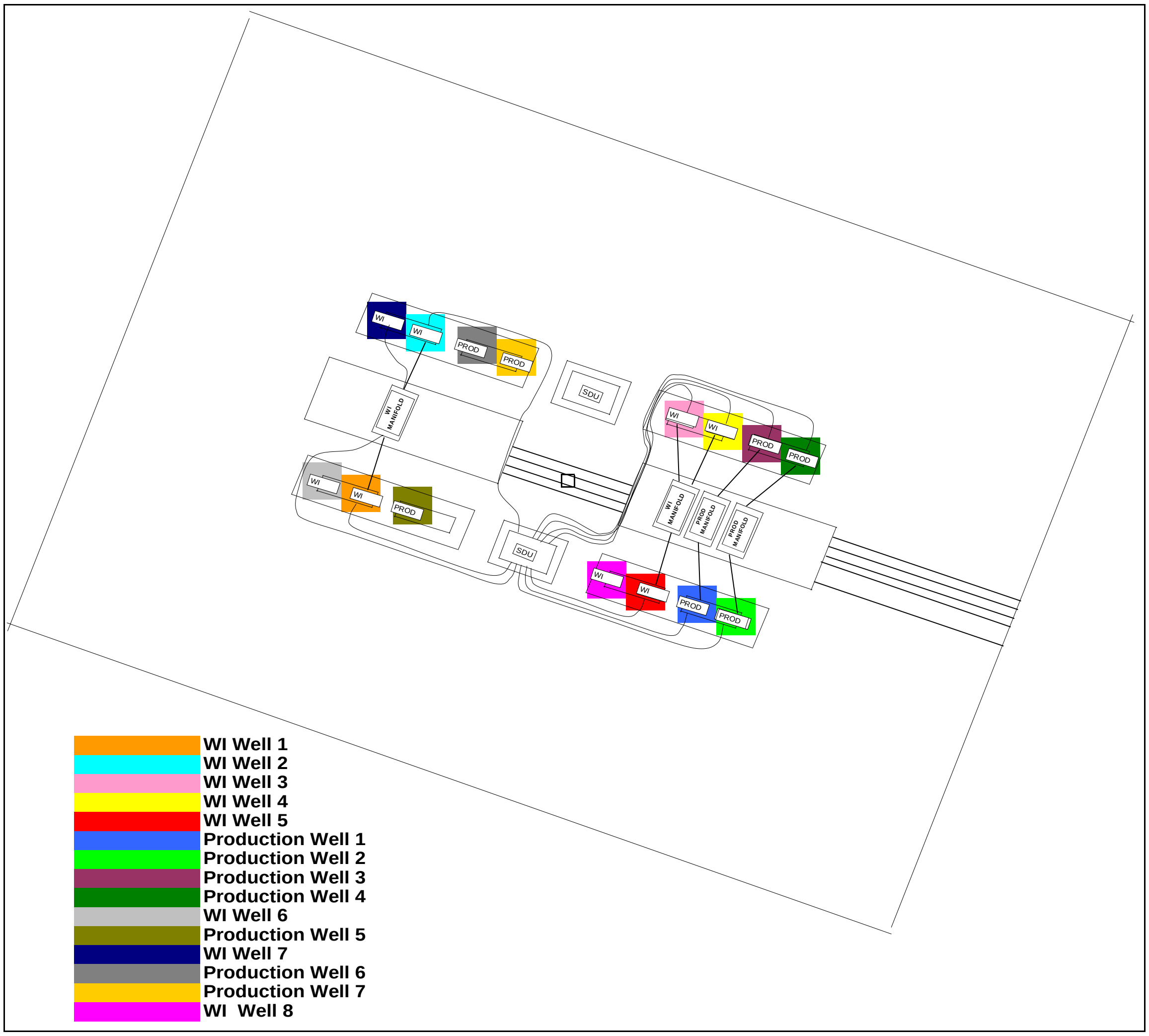


Figure 5-5: West Glory Hole - Subsea Well Targets

Six additional targets have been identified for the subsea equipment and are shown in Figure 5-6. As for North Amethyst the first batch of wells (4) to be drilled (shown in Figure 5-5) will also be targets during these lifts.

Note that no subsea layout drawing for WWRX could be provided by Husky; the Project advised to use the North Amethyst drawing rotated as shown.

Figure 5-6: WWRX Glory Hole – Subsea Equipment Targets

5.9 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.

The dropped object assessment considers the risk of impact on each target for every lift being undertaken.

The potential for impact on each of the wellheads is dependent on the drilling schedule. For example, the third well to be installed can only be considered as a target during the drilling of the fourth well and thereafter. As a number of wells are drilled and then completed, rather than each well being drilling and completed in one stage, the potential for objects to hit the subsea equipment is different for the drilling and completion activities. It has been assumed that 10% of the lifts associated with each well are related to completion activities and 90% are for drilling activities. In the case of North Amethyst, for example, the schedule shows that wells 1-7 are drilled first, then those wells are completed and then wells 8-10 are drilled and completed. The 3 additional contingency wells have been assumed all to be drilled and then all completed after the ten Base Case wells have all been completed. The risk of dropped objects hitting target well 3 will therefore be the 90% of the sum of the potential for objects dropped during the drilling of wells 4-13 to hit target 3 plus the 10% of the sum of the risk from objects dropped during the completion of all 13 wells.

5.10 Damage Probability

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

The damage probability rule sets use the same principles that were applied in earlier dropped object studies for the White Rose development [5]. 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 outwith the centre of gravity of the object).

In the event of a dropped object impacting on the targets, there is the potential for the pipeline 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 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. This was based on Finite Element Analyses (FEA) and engineering judgement. 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.

5.10.1 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 damaged by an impact of 25kJ with the exception of the flowlines, which could be damaged by an impact of 5kJ. As a conservative estimate, it is assumed that this level of damage would be sufficient to cause a loss of hydrocarbon containment.

These damage values are also the same as those used in the existing MODU Dropped Object Study [5]. However, it should be noted that it is the intention of the extension projects to install protection on the flowlines and umbilicals up to 100m from the manifold in a similar manner to existing White Rose flowlines [25]. This should provide protection to the flowlines against impacts of 25kJ.

5.11 Impact Diagrams

Impact frequency diagrams have been created for each lift location; a sample of these drawings is included in Appendix A of this report. Figures A1-A6 show the overall impact frequency at SWRX and SGH, the impact frequency during the drilling of the final well at NADC and WWRX and the sensitivity (discussed in Section 5.12.1) where the larger Henry Goodrich MODU was used.

5.12 Impairment Frequency of the Subsea Targets

To estimate the total frequency of impairment from dropped object impact during the drilling and hook-up operations, the impact frequencies and impairment probabilities are considered (impairment frequency = impact frequency x impairment probability).

Table 5-6 shows the Base Case Impairment Frequency for the subsea equipment at the new glory hole as a result of dropped objects during the SWRX project. Table 5-10 shows the impairment frequencies for the contingency case.

Target	Total Frequency of Damage	Annualised Frequency of Damage (/yr)
pipelines	1.84E-04	2.50E-04
production well 1	1.26E-05	4.08E-05
production well 2	1.71E-05	1.76E-05
production well 3	6.23E-06	6.42E-06
water injection well 1	3.03E-05	6.08E-05
water injection well 2	3.97E-05	4.10E-05
production manifold	1.57E-04	2.24E-04
water injection manifold	1.13E-04	1.73E-04
Total	**5.60E-04**	**8.14E-04**

Table 5-6: Impairment Frequency for Objects Dropped at SWRX (Base Case)

Target	Total Frequency of Damage	Annualised Frequency of Damage (/yr)
pipelines	3.58E-04	3.23E-04
production well 1	1.64E-05	4.10E-05
production well 2	5.39E-05	3.90E-05
production well 3	5.49E-05	3.98E-05
water injection well 1	3.44E-05	5.59E-05
water injection well 2	7.99E-05	5.79E-05
water injection well 3	4.00E-05	2.89E-05
water injection well 4	3.78E-06	2.74E-06
production well 4	2.70E-05	1.96E-05
production manifold	3.05E-04	2.86E-04
water injection manifold	2.17E-04	2.17E-04
Total	**1.19E-03**	**1.11E-03**

Table 5-7: Impairment Frequency for Objects Dropped at SWRX (Contingency)

The impairment frequencies shown in Table 5-6 - Table 5-7 above are the total frequencies with which objects dropped during the SWRX project could cause damage to the installed subsea facilities. As previously discussed, not all incidents of damage will result in a loss of hydrocarbon containment; only those production wells or facilities which have been connected at the time of damage occurring are considered to result in a loss of hydrocarbon containment.

Table 5-8 and Table 5-9 show the frequency of damage to each target resulting in a hydrocarbon release, firstly for the Base Case and secondly for the Contingency Case. Note that the annualised Base Case frequency is higher than the Contingency case because the duration of the project will be longer if the contingency wells are drilled.

Target	Total Frequency of Loss of HC Containment	Annualised Frequency of Loss of HC Containment (/yr)
pipelines	1.84E-04	2.50E-04
production well 1	9.58E-06	1.28E-05
production well 2	0.00E+00	0.00E+00
production well 3	0.00E+00	0.00E+00
water injection well 1	N/A	N/A
water injection well 2	N/A	N/A
production manifold	1.57E-04	2.24E-04
water injection manifold	N/A	N/A
Total	**3.51E-04**	**4.87E-04**

Table 5-8: Loss of Containment Frequency for Objects Dropped at SWRX (Base Case)

The frequency of hydrocarbon release from production wells 1 and 2 is zero because, for the Base Case, there will be no further drilling or construction activities after these wells have been connected.

Target	Total Frequency of Loss of HC Containment	Annualised Frequency of Loss of HC Containment (/yr)
pipelines	3.58E-04	3.23E-04
production well 1	1.34E-05	1.07E-05
production well 2	3.68E-05	2.66E-05
production well 3	4.87E-05	3.53E-05
water injection well 1	N/A	N/A
water injection well 2	N/A	N/A
water injection well 3	N/A	N/A
water injection well 4	N/A	N/A
production well 4	0.00E+00	0.00E+00
production manifold	3.05E-04	2.86E-04
water injection manifold	N/A	N/A
Total	**7.62E-04**	**6.81E-04**

Table 5-9: Loss of Containment Frequency for Objects Dropped at SWRX (Contingency Case)

The total frequency of loss of hydrocarbon containment from the production wells at SWRX is therefore 1.28E-05 per annum for the Base Case and 7.26E-05 per annum for the Contingency Case, whilst the loss of containment frequency from the flowlines and manifolds is 4.74E-04 per annum for the Base Case and 6.09E-04 per annum for the Contingency Case. The higher value in each case will be carried forward to the MODU risk assessment in Section 6.

Table 5-10 shows the Impairment Frequency for the subsea equipment at the existing Southern glory hole as a result of objects dropped by the DSV as a result of modifications to the SGH conducted as part of the SWRX project.

Target #	Name	Actual Total Impairment Frequency for SWRX Project	Total Annualised Impairment Frequency (/yr)
1	SW1-3	7.50E-07	5.70E-06
2	water injection manifold	4.25E-06	3.23E-05
3	SW 4-6	9.58E-06	7.28E-05
4	SDU	7.52E-06	5.72E-05
5	SP1/2/5	3.19E-07	2.43E-06
6	production manifold	1.56E-06	1.19E-05
7	SP3/4/6	5.57E-06	4.24E-05
8	pipelines	1.81E-07	1.38E-06
9	New SDU	7.17E-06	5.45E-05
10	SW7-8	1.68E-05	1.27E-04
11	flowlines from FPSO	2.27E-06	1.73E-05
	Total for SGH	**5.59E-05**	**4.25E-04**

Table 5-10: Impairment Frequency for Objects Dropped at SGH

The frequency of equipment damage at the SGH is significantly lower than the previously calculated frequency. This is due to the reduced activities that will be carried out at the SGH for the SWRX project, compared to the previous drilling operations at field start-up.

Table 5-11 shows the Impairment Frequency for the subsea equipment at the new glory hole as a result of dropped objects during the NADC project.

	Base Case	
Target Name	**Actual Total Impairment Frequency for NA Project**	**Total Annualised Impairment Frequency (/yr)**
WI well 1	3.34E-05	2.00E-05
WI well 2	2.22E-05	1.24E-05
WI well 3	9.03E-05	4.69E-05
WI well 4	7.42E-05	3.90E-05
WI well 5	1.22E-04	6.19E-05
production well 1	7.54E-05	4.08E-05
production well 2	5.98E-05	3.26E-05
production well 3	4.66E-05	2.51E-05
production well 4	3.47E-05	1.76E-05
WI well 6	4.59E-06	2.33E-06
Contingency production well 1	N/A	N/A
Contingency production well 2	N/A	N/A
Contingency WI well 1	N/A	N/A
pipelines	1.71E-05	3.02E-05
production manifolds	1.75E-05	3.13E-05
WI manifolds	4.48E-05	3.13E-05
SDU & manifold flowlines	5.73E-05	1.02E-04
Additional equipment	1.18E-04	7.95E-05
Total for NADC	**8.18E-04**	**5.72E-04**

Table 5-11: Impairment Frequency for Objects Dropped at NADC (Base Case)

Table 5-12 shows the total frequency of damage to subsea targets for the drilling and completion of all thirteen wells, including the three contingency wells.

	Total Including Contingency Wells	
Target Name	**Actual Total Impairment Frequency for NA Project**	**Total Annualised Impairment Frequency (/yr)**
WI well 1	7.37E-05	3.17E-05
WI well 2	4.84E-05	1.99E-05
WI well 3	1.21E-04	4.80E-05
WI well 4	8.82E-05	3.55E-05
WI well 5	1.27E-04	4.91E-05
production well 1	7.95E-05	3.34E-05
production well 2	6.35E-05	2.69E-05
production well 3	5.24E-05	2.17E-05
production well 4	3.78E-05	1.46E-05
WI well 6	1.01E-05	3.89E-06
Contingency production well 1	1.97E-05	7.62E-06
Contingency production well 2	1.04E-05	4.02E-06
Contingency WI well 1	3.83E-06	1.48E-06
pipelines	3.40E-05	1.58E-05
production manifolds	3.47E-05	1.66E-05
WI manifolds	8.89E-05	4.19E-05
SDU & manifold flowlines	1.14E-04	5.35E-05
Additional equipment	2.33E-04	3.18E-05
Total for NADC	**1.24E-03**	**4.57E-04**

Table 5-12: Impairment Frequency for Objects Dropped at NADC (Total Including Contingency Wells)

Note that although the total risk of damage is higher for the case including the contingency wells (1.24E-03 as opposed to 8.18E-04), drilling the contingency wells extends the total duration of the project from 23.6 months to 31 months. Therefore once annualised, the total predicted frequency of damage is slightly higher for the Base Case than for the case including the contingency wells.

Table 5-8 and Table 5-9 show the frequency of damage to each target resulting in a hydrocarbon release, firstly for the Base Case and secondly for the Contingency Case. Note that the annualised Base Case frequency is higher than the Contingency case because the duration of the project will be longer if the contingency wells are drilled.

	Base Case	
Target Name	**Actual Total Loss of Containment Frequency for NA Project**	**Total Annualised Loss of Containment Frequency for NA Project**
WI well 1	N/A	N/A
WI well 2	N/A	N/A
WI well 3	N/A	N/A
WI well 4	N/A	N/A
WI well 5	N/A	N/A
production well 1	9.64E-05	1.67E-04
production well 2	4.61E-05	8.17E-05
production well 3	4.46E-05	7.79E-05
production well 4	0.00E+00	0.00E+00
WI well 6	N/A	N/A
Contingency WI well 7	N/A	N/A
Contingency production well 5	N/A	N/A
Contingency production well 6	N/A	N/A
pipelines	1.71E-05	3.02E-05
production manifolds	1.75E-05	3.13E-05
WI manifolds	N/A	N/A
SDU & manifold flowlines	5.73E-05	1.02E-04
Additional equipment	N/A	N/A
Total	**2.79E-04**	**4.90E-04**

Table 5-13: Loss of Containment Frequency for Objects Dropped at North Amethyst (Base Case)

	Total with Contingency Wells	
Target Name	**Actual Total Loss of Containment Frequency for NA Project**	**Total Annualised Loss of Containment Frequency for NA Project**
WI well 1	N/A	N/A
WI well 2	N/A	N/A
WI well 3	N/A	N/A
WI well 4	N/A	N/A
WI well 5	N/A	N/A
production well 1	1.01E-04	8.84E-05
production well 2	5.00E-05	4.50E-05
production well 3	4.83E-05	4.32E-05
production well 4	3.47E-06	5.34E-06
WI well 6	N/A	N/A
Contingency WI well 7	N/A	N/A
Contingency production well 5	0.00E+00	0.00E+00
Contingency production well 6	0.00E+00	0.00E+00
pipelines	3.40E-05	1.58E-05
production manifolds	3.47E-05	1.66E-05
WI manifolds	N/A	N/A
SDU & manifold flowlines	1.14E-04	5.35E-05
Additional equipment	N/A	N/A
Total	**3.85E-04**	**2.68E-04**

Table 5-14: Loss of Containment Frequency for Objects Dropped at North Amethyst (Contingency Case)

The total annualised frequency of loss of hydrocarbon containment from the production wells at North Amethyst is therefore 3.27E-04 per annum for the Base Case and 1.82E-04 per annum for the Contingency Case, whilst the loss of containment frequency from the flowlines and manifolds is 1.63E-04 per annum for the Base Case and 8.59E-05 per annum for the Contingency Case. As the Base Case values are higher, these will be carried forward to the MODU risk assessment in Section 6.

Similarly, impairment frequencies for the WWRX project are shown in Table 5-15 and Table 5-16.

	Base Case	
Target Name	**Actual Total Impairment Frequency for NA Project**	**Total Annualised Impairment Frequency (/yr)**
WI well 1	8.26E-05	3.65E-05
WI well 2	4.28E-05	1.85E-05
production well 1	9.90E-05	4.26E-05
production well 2	6.82E-05	2.98E-05
WI well 3	1.09E-04	4.42E-05
production well 3	6.77E-05	2.75E-05
WI well 4	4.73E-05	1.92E-05
production well 4	2.66E-05	1.08E-05
WI well 5	5.52E-06	2.24E-06
WI well 6	2.88E-05	1.17E-05
WI well 7	5.63E-05	2.28E-05
production well 5	4.65E-06	1.89E-06
Contingency WI well 8	N/A	N/A
Contingency Prod well 6	N/A	N/A
Contingency Prod well 7	N/A	N/A
pipelines	1.58E-05	1.10E-05
production manifolds	2.65E-05	1.79E-05
WI manifolds	6.66E-05	4.46E-05
SDU & manifold flowlines	9.10E-05	6.04E-05
Additional equipment	1.37E-04	2.68E-06
Total for WWRX	**9.75E-04**	**4.04E-04**

Table 5-15: Impairment Frequency for Objects Dropped at WWRX (Base Case)

	Total Including Contingency Wells	
Target Name	**Actual Total Impairment Frequency for NA Project**	**Total Annualised Impairment Frequency (/yr)**
WI well 1	1.66E-04	5.71E-05
WI well 2	7.06E-05	2.41E-05
production well 1	1.15E-04	3.72E-05
production well 2	7.53E-05	2.44E-05
WI well 3	1.19E-04	3.86E-05
production well 3	9.49E-05	3.08E-05
WI well 4	6.34E-05	2.06E-05
production well 4	6.01E-05	1.95E-05
WI well 5	6.52E-05	2.12E-05
WI well 6	1.52E-04	4.94E-05
WI well 7	6.80E-05	2.21E-05
production well 5	4.73E-05	1.54E-05
Contingency WI well 8	8.97E-05	2.91E-05
Contingency Prod well 6	2.89E-05	9.38E-06
Contingency Prod well 7	7.26E-06	2.36E-06
pipelines	3.40E-05	1.35E-05
production manifolds	3.47E-05	1.42E-05
WI manifolds	8.89E-05	3.56E-05
SDU & manifold flowlines	1.14E-04	4.54E-05
Additional equipment	2.32E-04	2.40E-06
Total for WWRX	**1.73E-03**	**5.12E-04**

Table 5-16: Impairment Frequency for Objects Dropped at WWRX (Total Including Contingency Wells)

From Table 5-16, it can be seen that, including the contingency wells (i.e. a total of fifteen wells), the overall predicted frequency of damage is **5.12E-04** per annum.

Whereas the Base Case risk of loss of hydrocarbon containment was higher than the contingency case for North Amethyst, the opposite is true for WWRX. This is due to the assumed order of drilling; the contingency wells are assumed to be located closer to existing Base Case wells and therefore the additional risk of damage is greater.

Table 5-8 and Table 5-9 show the frequency of damage to each target resulting in a hydrocarbon release, firstly for the Base Case and secondly for the Contingency Case. Note that the annualised Base Case frequency is higher than the Contingency case because the duration of the project will be longer if the contingency wells are drilled.

	Base Case	
Target Name	Actual Total Loss of Containment Frequency for NA Project	Total Annualised Loss of Containment Frequency for NA Project
WI well 1	N/A	N/A
WI well 2	N/A	N/A
production well 1	7.68E-05	5.16E-05
production well 2	6.42E-05	4.33E-05
WI well 3	N/A	N/A
production well 3	6.40E-05	3.89E-05
WI well 4	N/A	N/A
production well 4	2.33E-05	1.42E-05
WI well 5	N/A	N/A
WI well 6	N/A	N/A
WI well 7	N/A	N/A
production well 5	0.00E+00	0.00E+00
Contingency WI well 8	N/A	N/A
Contingency Prod well 6	N/A	N/A
Contingency Prod well 7	N/A	N/A
pipelines	1.58E-05	1.10E-05
production manifolds	2.65E-05	1.79E-05
WI manifolds	N/A	N/A
SDU & manifold flowlines	9.10E-05	6.04E-05
Additional equipment	N/A	N/A
Total	**2.71E-04**	**1.77E-04**

Table 5-17: Loss of Containment Frequency for Objects Dropped at WWRX (Base Case)

	Total with Contingency Wells	
Target Name	Actual Total Loss of Containment Frequency for NA Project	Total Annualised Loss of Containment Frequency for NA Project
WI well 1	N/A	N/A
WI well 2	N/A	N/A
production well 1	9.27E-05	7.01E-05
production well 2	7.16E-05	5.46E-05
WI well 3	N/A	N/A
production well 3	9.12E-05	6.41E-05
WI well 4	N/A	N/A
production well 4	5.68E-05	3.99E-05
WI well 5	N/A	N/A
WI well 6	N/A	N/A
WI well 7	N/A	N/A
production well 5	4.27E-05	3.00E-05
Contingency WI well 8	0.00E+00	0.00E+00
Contingency Prod well 6	0.00E+00	0.00E+00
Contingency Prod well 7	0.00E+00	0.00E+00
pipelines	3.40E-05	1.35E-05
production manifolds	3.47E-05	1.42E-05
WI manifolds	N/A	N/A
SDU & manifold flowlines	1.14E-04	4.54E-05
Additional equipment	N/A	N/A
Total	**4.24E-04**	**2.86E-04**

Table 5-18: Loss of Containment Frequency for Objects Dropped at WWRX (Contingency Case)

The total annualised frequency of loss of hydrocarbon containment from the production wells at WWRX is therefore 1.48E-04 per annum for the Base Case and 2.59E-04 per annum for the Contingency Case, whilst the loss of containment frequency from the flowlines and manifolds is 8.95E-05 per annum for the Base Case and 7.31E-05 per annum for the Contingency Case. The higher value in each case will be carried forward to the MODU risk assessment in Section 6.

5.12.1 Sensitivity – Larger MODU

It has not yet been confirmed that the GSF Grand Banks MODU will be used to carry out the drilling activities for the subsea extensions. A sensitivity has been performed based on the use of the much larger Henry Goodrich MODU. The sensitivity calculates the impact frequency for each well during the drilling of the thirteenth well at the NADC.

The Henry Goodrich is much larger than the Grand Banks; the distance between the port and starboard cranes is 76m (compared with 46m for the Grand Banks) and the maximum and minimum lifting radii are 48m and 20m respectively (compared to 36m and 16m for Grand Banks).

The moon pool is also larger on Henry Goodrich at 7.8m x 7.8m, compared to 6.4m x 6.4m on the GSF Grand Banks.

Table 5-19 shows the frequency of impact on each of the wells as a result of dropped objects from either MODU during the drilling of the thirteenth well at North Amethyst. Note that these are just the frequencies of impact during the drilling of the thirteenth well – not the total frequency of impact on each target.

	Impact Frequency (per annum)	
Target	Grand Banks	Henry Goodrich
WI well 1	4.62E-05	4.44E-05
WI well 2	1.46E-05	4.15E-06
WI well 3	2.20E-05	2.42E-05
WI well 4	1.32E-06	1.69E-06
WI well 5	2.04E-05	1.19E-05
Production Well 1	1.48E-06	9.66E-07
Production Well 2	1.20E-06	7.51E-07
Production Well 3	1.17E-06	1.50E-06
Production Well 4	9.48E-07	1.09E-06
WI well 6	2.27E-06	1.51E-06
Production Well 5	8.45E-06	6.44E-06
Production Well 6	1.77E-05	1.66E-05
WI well 7	8.32E-05	7.92E-05
Total	**1.83E-04**	**1.64E-04**

Table 5-19: Comparison of Impact Frequency at North Amethyst for Objects Dropped from Different MODUs

It can be seen that the impact frequencies are higher for objects dropped from the GSF Grand Banks MODU. When using the larger Henry Goodrich MODU, although this vessel produces a wider drop pattern, the majority of objects would fall outwith the areas where the wells are concentrated.

This sensitivity has been performed for North Amethyst, but as the dimensions and layout of the WWRX glory hole is the same, the above conclusion will also apply to the WWRX project.

5.13 Conclusions

The frequency of objects being dropped during lifting operations and impacting on subsea equipment with sufficient energy as to damage the equipment at the SWRX, NADC and WWRX Glory Holes is **8.14E-04, 5.72E-04** and **4.04E-04** per annum respectively. Including the drilling and completion of the three contingency wells at each Glory Hole changes the damage frequency to **1.11E-04, 4.57E-04** and **5.12E-04** per annum for SWRX, NADC and WWRX respectively.

Not all instances of damage to equipment will result in a loss of hydrocarbon containment; the Base Case frequency of loss of containment at the SWRX, NADC and WWRX Glory Holes is **4.87 E-04, 4.90E-04** and **1.77E-04** per annum respectively. Including the drilling and completion of the three contingency wells at each Glory Hole changes the loss of containment frequency to **6.81E-04, 2.68E-04** and **2.86E-04** per annum for SWRX, NADC and WWRX respectively.

The main reason for the lower loss of containment frequency from WWRX (compared to SWRX and NADC) is that the frequencies are annualised over the period of time taken to complete the project after the first batch of wells have been hooked-up. At WWRX, that period of time is significantly longer than at either SWRX or North Amethyst.

The higher annualised loss of containment frequency (base case v total) for each drill centre is carried forward to the MODU risk assessment. Using the higher frequencies will ensure conservatism in the MODU risk assessment.

The DSV risk assessment (SGH Glory Hole) uses the calculated impairment frequencies in Table 5-10 to determine the risks on the vessel. It is assumed that the risks associated with objects dropped from the DSV at the CGH during activities associated with the WWRX extension will be the same as those identified for the SGH. The risk assessments are found in Sections 6 & 7. The impairment frequencies will be split evenly and added to the leak frequency for the subsea production and gas lift facilities events.

6 MODU RISK ASSESSMENT

The analysis presented here is based upon the use of a semi-submersible MODU for the planned developments' drilling and completion activities. This assessment has identified hazards to which MODU personnel will be exposed during the well operations performed as part of the SWRX, WWRX and North Amethyst projects. 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 Case in place [27] which has been supported by QRA [26] 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 [6]. However, should the operations be planned for another MODU then this assessment should be revised to ensure that the specific MODU risks are addressed.

This assessment therefore focuses on the risks or hazards that are different as a result of the operations at the new drill centres. 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; the WWRX glory hole is located approximately 3km from the CGH, which is 2km from the FPSO and the North Amethyst glory hole is located approximately 7km from the FPSO. 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 [27], 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) – potential annual number of fatalities 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 [6] 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 each of the new drill centres, but that the frequency of occurrence of each hydrocarbon event may be different and this is assessed in more detail next.

6.1 Hydrocarbon Events

Hydrocarbon releases that occur as a result of operations at the new drill centres 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 which 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.

6.1.1 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); the frequency of hydrocarbon release as a result of objects dropped during the drilling and construction phases has been investigated in detail in Section 5.

6.1.1.1 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. At this stage the equipment / manifold information was based on that previously supplied for equipment at the Southern Glory Hole [5] and this shall be reviewed and revised as the Tieback Project progresses.

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 6-1. Failure rate data for each equipment item identified has been drawn from [28] 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 6-1: Sample Failure Rate Input Sheet

This process has been repeated for each of the subsea events identified. Each of the three drill centres has a production manifold and a gas lift manifold; although the number of wells tied in to each production manifold may be different, the leak frequency is assumed to be the same for the manifolds from each drill centre. Total release frequencies (per annum) for each set of subsea equipment is summarised in Table 6-1 below.

Event Description	Leak Frequency (/yr)		
	Small	Medium	Large
Subsea Release from production manifold and wells	1.43E-02	8.21E-04	4.39E-04
Subsea release from gas lift manifold	1.05E-02	4.38E-04	4.97E-05

Table 6-1: Equipment Failure Rates for Subsea Manifolds and Wellheads (Flowlines and Flexible Jumpers Not Included)

For subsea flowlines and flexible jumpers the latest AME release frequency data [29] (see Table 6-2) 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 6-2: Base PARLOC 2001 [29] Pipeline Release Frequency Data

The above data is based upon a length of flowline equivalent to 500m (typical safety zone).

Since not all of the steel flowline releases will be sufficiently close to the MODU to impact the rig, the results of the consequence analysis conducted and presented in Appendix A, have been used to determine the proportion of the steel flowline releases which can impact the rig. These are presented in Table 6-3 below. Again, this applies to MODU activities at any of the three new drill centres.

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

Table 6-3: Proportion of Steel 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 6-2 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 reduced by a factor of 50/500.

Overall pipeline and flexible flowline release frequencies for each subsea event can therefore be calculated for events occurring at each drill centre.

Medium (50mm) Releases From Gas Lift Flowlines & Flexible Jumpers:

Release Frequency = [0.05 x 9.9E-05 + 0.1 x 1.4E-04]$_{\text{(Table 6-2, Table 6-3)}}$ *= 1.89E-05/yr*

Results are presented in Table 6-4.

Event Description	Leak Frequency (/yr)		
	10mm	50mm	FB
Release from Production Flowlines	-	4.95E-06	5.23E-05
Release from Gas Lift Flowlines	8.85E-05	1.89E-05	4.88E-05

Table 6-4: 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 each of the new Glory Holes shall also be reviewed in this assessment.

Equipment failure release frequencies for each event are thus presented in Table 6-5 below.

Event Description	Leak Frequency (/yr)		
	10mm	50mm	FB
Subsea Release from Production Facilities	1.43E-02	8.26E-04	4.91E-04
Subsea Release from Gas Lift Facilities	1.06E-02	4.57E-04	9.86E-05

Table 6-5: Equipment Failure Subsea Hydrocarbon Events Release Frequencies

6.1.1.2 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 5

Each of the calculated 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.

It is assumed that dropped object incidents are most likely to result in a large hydrocarbon release. The frequency of release from the permanent subsea equipment (flowlines, manifolds etc.) is split evenly between the subsea hydrocarbon facilities events at that drill centre; this gives the following release frequencies, to be added to calculated release frequencies in Table 6-5.

Event Description	Leak Frequency (/yr)		
	10mm	50mm	FB
Subsea Release from SWRX Production Facilities	-	-	3.04E-04
Subsea Release from SWRX Gas Lift Facilities	-	-	3.04E-04
Subsea Release from North Amethyst Production Facilities	-	-	8.15E-05
Subsea Release from North Amethyst Gas Lift Facilities	-	-	8.15E-05
Subsea Release from WWRX Production Facilities	-	-	4.47E-05
Subsea Release from WWRX Gas Lift Facilities	-	-	4.47E-05

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

The frequency of damage to the production wells, as shown in Table 6-7 is added to the subsea blowout frequencies at each glory hole.

Event Description	Leak Frequency (/yr)		
	10mm	50mm	FB
Subsea Release from SWRX Production Wells	-	-	1.28E-05
Subsea Release from North Amethyst Production Wells	-	-	3.27E-04
Subsea Release from WWRX Production Wells	-	-	2.59E-04

Table 6-7: Subsea Hydrocarbon Events Release Frequencies as a Result of Dropped Object Incidents for NADC and WWRX

6.1.1.3 Fishing Impacts

The threat of impact to subsea pipelines as a result of fishing activities at the White Rose field was previously examined in [30], 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, safety 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.

6.1.1.4 Overall Release Frequencies

Bringing together the equipment failure rates calculated in Section 6.1.1.1 and dropped object failure rates presented in Section 6.1.1.2, overall annualised hydrocarbon release frequencies for subsea events are presented in Table 6-8 below.

Event Description	Leak Frequency (/yr)		
	10mm	50mm	FB
Subsea Release from SWRX Production Facilities	1.43E-02	8.26E-04	7.96E-04
Subsea Release from SWRX Gas Lift Facilities	1.06E-02	4.57E-04	4.03E-04
Subsea Blowout from SWRX	3.26E-03	-	8.25E-03
Drillfloor Blowout from SWRX	4.21E-03	2.53E-03	5.26E-04
Subsea Release from North Amethyst Production Facilities	1.43E-02	8.21E-04	5.21E-04
Subsea Release from North Amethyst Gas Lift Facilities	1.05E-02	4.38E-04	1.31E-04
Subsea Blowout from North Amethyst	3.18E-03	-	8.38E-03
Drillfloor Blowout from North Amethyst	4.11E-03	2.46E-03	5.13E-04
Subsea Release from WWRX Production Facilities	1.43E-02	8.21E-04	4.84E-04
Subsea Release from WWRX Gas Lift Facilities	1.05E-02	4.38E-04	9.44E-05
Subsea Blowout from WWRX	3.08E-03	-	8.05E-03
Drillfloor Blowout from WWRX	3.97E-03	2.38E-03	4.96E-04

Table 6-8: Overall Annualised Hydrocarbon Events Release Frequencies

6.1.1.5 Ignition Probabilities and Consequences

The ignition and explosion probabilities used in this QRA are based on the UKOOA ignition model [31,32], which determines the ignition probability based on the mass release rate, the type of fluid and the type of module in which it is released. The gas mass flowrate from the production flowline was determined based on a flash fraction of 7.3%.

The ignition and explosion probabilities for the releases from the subsea production and gas lift facilities at SWRX were previously [7] based on the Cox, Lees and Ang model [33]. The UKOOA model is now accepted as the industry standard for the calculation of hydrocarbon ignition probabilities and therefore the values have been revised.

Note that, as discussed in Section 4.3.2, the ignition probability for all blowout events has been taken to be 0.23.

Ignition probabilities for each release size are presented in Table 6-9 below.

Event Description	Ignition Probability		
	10mm	50mm	FB
Subsea Release/Dropped Object Damage from Production Facilities	-	0.022	0.1
Subsea Release/Dropped Object Damage from Gas Lift Facilities	-	0.025	0.1
Subsea Blowout	0.23	-	0.23
Drillfloor Blowout	0.23	0.23	0.23

Table 6-9: Ignition Probabilities for Subsea Releases

Releases from the subsea facilities at the new glory holes are assumed to be similar to previously assessed releases from the SDC equipment and therefore the ignition probabilities are also assumed to be the same. The production and gas lift flowlines are longer than the SDC flowlines back to the FPSO. However, the fire sizes and durations from the new flowlines are still 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 production and gas lift equipment have been included in the QRA model used previously for the MODU [6] to determine the risks to the MODU and personnel as a result of operations at each of the new drill centres.

6.1.2 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 Case [27] and QRAs [6,26] prepared previously. As they are not anticipated to change as a result of the tiebacks 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 drilling / construction operations are taken into account.

6.2 Non-Hydrocarbon Events

The following events have also been included in the assessment of the 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 Case [27] and QRA [6, 26] 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 each of the new drill centres have been described here in detail.

6.2.1 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 over the past 10 years for from the UK Civil Aviation Authority (CAA) [34], the following accident rates are applicable:

- Accident Rate during take-off/landing = 3.10E-06 per flight stage
- Accident Rate during flight = 5.57E-06 per hour flown
- Fatality Fraction (crash during flight) 0.12
- Fatality Fraction (crash during take off or landing 0.17

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)

= 2.98×10^{-5} 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

= 5.61E-03 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. Similarly, 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.

6.2.2 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 [35]. These FARs exclude marine, diving and helicopter risks.

Worker Group	Occupational FAR (per 10^8 working hours)
Drill Crew	9.2
Deck Crew	4.7
Motorman	4.7
Catering / Admin Crew	1
Divers	20

Table 6-10: 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 7.

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 2.02×10^{-4} per annum;
- deck crew 1.03×10^{-4} per annum;
- motorman 1.03×10^{-4} per annum;
- catering 2.18×10^{-5} per annum;
- divers 4.39×10^{-4} per annum;

Note that the occupational risks have been revised since the previous revision of the MODU risk assessment [7] to account for the most recent information presented in [36], [37], [38], [39] and [40] and is consistent with the values used in the most recent revision of the QRA [1].

6.2.3 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 unit's periods of operation at the new Glory Holes, 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 they are 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 be highly unlikely to be involved in a high velocity impact and so, given their smaller size (less than 5,000 Tonnes) will have relatively low impact energies. As a result it is considered that the energy of impact will be insufficient to cause significant damage to the unit.

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 a safety 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 [41].

This dataset has been used to determine the MODU ship collision risk as reported within the MODU Safety Case [27]. However, the same data set was also used for the SeaRose FPSO Safety Plan [42] 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 [27] information.

The frequency of severe or total loss ship collisions is therefore taken to be 5.3×10^{-5} per annum.

For MODU operations at each of the new Glory Hole locations, the resulting risk to personnel is presented in Table 6-11 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 6-11: Ship Collision Societal and Individual Risk Levels

These frequencies are generic and therefore it is recommended that a ship collision study for each of the individual Glory Holes 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.

6.2.4 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 [43] and [30].

The event tree presented in Figure 6-2 demonstrates how the risk to the MODU of iceberg collision has been considered within this analysis.

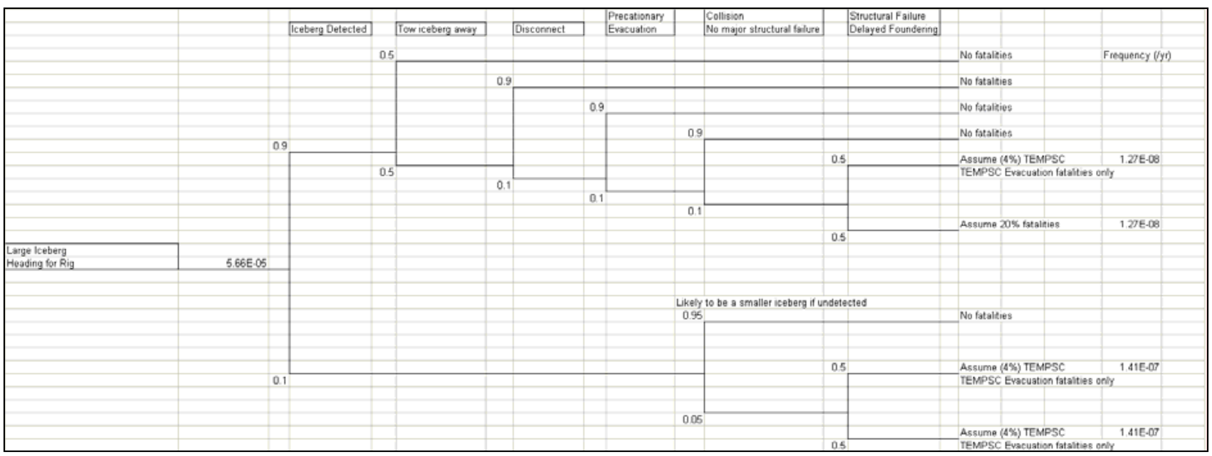


Figure 6-2: Iceberg Collision Event Tree

The frequency of hazardous outcomes and the potential fatality fraction following an iceberg collision are presented in Table 6-12.

Event	Frequency (per year)	Fatality Fraction
Iceberg collision resulting in rapid collapse	1.27×10^{-8}	0.2
Iceberg collision resulting in delayed foundering	2.96×10^{-7}	0.04

Table 6-12: Iceberg Collision Frequency and Fatality Fraction

For MODU operations at each Glory Hole the resulting risk to personnel is presented in Table 6-13 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 6-13: 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 new Glory Holes is the same as it shall be for any other location in the White Rose field. 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.

6.3 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.

6.4 Results

The MODU Risk Assessment has been carried out separately for drilling and construction activities at each of the new drill centres. The RISKMODEL summary output sheets are presented in Figure 6-3 – Figure 6-5.

RESULTS SUMMARY SHEET

TR Impairment Frequency within 1 hr	-	**1.93E-04**	**Highest IRPA Total**	-	**5.49E-04**	**Drill Crew**
TR Impairment Frequency	-	**3.69E-04**	**Hydrocarbon IRPA**	-	**2.81E-04**	
Hydrocarbon PLL	-	**3.18E-02**	**Non Hydrocarbon IRPA**	-	**2.67E-04**	
Non Hydrocarbon PLL	-	**2.84E-02**	**Freq. HC Release**	-	**0.2046**	
Total PLL	-	**6.03E-02**	**Freq. Ignited Events**	-	**0.0064**	

		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	2.09E-05	10.8%	4.18E-05	11.3%										
	HVAC Failure - Gas	6.03E-06	3.1%	6.03E-06	1.6%										
	HVAC Failure - Smoke	3.31E-07	0.2%	3.31E-07	0.1%										
	RainOut			1.40E-06	0.4%										
	Sea Fire	1.32E-04	68.4%	2.65E-04	71.8%										
	Thermal Breach	2.08E-05	10.7%	4.15E-05	11.3%										
Calculated PLL :															
Hydrocarbon	Immediate					1.35E-02	22.4%	1.94E-04	35.3%			1.81E-04	41.0%		
	Muster														
	TR Fatalities					1.06E-02	17.6%	5.37E-05	9.8%	5.80E-05	20.9%	5.35E-05	12.1%	5.80E-05	32.2%
	Evacuation Fatalities					6.27E-03	10.4%	3.33E-05	6.1%	3.35E-05	12.1%	3.30E-05	7.5%	3.35E-05	18.6%
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	0.3%	3.65E-07	0.1%	3.65E-07	0.1%	3.82E-06	0.9%	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	0.2%	8.52E-07	0.2%	4.17E-07	0.2%
	Fire - Helicopter Fuel	1.43E-06	0.7%	1.43E-06	0.4%	1.16E-03	1.9%			1.59E-05	5.7%				
Non Hydrocarbon	Helicopter Travel					5.61E-03	9.3%	2.98E-05	5.4%	2.98E-05	10.8%	2.98E-05	6.8%	2.98E-05	16.5%
	Occupational					1.58E-02	26.3%	2.01E-04	36.7%	1.03E-04	37.2%	1.03E-04	23.3%	2.19E-05	12.1%
	Loss of Stability					1.05E-03	1.7%	5.43E-06	1.0%	5.43E-06	2.0%	5.69E-06	1.3%	5.69E-06	3.2%
	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	6.3%	1.97E-05	3.6%	1.97E-05	7.1%	2.03E-05	4.6%	2.03E-05	11.3%
	Mechanical Failure - Lifting Equipment					3.96E-05	0.1%	6.18E-07	0.1%	6.18E-07	0.2%				
	Extreme Weather					3.28E-04	0.5%	6.33E-07	0.1%	7.35E-07	0.3%	7.35E-07	0.2%	7.35E-07	0.4%
	Ship Collision					1.63E-03	2.7%	8.68E-06	1.6%	8.68E-06	3.1%	8.68E-06	2.0%	8.68E-06	4.8%
	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	6.0%	1.15E-05	3.1%	5.24E-05	0.1%	2.56E-07	0.0%	2.56E-07	0.1%	2.56E-07	0.1%	3.02E-07	0.2%
Hydrocarbon Total						3.18E-02	52.8%	2.81E-04	51.3%	1.08E-04	39.0%	2.72E-04	61.6%	9.23E-05	51.1%
Non Hydrocarbon Total						2.84E-02	47.2%	2.67E-04	48.7%	1.69E-04	61.0%	1.69E-04	38.4%	8.81E-05	48.9%
Totals		1.93E-04	100.0%	3.69E-04	100.0%	6.03E-02	100.0%	5.49E-04	100.0%	2.77E-04	100.0%	4.41E-04	100.0%	1.80E-04	100.0%

Figure 6-3: MODU Risk Model Results at SWRX Glory Hole

RESULTS SUMMARY SHEET

TR Impairment Frequency within 1 hr	-	**1.92E-04**	**Highest IRPA Total**	-	**5.43E-04**	**Drill Crew**
TR Impairment Frequency	-	**3.67E-04**	**Hydrocarbon IRPA**	-	**2.76E-04**	
Hydrocarbon PLL	-	**3.13E-02**	**Non Hydrocarbon IRPA**	-	**2.67E-04**	
Non Hydrocarbon PLL	-	**2.84E-02**	**Freq. HC Release**	-	**0.2046**	
Total PLL	-	**5.98E-02**	**Freq. Ignited Events**	-	**0.0063**	

		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	2.04E-05	10.6%	4.07E-05	11.1%										
	HVAC Failure - Gas	5.43E-06	2.8%	5.43E-06	1.5%										
	HVAC Failure - Smoke	3.32E-07	0.2%	3.32E-07	0.1%										
	RainOut			1.36E-06	0.4%										
	Sea Fire	1.33E-04	69.1%	2.66E-04	72.4%										
	Thermal Breach	2.02E-05	10.5%	4.05E-05	11.0%										
Calculated PLL :															
Hydrocarbon	Immediate					1.31E-02	22.0%	1.89E-04	34.8%			1.74E-04	40.2%		
	Muster														
	TR Fatalities					1.05E-02	17.6%	5.34E-05	9.8%	5.76E-05	20.9%	5.31E-05	12.2%	5.76E-05	32.1%
	Evacuation Fatalities					6.22E-03	10.4%	3.30E-05	6.1%	3.32E-05	12.0%	3.28E-05	7.5%	3.32E-05	18.5%
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	0.3%	3.65E-07	0.1%	3.65E-07	0.1%	3.82E-06	0.9%	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	0.2%	8.52E-07	0.2%	4.17E-07	0.2%
	Fire - Helicopter Fuel	1.43E-06	0.7%	1.43E-06	0.4%	1.16E-03	1.9%			1.59E-05	5.8%				
Non Hydrocarbon	Helicopter Travel					5.61E-03	9.4%	2.98E-05	5.5%	2.98E-05	10.8%	2.98E-05	6.9%	2.98E-05	16.6%
	Occupational					1.58E-02	26.5%	2.01E-04	37.1%	1.03E-04	37.2%	1.03E-04	23.7%	2.19E-05	12.2%
	Loss of Stability					1.05E-03	1.8%	5.43E-06	1.0%	5.43E-06	2.0%	5.69E-06	1.3%	5.69E-06	3.2%
	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	6.3%	1.97E-05	3.6%	1.97E-05	7.1%	2.03E-05	4.7%	2.03E-05	11.3%
	Mechanical Failure - Lifting Equipment					3.96E-05	0.1%	6.18E-07	0.1%	6.18E-07	0.2%				
	Extreme Weather					3.28E-04	0.5%	6.33E-07	0.1%	7.35E-07	0.3%	7.35E-07	0.2%	7.35E-07	0.4%
	Ship Collision					1.63E-03	2.7%	8.68E-06	1.6%	8.68E-06	3.1%	8.68E-06	2.0%	8.68E-06	4.8%
	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	6.0%	1.15E-05	3.1%	5.24E-05	0.1%	2.56E-07	0.0%	2.56E-07	0.1%	2.56E-07	0.1%	3.02E-07	0.2%
Hydrocarbon Total						3.13E-02	52.4%	2.76E-04	50.8%	1.08E-04	38.9%	2.65E-04	61.0%	9.16E-05	51.0%
Non Hydrocarbon Total						2.84E-02	47.6%	2.67E-04	49.2%	1.69E-04	61.1%	1.69E-04	39.0%	8.81E-05	49.0%
Totals		1.92E-04	100.0%	3.67E-04	100.0%	5.98E-02	100.0%	5.43E-04	100.0%	2.76E-04	100.0%	4.34E-04	100.0%	1.80E-04	100.0%

Figure 6-4: MODU Risk Model Results at North Amethyst Glory Hole

RESULTS SUMMARY SHEET

TR Impairment Frequency within 1 hr	**-**	**1.85E-04**	**Highest IRPA Total**	**-**	**5.34E-04**	**Drill Crew**
TR Impairment Frequency	**-**	**3.54E-04**	**Hydrocarbon IRPA**	**-**	**2.67E-04**	
Hydrocarbon PLL	**-**	**3.02E-02**	**Non Hydrocarbon IRPA**	**-**	**2.67E-04**	
Non Hydrocarbon PLL	**-**	**2.84E-02**	**Freq. HC Release**	**-**	**0.2046**	
Total PLL	**-**	**5.87E-02**	**Freq. Ignited Events**	**-**	**0.0061**	

		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	1.97E-05	10.6%	3.94E-05	11.1%										
	HVAC Failure - Gas	5.16E-06	2.8%	5.16E-06	1.5%										
	HVAC Failure - Smoke	3.20E-07	0.2%	3.20E-07	0.1%										
	RainOut			1.32E-06	0.4%										
	Sea Fire	1.28E-04	68.9%	2.56E-04	72.2%										
	Thermal Breach	1.96E-05	10.6%	3.92E-05	11.1%										
Calculated PLL :															
Hydrocarbon	Immediate					1.27E-02	21.6%	1.83E-04	34.2%			1.67E-04	39.4%		
	Muster														
	TR Fatalities					1.01E-02	17.3%	5.15E-05	9.6%	5.56E-05	20.3%	5.12E-05	12.1%	5.56E-05	31.5%
	Evacuation Fatalities					6.00E-03	10.2%	3.18E-05	6.0%	3.20E-05	11.7%	3.16E-05	7.5%	3.20E-05	18.1%
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	0.3%	3.65E-07	0.1%	3.65E-07	0.1%	3.82E-06	0.9%	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	0.2%	8.52E-07	0.2%	4.17E-07	0.2%
	Fire - Helicopter Fuel	1.43E-06	0.8%	1.43E-06	0.4%	1.16E-03	2.0%			1.59E-05	5.8%				
Non Hydrocarbon	Helicopter Travel					5.61E-03	9.6%	2.98E-05	5.6%	2.98E-05	10.9%	2.98E-05	7.0%	2.98E-05	16.9%
	Occupational					1.58E-02	27.0%	2.01E-04	37.7%	1.03E-04	37.7%	1.03E-04	24.3%	2.19E-05	12.4%
	Loss of Stability					1.05E-03	1.8%	5.43E-06	1.0%	5.43E-06	2.0%	5.69E-06	1.3%	5.69E-06	3.2%
	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	6.4%	1.97E-05	3.7%	1.97E-05	7.2%	2.03E-05	4.8%	2.03E-05	11.5%
	Mechanical Failure - Lifting Equipment					3.96E-05	0.1%	6.18E-07	0.1%	6.18E-07	0.2%				
	Extreme Weather					3.28E-04	0.6%	6.33E-07	0.1%	7.35E-07	0.3%	7.35E-07	0.2%	7.35E-07	0.4%
	Ship Collision					1.63E-03	2.8%	8.68E-06	1.6%	8.68E-06	3.2%	8.68E-06	2.0%	8.68E-06	4.9%
	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	6.2%	1.15E-05	3.3%	5.24E-05	0.1%	2.56E-07	0.0%	2.56E-07	0.1%	2.56E-07	0.1%	3.02E-07	0.2%
Hydrocarbon Total						3.02E-02	51.5%	2.67E-04	49.9%	1.04E-04	38.2%	2.55E-04	60.1%	8.84E-05	50.1%
Non Hydrocarbon Total						2.84E-02	48.5%	2.67E-04	50.1%	1.69E-04	61.8%	1.69E-04	39.9%	8.81E-05	49.9%
Totals		1.85E-04	100.0%	3.54E-04	100.0%	5.87E-02	100.0%	5.34E-04	100.0%	2.73E-04	100.0%	4.24E-04	100.0%	1.76E-04	100.0%

Figure 6-5: MODU Risk Model Results at WWRX Glory Hole

6.4.1 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 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.

6.4.1.1 SWRX

The MODU TRIF within 1 hour for the SWRX development is **1.93E-04** per annum.

The Total Hydrocarbon MODU TRIF for the SWRX Project is **3.69E-04** per annum, which includes events that cause impairment after 1 hour.

The calculated TRIF for the representative impairment parameters are presented in Table 6-14.

Source	**Within 1 Hour**		**Total**	
	TRIF (per annum)	**%**	**TRIF (per annum)**	**%**
Derrick Collapse & Thermal	2.09E-05	11%	4.18E-05	11%
HVAC Failure - Gas	6.03E-06	3%	6.03E-06	2%
HVAC Failure - Smoke	3.31E-07	0%	3.31E-07	0%
RainOut	0.00E+00	0%	1.40E-06	0%
Sea Fire	1.32E-04	68%	2.65E-04	72%
Thermal Breach	2.08E-05	11%	4.15E-05	11%
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	1%	1.43E-06	0%
Fire - Accommodation	1.15E-05	6%	1.15E-05	3%
	1.93E-04	**100%**	**3.69E-04**	**100%**

Table 6-14: Hydrocarbon TRIF Results for the MODU at SWRX

Table 6-15 below shows the contribution from each of the fire and explosion events to the overall hydrocarbon TR impairment frequency within one hour and the total frequency, a discussion of the TRIF results for all three drill centres follows in Section 6.4.1.4.

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	0.7%
4	Engine Room Fire	1.57E-08	0.0%
5	Acommodation Fire	1.15E-05	6.0%
13	Subsea Release from SWRX Production Facilities	0.00E+00	0.0%
14	Subsea Release from SWRX Gas Lift Facilities	1.15E-06	0.6%
15	Subsea Blowouts at SWRX	1.37E-04	71.1%
16	Drillfloor Blowouts at SWRX	4.16E-05	21.5%
	Total	**1.93E-04**	**100.0%**

Table 6-15: TR Impairment Frequency Contribution for Fire and Explosion Events (SWRX)

6.4.1.2 North Amethyst

The MODU TRIF within 1 hour for the North Amethyst Project is **1.92E-04** per annum.

The Total Hydrocarbon MODU TRIF for the North Amethyst Project is **3.67E-04** per annum.

The calculated TRIF for the representative impairment parameters are presented in Table 6-16.

Source	Within 1 Hour		Total	
	TRIF (per annum)	%	TRIF (per annum)	%
Derrick Collapse & Thermal	2.04E-05	11%	4.07E-05	11%
HVAC Failure - Gas	5.43E-06	3%	5.43E-06	1%
HVAC Failure - Smoke	3.32E-07	0%	3.32E-07	0%
RainOut	0.00E+00	0%	1.36E-06	0%
Sea Fire	1.33E-04	69%	2.66E-04	72%
Thermal Breach	2.02E-05	11%	4.05E-05	11%
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	1%	1.43E-06	0%
Fire - Accommodation	1.15E-05	6%	1.15E-05	3%
	1.92E-04	**100%**	**3.67E-04**	**100%**

Table 6-16: Hydrocarbon TRIF Results for the MODU at North Amethyst

Table 6-19 below shows the contribution from each of the fire and explosion events to the overall hydrocarbon TR impairment frequency within one hour and to the total frequency, a discussion of the TRIF results for all three drill centres follows in Section 6.4.1.4.

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	0.7%
4	Engine Room Fire	1.57E-08	0.0%
5	Acommodation Fire	1.15E-05	6.0%
17	Subsea Release from North Amethyst Production Facilities	0.00E+00	0.0%
18	Subsea Release from North Amethyst Gas Lift Facilities	5.30E-07	0.3%
19	Subsea Blowouts at North Amethyst	1.38E-04	71.8%
20	Drillfloor Blowouts at North Amethyst	4.06E-05	21.2%
	Total	**1.92E-04**	**100.0%**

Table 6-17: TR Impairment Frequency Contribution for Fire and Explosion Events

6.4.1.3 WWRX

The MODU TRIF within 1 hour for the WWRX Project is **1.85E-04** per annum.

The Total Hydrocarbon MODU TRIF for the WWRX Project is **3.54E-04** per annum.

The calculated TRIF for the representative impairment parameters are presented in Table 6-18.

Source	Within 1 Hour		Total	
	TRIF (per annum)	%	TRIF (per annum)	%
Derrick Collapse & Thermal	1.97E-05	11%	3.94E-05	11%
HVAC Failure - Gas	5.16E-06	3%	5.16E-06	1%
HVAC Failure - Smoke	3.20E-07	0%	3.20E-07	0%
RainOut	0.00E+00	0%	1.32E-06	0%
Sea Fire	1.28E-04	69%	2.56E-04	72%
Thermal Breach	1.96E-05	11%	3.92E-05	11%
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	1%	1.43E-06	0%
Fire - Accommodation	1.15E-05	6%	1.15E-05	3%
	1.85E-04	**100%**	**3.54E-04**	**100%**

Table 6-18: Hydrocarbon TRIF Results for the Base Case (WWRX)

Table 6-19 below shows the contribution from each of the fire and explosion events to the overall hydrocarbon TR impairment frequency within one hour and to the total frequency, a discussion of the TRIF results for all three drill centres follows in Section 6.4.1.4.

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	0.8%
4	Engine Room Fire	1.57E-08	0.0%
5	Acommodation Fire	1.15E-05	6.2%
21	Subsea Release from WWRX Production Facilities	0.00E+00	0.0%
22	Subsea Release from WWRX Gas Lift Facilities	4.47E-07	0.2%
23	Subsea Blowouts at WWRX	1.33E-04	71.6%
24	Drillfloor Blowouts at WWRX	3.93E-05	21.2%
	Total	**1.85E-04**	**100.0%**

Table 6-19: TR Impairment Frequency Contribution for Fire and Explosion Events (WWRX)

6.4.1.4 Discussion of Results

The results show that, for all of the new drill centres, the main contributors are blowout events, either subsea or on the drill floor. These account for approximately 93% of the TRIF within 1 hour and accommodation fires account for around a further 6% of the TRIF.

Husky Oil 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)					
		SWRX	%	North Amethyst	%	WWRX	%
1	Mud Room Fire	4.41E-10	0.0%	4.41E-10	0.0%	4.41E-10	0.0%
2	Shaker Room Fire	1.99E-08	0.0%	1.99E-08	0.0%	1.99E-08	0.0%
3	Helifuel Fire	1.43E-06	0.3%	1.43E-06	0.3%	1.43E-06	0.3%
4	Engine Room Fire	1.57E-08	0.0%	1.57E-08	0.0%	1.57E-08	0.0%
5	Acommodation Fire	1.15E-05	2.5%	1.15E-05	2.5%	1.15E-05	2.5%
6	Subsea Release from Production Facilities	0.00E+00	0.0%	0.00E+00	0.0%	0.00E+00	0.0%
7	Subsea Release from Gas Lift Facilities	1.15E-06	0.2%	5.30E-07	0.1%	4.47E-07	0.1%
8	Subsea Blowouts	1.37E-04	29.6%	1.38E-04	29.8%	1.33E-04	29.0%
9	Drillfloor Blowouts	4.16E-05	9.0%	4.06E-05	8.8%	3.93E-05	8.6%
10	Mooring Failure	1.85E-06	0.4%	1.85E-06	0.4%	1.85E-06	0.4%
11	Loss of Tow	1.50E-05	3.2%	1.50E-05	3.2%	1.50E-05	3.3%
12	Structural Failure	1.01E-04	21.7%	1.01E-04	21.8%	1.01E-04	22.1%
13	Extreme Weather	1.00E-04	21.5%	1.00E-04	21.6%	1.00E-04	21.9%
14	Ship Collision	5.32E-05	11.4%	5.32E-05	11.5%	5.32E-05	11.6%
15	Iceberg Collision	3.08E-07	0.1%	3.08E-07	0.1%	3.08E-07	0.1%
	Total	4.65E-04	100.0%	4.63E-04	100.0%	4.57E-04	100.0%

Table 6-20: MODU Impairment Based TR Integrity Frequency Contribution

It can be seen from Table 6-20 that, for each case, the overall frequency of impairment of the TR integrity is below 1E-03 per annum. However, the frequencies of subsea blowouts causing loss of the TR integrity exceed the 1E-04 per annum frequency for a single major accident hazard, however, they are of the same order of magnitude, and within the range of reasonable sensitivities for a QRA of this nature. Structural failures also exceed 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 operations at the new drill centres is low. It should also be noted that the subsea blowout frequency shown includes the frequency of loss of containment from the production wells caused by dropped objects.

6.4.2 Potential Loss of Life (PLL)

6.4.2.1 SWRX

The total PLL for the MODU based on activities at SWRX is **6.03E-02** fatalities per annum, of which 53% can be attributed to hydrocarbon events and 47% to non-hydrocarbon events.

The different types of fatalities which make up the total PLL are shown in Table 6-21, and discussed below.

Source	**PLL per Annum**	**%**
Immediate Hydrocarbon	1.35E-02	22%
Delayed Hydrocarbon	1.69E-02	28%
Occupational	1.58E-02	26%
Helicopter Travel	5.61E-03	9%
Structural Failure	3.77E-03	6%
Hydrocarbon - Rig Specific	1.44E-03	2%
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	**6.03E-02**	**100%**

Table 6-21: Potential Loss of Life (PLL) for SWRX Project

6.4.2.2 North Amethyst

The total PLL for the MODU based on activities at North Amethyst is **5.98E-02** fatalities per annum, of which 52% can be attributed to hydrocarbon events and 48% to non-hydrocarbon events.

The different types of fatalities which make up the total PLL are shown in Table 6-22.

Source	**PLL per Annum**	**%**
Immediate Hydrocarbon	1.31E-02	22%
Delayed Hydrocarbon	1.67E-02	28%
Occupational	1.58E-02	27%
Helicopter Travel	5.61E-03	9%
Structural Failure	3.77E-03	6%
Hydrocarbon - Rig Specific	1.44E-03	2%
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	**5.98E-02**	**100%**

Table 6-22: Potential Loss of Life (PLL) for North Amethyst Project

6.4.2.3 WWRX

The total PLL for the MODU based on activities at WWRX is **5.87E-02** fatalities per annum, of which 52% can be attributed to hydrocarbon events and 48% to non-hydrocarbon events.

The different types of fatalities which make up the total PLL are shown in Table 6-23.

Source	**PLL per Annum**	**%**
Immediate Hydrocarbon	1.27E-02	22%
Delayed Hydrocarbon	1.61E-02	28%
Occupational	1.58E-02	27%
Helicopter Travel	5.61E-03	10%
Structural Failure	3.77E-03	6%
Hydrocarbon - Rig Specific	1.44E-03	2%
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	**5.87E-02**	**100%**

Table 6-23: Potential Loss of Life (PLL) for WWRX Project

6.4.2.4 Discussion of Results

At each of the drill centres, the PLL due to immediate fatalities accounts for around 22% 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 around 28% 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 36-37% 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.

6.4.3 Individual Risk Per Annum (IRPA)

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

6.4.3.1 SWRX

For the Drill Crew, the IRPA is **5.49E-04** per annum, for Maintenance/Deck Crew it is **2.77E-04** per annum. The Motorman Crew has an IRPA of **4.41E-04** per annum and the lowest risk group is the Catering/Admin Crew, whose IRPA is **1.80E-04** per annum.

The breakdown of contributors to the IRPAs for the main worker categories on the MODU are presented below in Table 6-24.

Source	Drill Crew	%	Maintenance / Deck	%	Motorman	%	Catering	%
Immediate Hydrocarbon	1.94E-04	35.3%	0.00E+00	0.0%	1.81E-04	41.0%	0.00E+00	0.0%
Delayed Hydrocarbon	8.69E-05	15.8%	9.15E-05	33.0%	8.65E-05	19.6%	9.15E-05	50.7%
Hydrocarbon - Rig Specific	7.83E-07	0.1%	1.67E-05	6.0%	4.69E-06	1.1%	7.83E-07	0.4%
Helicopter Travel	2.98E-05	5.4%	2.98E-05	10.8%	2.98E-05	6.8%	2.98E-05	16.5%
Occupational	2.01E-04	36.7%	1.03E-04	37.2%	1.03E-04	23.3%	2.19E-05	12.1%
Loss of Stability	5.43E-06	1.0%	5.43E-06	2.0%	5.69E-06	1.3%	5.69E-06	3.2%
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	3.6%	1.97E-05	7.1%	2.03E-05	4.6%	2.03E-05	11.3%
Mechanical Failure - Lifting Equipment	6.18E-07	0.1%	6.18E-07	0.2%	0.00E+00	0.0%	0.00E+00	0.0%
Extreme Weather	6.33E-07	0.1%	7.35E-07	0.3%	7.35E-07	0.2%	7.35E-07	0.4%
Ship Collision	8.68E-06	1.6%	8.68E-06	3.1%	8.68E-06	2.0%	8.68E-06	4.8%
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	0.0%	2.56E-07	0.1%	2.56E-07	0.1%	3.02E-07	0.2%
Totals	**5.49E-04**	**100.00%**	**2.77E-04**	**100.0%**	**4.41E-04**	**100.0%**	**1.80E-04**	**100.0%**

Table 6-24: MODU IRPA Results for the SWRX Project

6.4.3.2 North Amethyst

For the Drill Crew, the IRPA is **5.43E-04** per annum, for Maintenance/Deck Crew it is **2.76E-04** per annum. The Motorman Crew has an IRPA of **4.34E-04** per annum and the lowest risk group is the Catering/Admin Crew, whose IRPA is **1.80E-04** per annum.

The breakdown of contributors to the IRPAs for the main worker categories on the MODU are presented below in Table 6-25.

Source	Drill Crew	%	Maintenance / Deck	%	Motorman	%	Catering	%
Immediate Hydrocarbon	1.89E-04	34.8%	0.00E+00	0.0%	1.74E-04	40.2%	0.00E+00	0.0%
Delayed Hydrocarbon	8.64E-05	15.9%	9.09E-05	32.9%	8.58E-05	19.8%	9.09E-05	50.5%
Hydrocarbon - Rig Specific	7.83E-07	0.1%	1.67E-05	6.0%	4.69E-06	1.1%	7.83E-07	0.4%
Helicopter Travel	2.98E-05	5.5%	2.98E-05	10.8%	2.98E-05	6.9%	2.98E-05	16.6%
Occupational	2.01E-04	37.1%	1.03E-04	37.2%	1.03E-04	23.7%	2.19E-05	12.2%
Loss of Stability	5.43E-06	1.0%	5.43E-06	2.0%	5.69E-06	1.3%	5.69E-06	3.2%
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	3.6%	1.97E-05	7.1%	2.03E-05	4.7%	2.03E-05	11.3%
Mechanical Failure - Lifting Equipment	6.18E-07	0.1%	6.18E-07	0.2%	0.00E+00	0.0%	0.00E+00	0.0%
Extreme Weather	6.33E-07	0.1%	7.35E-07	0.3%	7.35E-07	0.2%	7.35E-07	0.4%
Ship Collision	8.68E-06	1.6%	8.68E-06	3.1%	8.68E-06	2.0%	8.68E-06	4.8%
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	0.0%	2.56E-07	0.1%	2.56E-07	0.1%	3.02E-07	0.2%
Totals	**5.43E-04**	**100.00%**	**2.76E-04**	**100.0%**	**4.34E-04**	**100.0%**	**1.80E-04**	**100.0%**

Table 6-25: MODU IRPA Results for the North Amethyst Project

6.4.3.3 WWRX

For the Drill Crew, the IRPA is **5.34E-04** per annum, for Maintenance/Deck Crew it is **2.73E-04** per annum. The Motorman Crew has an IRPA of **4.24E-04** per annum and the lowest risk group is the Catering/Admin Crew, whose IRPA is **1.76E-04** per annum.

The breakdown of contributors to the IRPAs for the main worker categories on the MODU are presented below in Table 6-26.

Source	Drill Crew	%	Maintenance / Deck	%	Motorman	%	Catering	%
Immediate Hydrocarbon	1.83E-04	34.2%	0.00E+00	0.0%	1.67E-04	39.4%	0.00E+00	0.0%
Delayed Hydrocarbon	8.33E-05	15.6%	8.76E-05	32.1%	8.27E-05	19.5%	8.76E-05	49.6%
Hydrocarbon - Rig Specific	7.83E-07	0.1%	1.67E-05	6.1%	4.69E-06	1.1%	7.83E-07	0.4%
Helicopter Travel	2.98E-05	5.6%	2.98E-05	10.9%	2.98E-05	7.0%	2.98E-05	16.9%
Occupational	2.01E-04	37.7%	1.03E-04	37.7%	1.03E-04	24.3%	2.19E-05	12.4%
Loss of Stability	5.43E-06	1.0%	5.43E-06	2.0%	5.69E-06	1.3%	5.69E-06	3.2%
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	3.7%	1.97E-05	7.2%	2.03E-05	4.8%	2.03E-05	11.5%
Mechanical Failure - Lifting Equipment	6.18E-07	0.1%	6.18E-07	0.2%	0.00E+00	0.0%	0.00E+00	0.0%
Extreme Weather	6.33E-07	0.1%	7.35E-07	0.3%	7.35E-07	0.2%	7.35E-07	0.4%
Ship Collision	8.68E-06	1.6%	8.68E-06	3.2%	8.68E-06	2.0%	8.68E-06	4.9%
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	0.0%	2.56E-07	0.1%	2.56E-07	0.1%	3.02E-07	0.2%
Totals	**5.34E-04**	**100.00%**	**2.73E-04**	**100.0%**	**4.24E-04**	**100.0%**	**1.76E-04**	**100.0%**

Table 6-26: MODU IRPA Results for the WWRX Project

6.4.3.4 Discussion of Results

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 drill 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 1E-03 per annum.

6.5 MODU Risk Assessment for Previous White Rose Activities

Figure 6-6 shows the risk levels that were previously calculated for the MODU carrying out drilling operations in the White Rose field. Details of the previous study are presented in [6], although the risk figures have been updated to incorporate revised dropped object frequencies, as detailed in [5].

It can be seen that the TRIF for the MODU carrying out drilling activities as part of the new extension projects are slightly higher than the previously calculated risks, primarily due to the increase in the number of wells to be drilled and completed. The IRPAs have been shown to be lower, this is primarily due to the revision of the Occupational risks.

Table 6-27 compares the main risk parameters for the SWRX, WWRX and North Amethyst projects with those from the previous study.

RESULTS SUMMARY SHEET

TR Impairment Frequency within 1 hr	**-**	**1.82E-04**	**Highest IRPA Total**	**-**	**6.08E-04**	**Drill Crew**
TR Impairment Frequency	**-**	**3.39E-04**	**Hydrocarbon IRPA**	**-**	**2.85E-04**	
Hydrocarbon PLL	**-**	**3.50E-02**	**Non Hydrocarbon IRPA**	**-**	**3.24E-04**	
Non Hydrocarbon PLL	**-**	**2.99E-02**	**Freq. HC Release**	**-**	**0.207633037**	
Total PLL	**-**	**6.49E-02**	**Freq. Ignited Events**	**-**	**0.007233496**	

		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	2.17E-05	11.9%	4.33E-05	12.8%										
	HVAC Failure - Gas	4.75E-06	2.6%	4.75E-06	1.4%										
	HVAC Failure - Smoke	2.81E-07	0.2%	2.81E-07	0.1%										
	RainOut			1.45E-06	0.4%										
	Sea Fire	1.21E-04	66.3%	2.33E-04	68.8%										
	Thermal Breach	2.15E-05	11.8%	4.31E-05	12.7%										
Calculated PLL :															
Hydrocarbon	Immediate					1.74E-02	26.8%	2.01E-04	33.0%			2.93E-04	51.1%		
	Muster														
	TR Fatalities					1.04E-02	16.0%	5.24E-05	8.6%	5.69E-05	19.2%	5.22E-05	9.1%	5.69E-05	38.0%
	Evacuation Fatalities					5.74E-03	8.9%	3.05E-05	5.0%	3.07E-05	10.3%	3.03E-05	5.3%	3.07E-05	20.5%
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	0.3%	3.65E-07	0.1%	3.65E-07	0.1%	3.82E-06	0.7%	3.65E-07	0.2%
	Fire - Engine Room	1.57E-08	0.0%	1.57E-08	0.0%	9.23E-05	0.1%	4.17E-07	0.1%	4.17E-07	0.1%	8.52E-07	0.1%	4.17E-07	0.3%
	Fire - Helicopter Fuel	1.43E-06	0.8%	1.43E-06	0.4%	1.16E-03	1.8%			1.59E-05	5.4%				
Non Hydrocarbon	Helicopter Travel					5.61E-03	8.6%	2.98E-05	4.9%	2.98E-05	10.1%	2.98E-05	5.2%	2.98E-05	19.9%
	Occupational					1.79E-02	27.6%	2.63E-04	43.2%	1.31E-04	44.3%	1.31E-04	22.9%		
	Loss of Stability					1.05E-03	1.6%	5.43E-06	0.9%	5.43E-06	1.8%	5.69E-06	1.0%	5.69E-06	3.8%
	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	0.3%
	Structural Failure					3.77E-03	5.8%	1.97E-05	3.2%	1.97E-05	6.6%	2.03E-05	3.5%	2.03E-05	13.5%
	Mechanical Failure - Lifting Equipment					3.96E-05	0.1%	6.18E-07	0.1%	6.18E-07	0.2%				
	Extreme Weather					3.28E-04	0.5%	6.33E-07	0.1%	7.35E-07	0.2%	7.35E-07	0.1%	7.35E-07	0.5%
	Ship Collision					1.05E-03	1.6%	3.70E-06	0.6%	3.70E-06	1.2%	3.94E-06	0.7%	3.94E-06	2.6%
	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	6.3%	1.15E-05	3.4%	5.24E-05	0.1%	2.56E-07	0.0%	2.56E-07	0.1%	2.56E-07	0.0%	3.02E-07	0.2%
Hydrocarbon Total						3.50E-02	53.9%	2.85E-04	46.8%	1.04E-04	35.1%	3.80E-04	66.3%	8.83E-05	59.0%
Non Hydrocarbon Total						2.99E-02	46.1%	3.24E-04	53.2%	1.92E-04	64.9%	1.93E-04	33.7%	6.15E-05	41.0%
Totals		1.82E-04	100.0%	3.39E-04	100.0%	6.49E-02	100.0%	6.08E-04	100.0%	2.97E-04	100.0%	5.73E-04	100.0%	1.50E-04	100.0%

Figure 6-6: Risk Assessment Results from Previous MODU Study

Risk Parameter	**WR Development**	**SWRX Project**	**% Change**	**NADC Project**	**% Change**	**WWRX Project**	**% Change**
TRIF (<1hr)	1.82E-04	1.93E-04	6%	1.92E-04	5%	1.85E-04	2%
Impairment Based TRIF	4.53E-04	4.65E-04	3%	4.63E-04	2%	4.57E-04	1%
PLL – Hydrocarbon	3.50E-02	3.18E-02	-9%	3.13E-02	-11%	3.02E-02	-14%
PLL – Non-Hydrocarbon	2.99E-02	2.84E-02	-5%	2.84E-02	-5%	2.84E-02	-5%
PLL – Total	6.49E-02	6.03E-02	-7%	5.98E-02	-8%	5.87E-02	-10%
IRPA – Drill Crew	**6.08E-04**	**5.49E-04**	-10%	**5.43E-04**	-11%	**5.34E-04**	-12%
IRPA – Maintenance/Deck	2.97E-04	2.77E-04	-7%	2.76E-04	-7%	2.73E-04	-8%
IRPA – Motorman	5.73E-04	4.41E-04	-23%	4.34E-04	-24%	4.24E-04	-26%
IRPA - Catering	1.50E-04	1.80E-04	20%	1.80E-04	20%	1.80E-04	20%

Table 6-27: Comparison of MODU Risks for SWRX / WWRX / North Amethyst with WR Development

6.6 Conclusions

The TRIF for the MODU carrying out the drilling activities for each of the South White Rose, West White Rose and North Amethyst Tiebacks is predicted to be higher than the previously assessed risks for the MODU operating in the White Rose field during the development phase. The individual risk is predicted to be lower at each of the drill centres, largely due to the revision of the occupational risk in line with latest industry data. In all cases, the risks remain well below the Target Levels of Safety for loss of TR integrity and individual risk.

At each drill centre, the frequency of subsea blowouts causing failure of the TR integrity exceeds Husky's 1E-04 per annum criteria for a single major accident hazard. However, it is considered that the subsea blowouts risks are conservative when the history of the MODU at the White Rose field and established procedures in place are taken into account.

The results of the MODU risk assessment for the three new drill centres have been compared to those for the original White Rose development period. In each case, the TRIF was found to be higher and the PLL and IRPA values lower. The main cause of the higher TRIF is the higher number of wells to be drilled and completed in the operational year. The lower PLL and IRPA values are predominantly due to the revision of the occupational risk figures in line with the latest industry data, as discussed in Section 6.2.2.

7 DSV RISK ASSESSMENT

The DSV risk assessment investigates the risks to personnel on board the DSV whilst it is on-station at the Southern Drill Centre, to allow modifications relating to the SWRX project to be carried out. The details of the diving contractors and dive support vessel required are not yet known.

There shall be a requirement for a DSV and a construction vessel to complete the installation of subsea equipment at both the Southern and SWRX Glory Holes. However, for simplicity within this assessment, it is assumed that the DSV will be performing all operations. In addition, the risks to the DSV from subsea hydrocarbon equipment releases are taken to be represented by the Southern Glory Hole equipment as there is likely to be a greater proportion of equipment live at SGH during DSV operations than at SWRX. This assessment is therefore conservative.

Similar activities are to be carried out at the Central Glory Hole as part of the WWRX project. As the layout of equipment, the dimensions of the glory holes and the number and types of lifts to be carried out are very similar; it was therefore judged unnecessary to repeat this assessment for the DSV at the CGH, as the risks will not be significantly different to those calculated for the DSV at the SGH.

The North Amethyst drill centre is to be tied back directly to the FPSO and therefore there are no associated activities at any of the existing drill centres.

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.

7.1 Hydrocarbon Events

The events of interest in this study are the subsea releases from the production and gas lift facilities at the Southern Drill Centre, fires in the Engine Room and the Accommodation There are no drilling activities to be carried out at the SGH and therefore no 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. The impairment frequency of the subsea equipment at the SDC due to dropped objects (as determined in Section 5) has been incorporated into the release frequencies for the SDC production and gas lift facilities.

Table 7-1 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 SDC Production Facilities	1.43E-02	8.26E-04	6.41E-04
Subsea Release from SDC Gas Lift Facilities	1.06E-02	4.57E-04	2.48E-04

Table 7-1: Hydrocarbon Events – DSV Risk Assessment

Note: FB stands for full bore release

The closer proximity of the engine room to the DSV accommodation means that the likelihood of impairing the TR is higher than the value assumed for the MODU. For the DSV, it is assumed that 1% of all engine fires result in impairment of the TR, giving an impairment frequency similar to that calculated for the SeaRose FPSO [42].

7.2 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.

7.3 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.

7.4 Risk Assessment Results

Figure 7-1 below shows the results of the DSV risk assessment for the SWRX development. Note that these risks have been annualised.

TR Impairment Frequency within 1 hr	-	**1.49E-05**	**Highest IRPA Total**	-	**7.07E-04**	**Divers Crew**
TR Impairment Frequency	-	**1.49E-05**	**Hydrocarbon IRPA**	-	**7.36E-07**	
Hydrocarbon PLL	-	**1.80E-04**	**Non Hydrocarbon IRPA**	-	**7.06E-04**	
Non Hydrocarbon PLL	-	**4.92E-02**	**Freq. HC Release**	-	**0.027110328**	
Total PLL	-	**4.94E-02**	**Freq. Ignited Events**	-	**0.000225606**	

		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	6.52E-07	4.4%	6.52E-07	4.4%								
	HVAC Failure - Smoke												
	RainOut												
	Sea Fire												
	Thermal Breach												
Calculated PLL :													
Hydrocarbon	Immediate												
	Muster												
	TR Fatalities												
	Evacuation Fatalities					2.35E-06	0.0%	1.30E-08	0.0%	1.30E-08	0.0%	1.30E-08	0.1%
Hydrocarbon - DSV Specific	Fire - Engine Room	2.78E-06	18.6%	2.78E-06	18.6%	1.77E-04	0.4%	7.23E-07	0.1%	2.11E-06	1.3%	7.23E-07	2.8%
Non Hydrocarbon	Occupational					4.40E-02	89.0%	6.81E-04	96.4%	1.31E-04	82.9%		
	Structural Failure					3.77E-03	7.6%	1.97E-05	2.8%	1.97E-05	12.4%	2.03E-05	78.0%
	Mechanical Failure - Lifting Equipment					3.96E-05	0.1%	6.18E-07	0.1%	6.18E-07	0.4%		
	Extreme Weather					3.28E-04	0.7%	6.33E-07	0.1%	7.35E-07	0.5%	7.35E-07	2.8%
	Ship Collision					1.05E-03	2.1%	3.70E-06	0.5%	3.70E-06	2.3%	3.94E-06	15.1%
	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	77.0%	1.15E-05	77.0%	5.24E-05	0.1%	2.56E-07	0.0%	2.56E-07	0.2%	3.02E-07	1.2%
Hydrocarbon Total						1.80E-04	0.4%	7.36E-07	0.1%	2.13E-06	1.3%	7.36E-07	2.8%
Non Hydrocarbon Total						4.92E-02	99.6%	7.06E-04	99.9%	1.56E-04	98.7%	2.53E-05	97.2%
Totals		1.49E-05	100.0%	1.49E-05	100.0%	4.94E-02	100.0%	7.07E-04	100.0%	1.59E-04	100.0%	2.60E-05	100.0%

Figure 7-1: DSV Risk Assessment Results

7.4.1 DSV TR Impairment Frequency (TRIF)

There are very few contributors to TR impairment – the total hydrocarbon TRIF is just **1.49E-05** per annum, all of which are assessed to occur within one hour. Fires in the Accommodation (77%), unignited gas ingress from subsea releases (4%) and fires in the Engine Room (19.0%) account for 100% of the TRIF.

In a similar manner to the MODU risks, the DSV impairment based TR integrity frequency has also been calculated and is shown in Table 7-3.

Description	**Impairment Based TR Integrity (per annum)**	**%**
Subsea Release from SDC Production Facilities	0.00E+00	0.0%
Subsea Release from SDC Gas Lift Facilities	6.52E-07	0.2%
Engine Room Fire	2.78E-06	1.0%
Accommodation Fire	1.15E-05	4.3%
Structural Failure	1.01E-04	37.5%
Extreme Weather	1.00E-04	37.1%
Ship Collision	5.32E-05	19.7%
Iceberg Collision	3.08E-07	0.1%
Total	2.69E-04	100.0%

Table 7-2: 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.

7.4.2 DSV Potential Loss of Life (PLL)

The total PLL for the DSV is **4.94E-02** fatalities per annum, of which 0.4% can be attributed to hydrocarbon events and 99.6% to non-hydrocarbon events.

The different types of fatalities which make up the total PLL are shown in Table 7-3, and discussed below.

Source	**PLL per Annum**	**%**
Occupational	4.40E-02	89.0%
Structural Failure	3.77E-03	7.6%
Immediate Hydrocarbon	0.00E+00	0.0%
Hydrocarbon - DSV Specific	1.77E-04	0.4%
Ship Collision	1.05E-03	2.1%
Extreme Weather	3.28E-04	0.7%
Fire - Accommodation	5.24E-05	0.1%
Mechanical Failure - Lifting Equipment	3.96E-05	0.1%
Iceberg Collision	1.29E-06	0.0%
Delayed Hydrocarbon	2.35E-06	0.0%
Total	**4.94E-02**	**100%**

Table 7-3: 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, which amounts to 89% 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 divers who traditionally have a high occupational risk associated with their jobs.

7.4.3 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 **7.07E-04** per annum, for Maintenance/Deck Crew it is **1.59E-04** per annum whilst the lowest risk group is the Catering/Admin Crew, whose IRPA is **2.60E-05** per annum.

The breakdown of contributors to the IRPAs for the main worker categories on the DSV are presented below in Table 6-24.

	Dive Crew	%	Maintenance/ Deck	%	Catering	%
Immediate Hydrocarbon	0.00E+00	0.0%	0.00E+00	0.0%	0.00E+00	0.0%
Delayed Hydrocarbon	1.30E-08	0.0%	1.30E-08	0.0%	1.30E-08	0.1%
Hydrocarbon - Rig Specific	7.23E-07	0.1%	2.11E-06	1.3%	7.23E-07	2.8%
Occupational	6.81E-04	96.4%	1.31E-04	82.9%	0.00E+00	0.0%
Structural Failure	1.97E-05	2.8%	1.97E-05	12.4%	2.03E-05	78.0%
Mechanical Failure - Lifting Equipment	6.18E-07	0.1%	6.18E-07	0.4%	0.00E+00	0.0%
Extreme Weather	6.33E-07	0.1%	7.35E-07	0.5%	7.35E-07	2.8%
Ship Collision	3.70E-06	0.5%	3.70E-06	2.3%	3.94E-06	15.1%
Iceberg Collision	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%
Fire - Accommodation	2.56E-07	0.0%	2.56E-07	0.2%	3.02E-07	1.2%
Totals	**7.07E-04**	**100.00%**	**1.59E-04**	**100.0%**	**2.60E-05**	**100.0%**

Table 7-4: DSV IRPA Results for the SWRX Project

It can be seen that the IRPA for the Dive Crew is the highest. This is primarily due to the nature of the activities that divers will be involved in their day to day activities.

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 1E-03 per annum.

7.5 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 **1.49E-05** per annum, or once in 67,114 years. The impairment based TR integrity frequency is calculated to be 2.69E-04 per annum should all hazards that may impair the DSV TR be taken into account. The total PLL is **4.94E-02** per annum or one fatality every 20 years. The highest risk worker category is the Dive Crew, whose IRPA is calculated to be **7.07E-04** per annum.

The risks associated with DSV operations during the SWRX development shall be reviewed and updated as the design progresses.

8 CONCLUSIONS & RECOMMENDATIONS

8.1 Conclusions

The conclusions of this Safety Assessment of the White Rose Tiebacks are as follows:

1) A number of topsides modifications are to be made to the SeaRose FPSO to debottleneck the process and allow an increase in the production throughput. It has been shown that the modifications have no significant impact on the overall risk levels on the SeaRose FPSO.
2) The tie-back of the SWRX pool and the WWRX pool under the current plan, will have no impact on the risk levels on the SeaRose FPSO as the pools will be tied-back via existing drill centres and risers.
3) The tie-back of the North Amethyst field directly to the SeaRose FPSO is predicted to result in an increase of 2% in the 'hydrocarbon only' TRIF, to 1.83E-04 per annum, the TRIF for all hazards increases by around 1% to 2.95E-04 per annum. The PLL is expected to rise by 2% to 4.08E-02 per annum and the maximum IRPA by 2% to 2.55E-04 (the maximum value remains for the Process Crew).
4) The tie-back of the WWRX pool directly to the FPSO will be via risers containing fluids from both WWRX and CDC. The arrival pressure of these new risers is lower than previously considered for the original CDC risers and therefore the risk levels will reduce. TRIF will reduce to 1.75E-04 per annum, the PLL to 3.91E-02 per annum and the maximum IRPA to 2.41E-04 per annum.
5) The hydrocarbon TR Loss of Integrity Frequency for the MODU is dependant on its location. For a year spent carrying out drilling activities at SWRX the TRIF, is 1.93E-04 per annum, or once every 5180 years. At North Amethyst, the TRIF is calculated to be 1.92E-04 per annum, whilst at WWRX it is 1.85E-04 per annum.
6) At SWRX, the total PLL on the MODU is 6.03E-02 fatalities per annum or one fatality every 17 years, at North Amethyst it is lower, at 5.98E-02 per annum whilst at WWRX it is 5.87E-02 per annum.
7) The IRPA for the highest risk worker category (the Drill Crew) is found to be 5.49E-04 per annum at SWRX, 5.43E-04 per annum at North Amethyst and 5.34E-04 per annum at WWRX.
8) The impairment based TR integrity frequency for the MODU is calculated to be 4.65E-04 per annum at SWRX, 4.63E-04 per annum at North Amethyst and 4.57E-04 per annum at WWRX. In each case, the highest contributor to this frequency is from subsea blowouts, which contribute around 30%.
9) The annual frequency of blowouts during the drilling and completion of the five new wells (or eight if the contingency wells are included) for the SWRX project is predicted to be **1.88E-02** per annum; for the drilling and completion of ten new wells at North Amethyst (or thirteen if the 3 contingency wells are included) it is **1.83E-02** per annum and for the drilling of twelve new wells at WWRA (or 15 including the contingency wells) the blowout frequency is **1.77E-02** per annum. These values compare with a frequency of **1.73E-02** per annum from the previous blowout assessment. The main reason for this increase is that there is the equivalent of 5.2 / 5 / 4.9 new wells being drilled in a one year period at SWRX / North Amethyst / WWRX respectively, whereas previously the drilling risks were based on the equivalent of 4 new wells being drilled in the year 2005.
10) The frequency of subsea blowouts exceeds Husky's TLS for a single MAH of 1E-04 per annum. However, the frequency is based on generic, historical information that is likely to be conservative as the MODU has been operating in

the White Rose field for a number of years with established procedures in place. Note that the subsea blowout frequency was greater than 1E-04 per annum for the original White Rose Development – the TLS has not been exceeded because of the new extensions.

11) 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 loss of hydrocarbon containment frequency at the new SWRX Glory Hole is **4.87E-04** per annum, at North Amethyst it is **4.90E-04** per annum, whereas at WWRX it is **1.77E-04** per annum.
12) The risk levels for the DSV carrying out the installation and hook-up activities are predicted to be low. The frequency of hydrocarbon TR impairment is **1.49E-05** per annum, or once in 67,114 years. The total PLL is **4.94E-02** per annum or one fatality every 20 years. The highest risk worker category is the Dive Crew, whose IRPA is calculated to be **7.07E-04** per annum.
13) 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).
14) In all cases on the MODU, the DSV and the SeaRose FPSO, the TR impairment frequency and IRPA values remain significantly below Husky's Target Levels of Safety (1E-03 per annum).
15) Consideration has been given to the potential for risk reduction through the installation of SSIVs on each of the risers that tie-back the North Amethyst field and WWRX pool. It has been shown that the cost of the installation of SSIVs on the new flowlines is unlikely to be justified in terms of the degree of risk reduction they may bring about to personnel, the asset or the environment.

8.2 Recommendations

1) As the Tieback 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) 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 subsea equipment, and any MODU working at the new Glory Holes, from vessels passing through the field.
3) 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.
4) Husky should also review in more detail the potential for icebergs to cause damage or scouring of equipment in the SWRX, WWRX and North Amethyst Glory Holes or flowlines. This review should also include the Ice Management procedures to ensure that the new equipment can be protected to a similar level as existing subsea equipment.
5) The project should review the impact on blowdown rates for the SDC production / test and gas lift lines as a result of the inclusion of the SWRX. A similar study should be completed for the NADC flow lines. Any increase in the blowdown rates and time may affect the time taken to release the riser buoy via the QCDC system in the turret during a controlled disconnect operation;

6) The ESD shut down times for the SWRX, WWRX and North Amethyst facilities should also be reviewed to ensure that the time to close valves is optimised and does not prolong the period of packing that may occur at the FPSO after the riser ESD valves have closed in the turret.
7) 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.

All recommendations in the report will be tracked in a Husky Safety Action Tracking System, and closed out formally, using a process similar to that used during the White Rose project.

REFERENCES

1 SeaRose FPSO Quantitative Risk Assessment, WR-HSE-RP-0003, Rev E2, November 2006.

2 White Rose Fire Risk Assessment, WR-HSE-RP-009, Rev E1, July 2005.

3 SeaRose FPSO TR Integrity Analysis, WR-HSE-RP-0004, November 2006

4 MODU Blowout Risk Assessment, WR-HSE-RP-0015, April 2003

5 MODU Dropped Object Analysis, WR-HSE-RP-0028,Rev 3, September 2004

6 MODU Risk Assessment, WR-HSE-RP-0020, August 2005

7 Safety Assessment of South White Rose Expansion Project, SX-HSE-RP-0001, Rev 1, October 2006.

8 "An Analysis of the OIR12 Data and its use in QRA", AEA for UKOOA, AEAT/NOIL/27564001/002(R) Draft A - Nov 2000

9 White Rose Fire Risk Assessment, WR-HSE-RP-009, Rev E1, July 2005.

10 White Rose FPSO Quantitative Risk Assessment, WR-HSE-RP-0003 Rev E1, July 2005.

11 Cost Benefit Analysis of Installation of Subsea Isolation Valve at White Rose, WR-HSE-RP-005400, March 2003.

12 Model for Blowout Risk Prediction - Phase III, Scandpower, Report 21.75.97, January 1996.

13 Environmental Blowout Rates Received in E-mail, J. Rapanakis to Liam Briody (Atkins Process), "Fwd: Blowout Scenarios", 13/05/2003

14 WS Atkins TORCH version 3.0

15 "Handbook for Fire Calculations and Fire Risk Assessment in the Process Industry", Scandpower-Sintef, 1992

16 Dispersion of Subsea Releases – Review of Prediction Methodologies, Offshore Technology Report 95465 Health and Safety Executive

17 "QRA Methodology", WS Atkins Internal Document, D1668-MS, Rev 5, January 1995

18 PLUME – A Computer Model for the Calculation of the Dispersion of Gases", Atkins Process, Version 5.0, June 1993.

19 Department of Energy / HSE Database for UK platforms during 1981-92 (Edmondson & Norman), 1993.

20 Det Norske Veritas, "Risk Assessment of Pipeline Protection", DNV-RP-F107, March 2001

21 Risk Assessment of Pipeline Protection, DNV Report RP-F107, March 2001.

22 Drilling and Completions Operations Manual (WR-DAC-MN-0001)

23 Email from J. Jenkins (Husky) to G. Chisholm (Atkins), "Fwd: Info for Atkins re: SWRX", 11th August 2006.

24 WR-HSE-RP-0032, MODU Moorings Analysis, Rev R01, September 2003.

25 Technip CSO Canada Ltd, White Rose Development Project, Flowline Protection Systems, CN49987/402/DES/1/033, Rev 0, August 2002.

26 Global Marine Glomar Grand Banks MODU, Quantitative Risk Assessment, Woodhill Engineering, Rev A, July 01

27 Global Marine Glomar Grand Banks Safety Case, Rev 4, June 2001

28 Hydrocarbon Leak and Ignition Database, E&P Forum, Report 11.4/180, May '92

29 PARLOC 2001, The Update of Loss of Containment Data for Offshore Pipelines

30 Cost Benefit Analysis of Flowline Trenching at the White Rose FPSO, WR-HSE-RP-000041, Rev 1, March 2003

31 Ignition Probability Review and Model Development, A report produced for UKOOA by AEA Technology, AEAT/NOIL/27780001/001 (R), Issue 1, January 2003

32 Ignition Probability Review and Model Development – Phase 2, Interim Report, AEAT/NOIL/28129001/001(R) Draft A

33 Classification of Hazardous Locations, Cox AW, Lees FP & Ang ML, 1991

34 UK Offshore Helicopter Operations Statistical Report for 1999, Civil Aviation Authority (CAA), Safety Data Department, June 2000

35 Development of Oil and Gas Resources in the UK, Dept. of Energy, 1991

36 UK Department of Energy, Development of UK Oil and Gas Resources ("Brown Book").

37 "Offshore Accident and Incident Statistics Report(s)", HSE, OTO 94010 (1993), OTO 95953 (1994), OTO 96955 (1996), OTO 97951 (1997), OTO 98952 (1998), OTO 99077 (1998/99), OTO 2000111 (1999/2000)

38 www.hse.gov.uk/offshore/statistics - "Offshore Injury and Incident Statistics Report(s)" (Provisional Data), HSE, 2000/1, 2001/2, 2002/3

39 "Offshore Injury, Ill Health and Incident Statistics Report 2003/2004 (Provisional Data)", HSE, http://www.hse.gov.uk/offshore/statistics/hsr0304/index.htm

40 "Offshore Safety Statistics Bulletin 2004/2005, http://www.hse.gov.uk/offshore/statistics/stat0405.htm

41 World Offshore Accident Database (WOAD), 1998, DNV

42 SeaRose FPSO Safety Plan, WR-O-99-X-PR-00003-001, Rev E1, August 2005.

43 White Rose FPSO Hull Integrity with Regard to Iceberg Collision Incursions, Ian Jordaan and Associates Inc., November 2002.

APPENDIX A
DROPPED OBJECT IMPACT DIAGRAMS

IMPACT FREQUENCY DIAGRAMS

The following plots show the frequency of impact of dropped objects onto the subsea equipment at the various glory holes considered in this project. 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

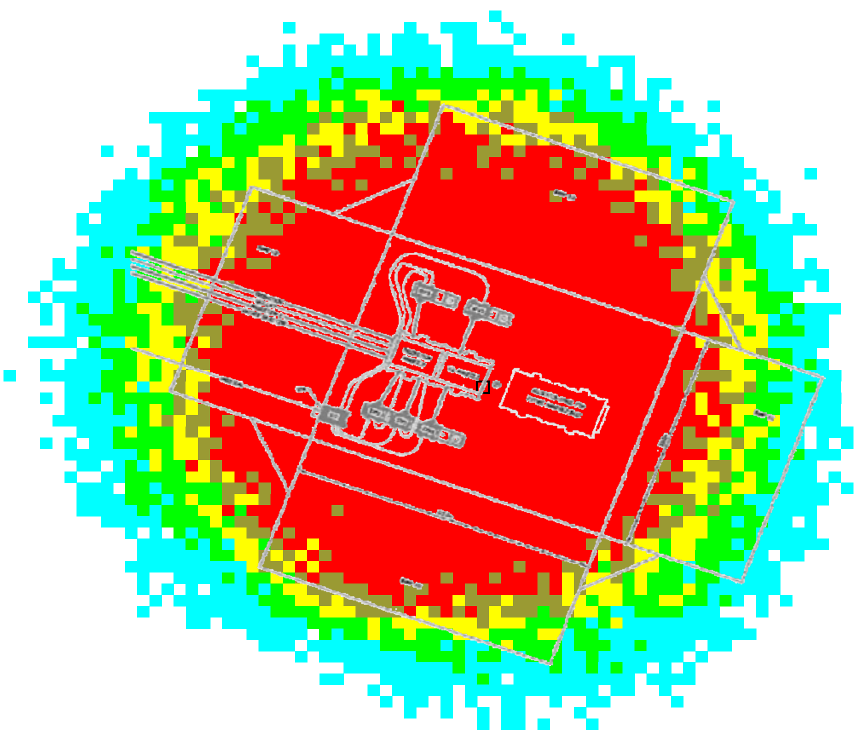


Figure A1: Overall Frequency of Dropped Objects at SWRX

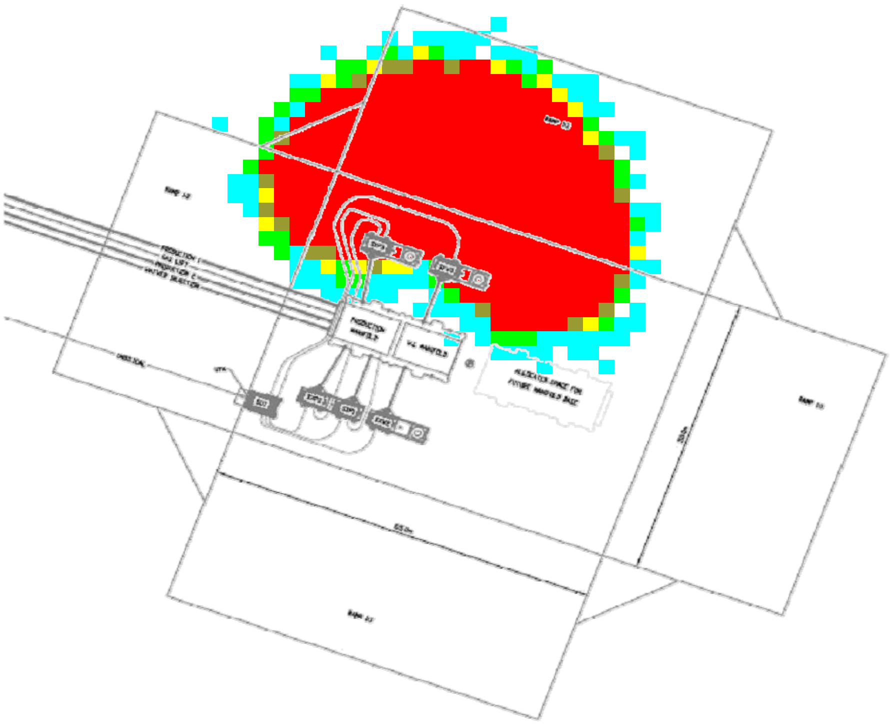


Figure A2: Small Container Lifted by Starboard-side Crane at SWRX

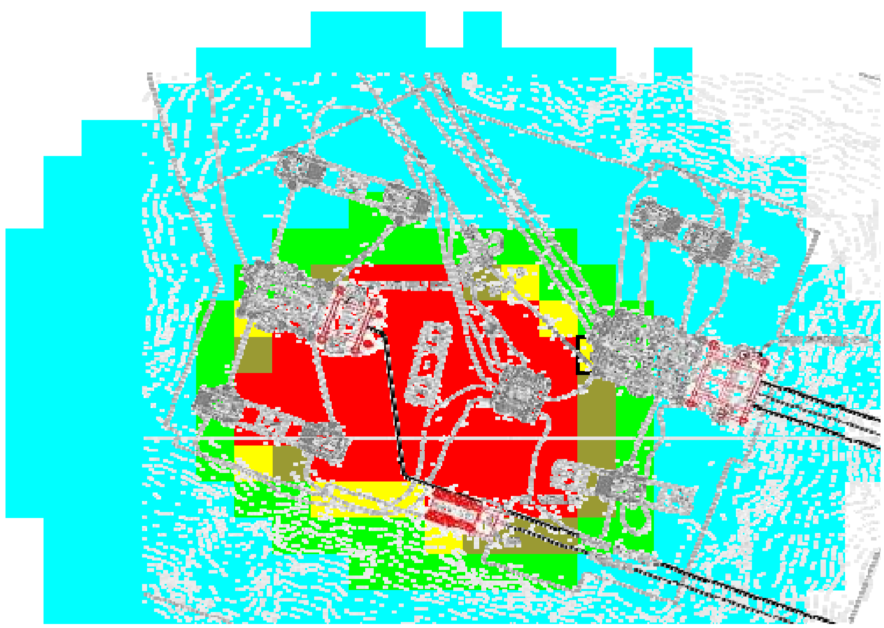


Figure A3: Overall Frequency of Dropped Objects at SGH

An impact frequency diagram based on the installation of the seventh and final water injection well is given below.

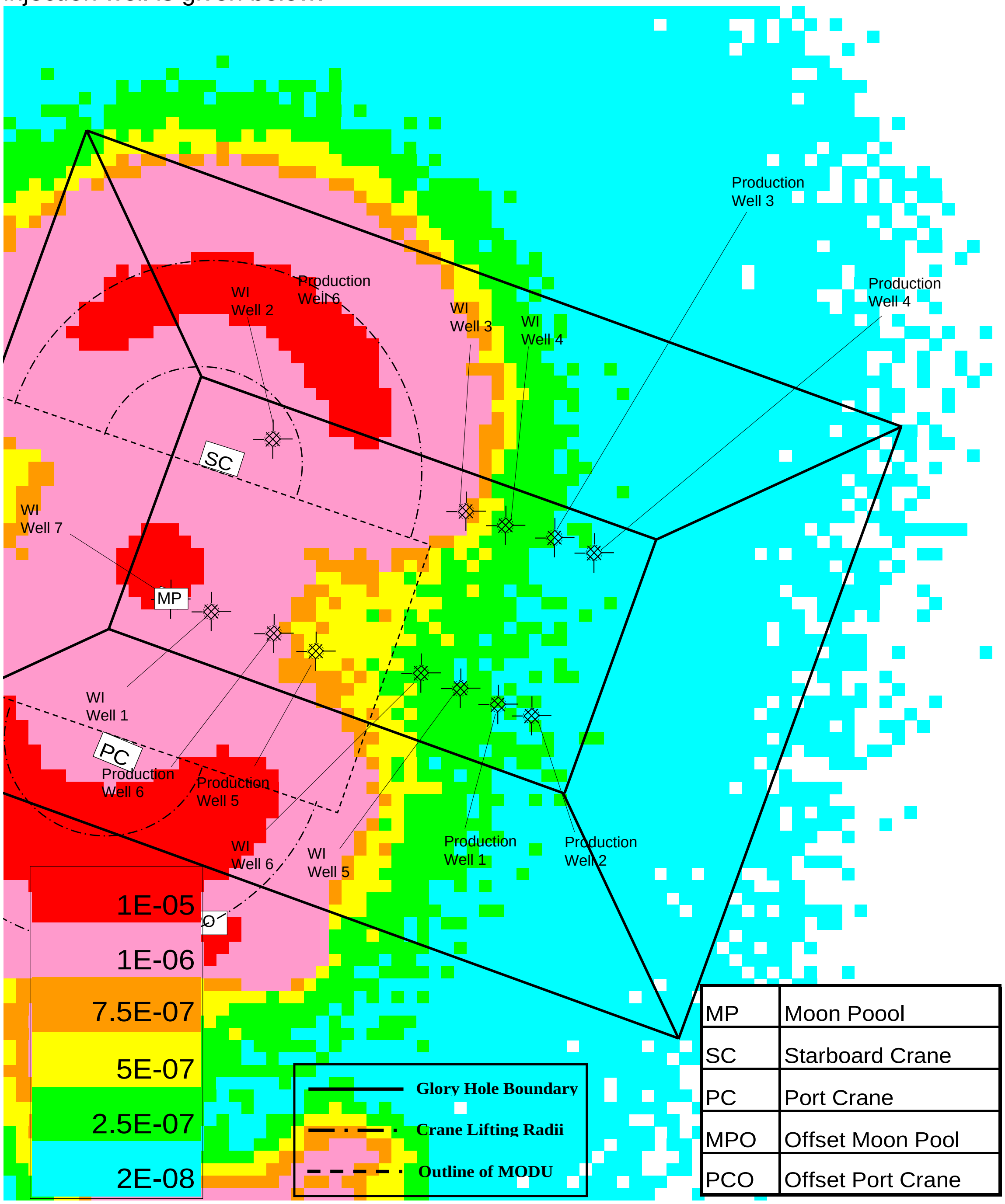


Figure A4: Impact Frequencies for Installation of NADC Water Injection Well 7

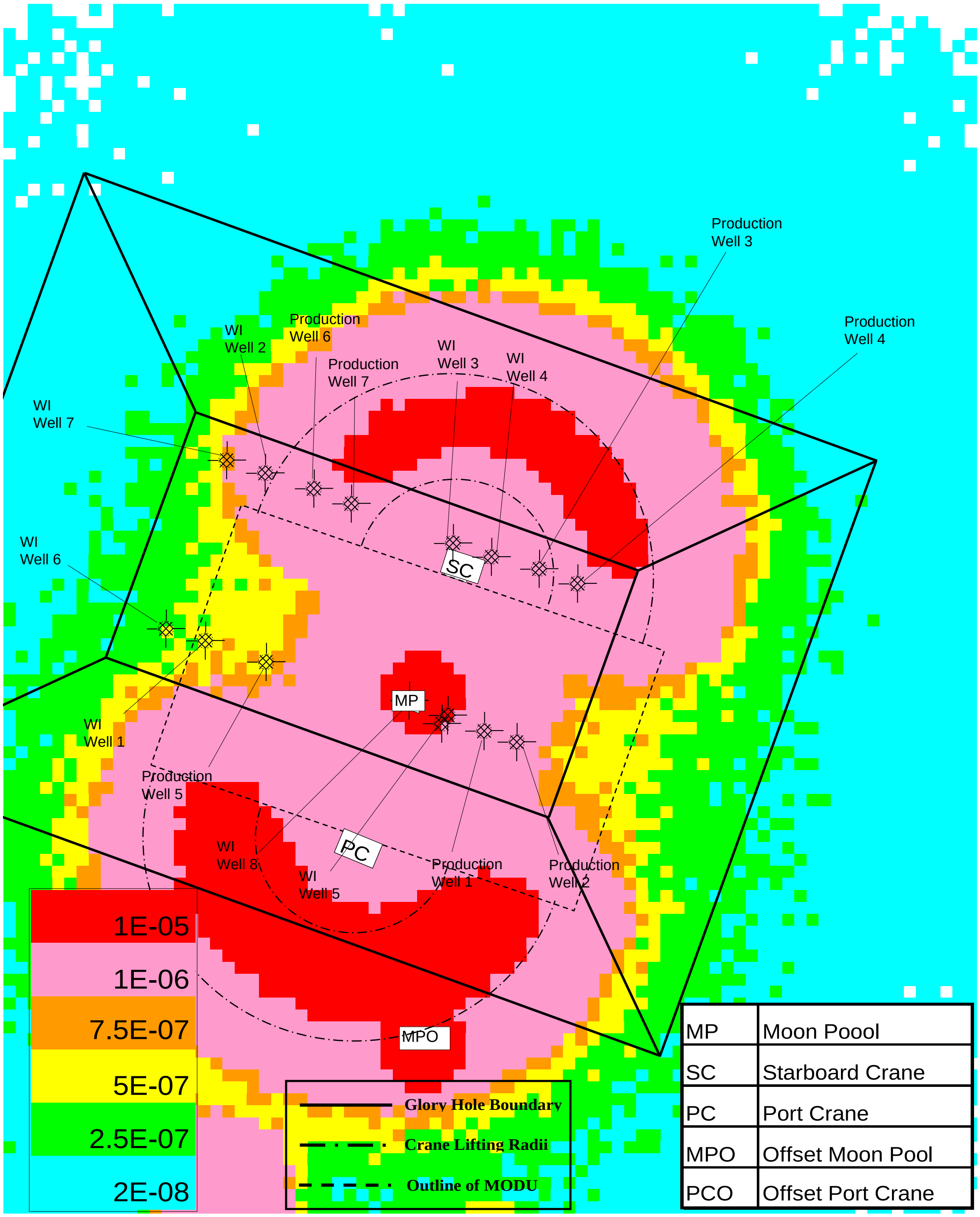
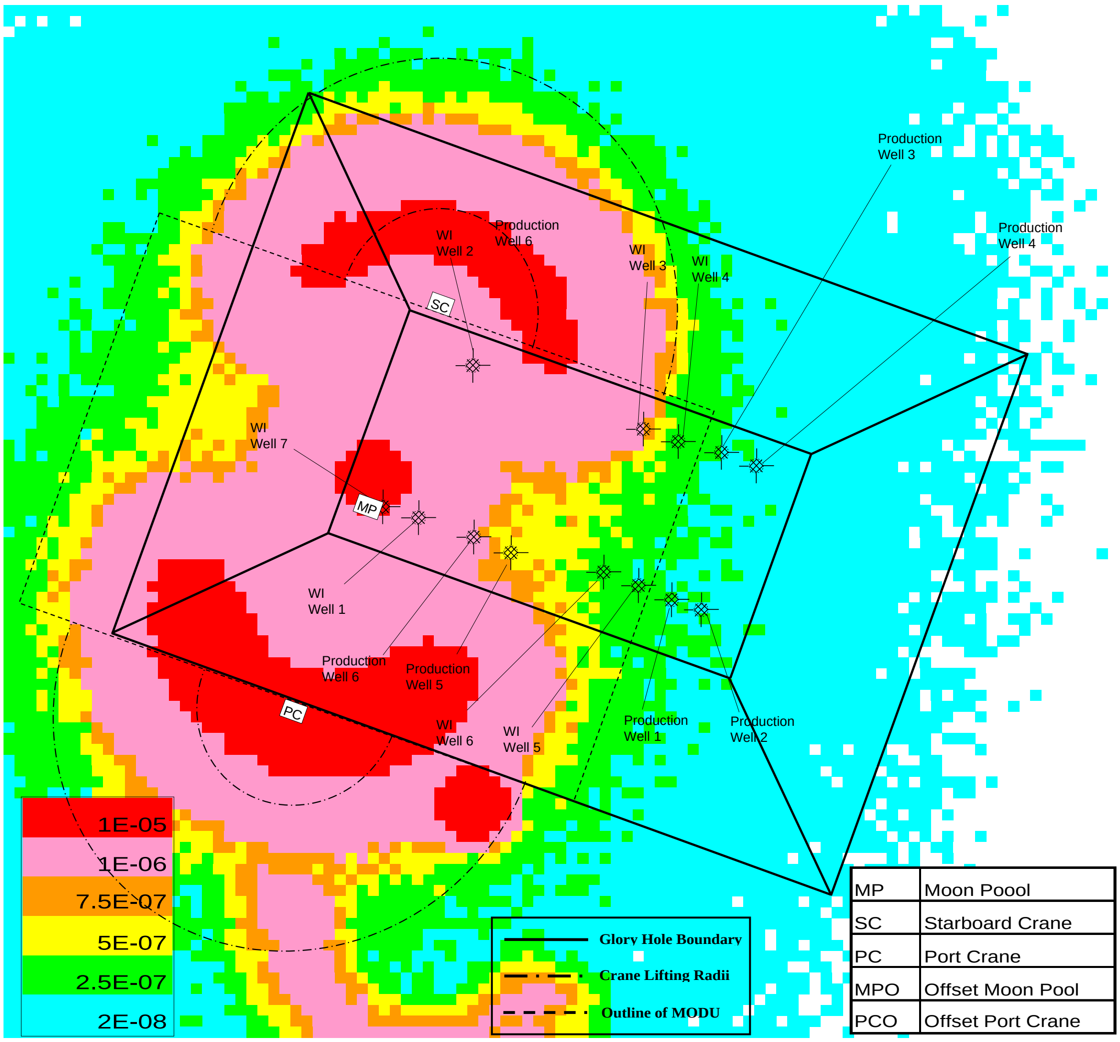


Figure A5: Impact Frequencies for Installation of WWRX Water Injection Well 8



MP	Moon Poool
SC	Starboard Crane
PC	Port Crane
MPO	Offset Moon Pool
PCO	Offset Port Crane

Figure A6: Sensitivity - NADC Impact Frequency Plot using Henry Goodrich MODU

APPENDIX B
BLOWOUT CONSEQUENCE ANALYSIS

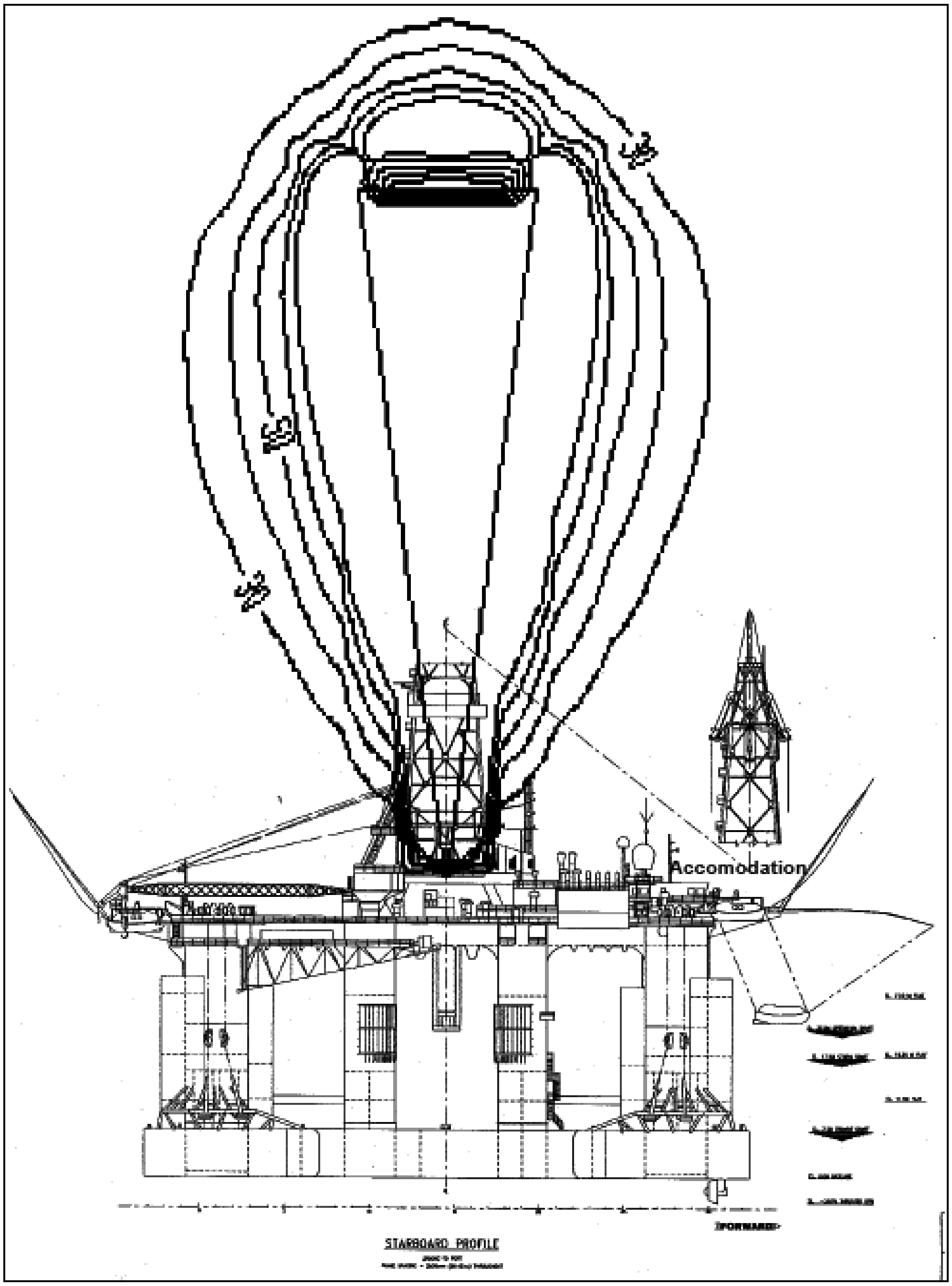


Figure B1: 50kg/s Vertical Drillfloor Blowout with 0m/s Wind (Contours in kW/m^2)

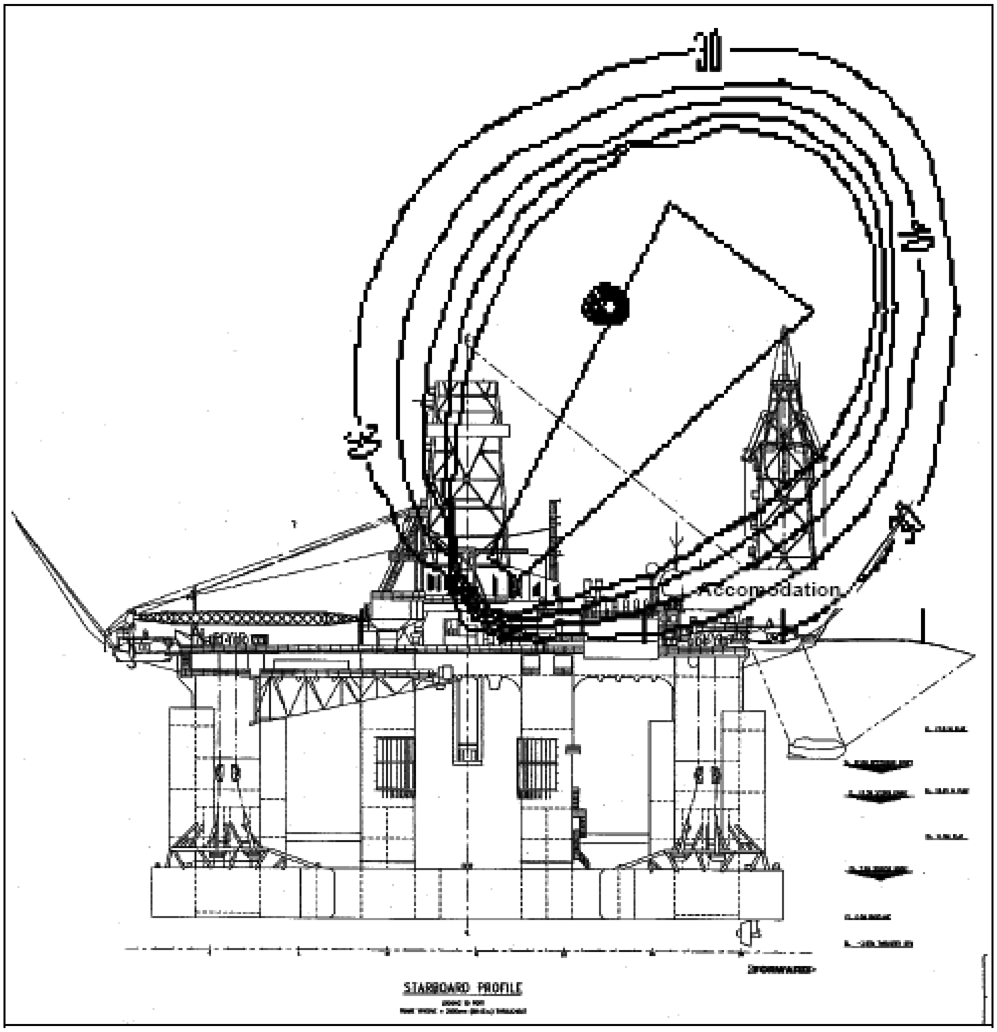


Figure B2: 50kg/s Vertical Drillfloor Blowout with 5m/s Wind Towards Accommodation (Contours in kW/m2)

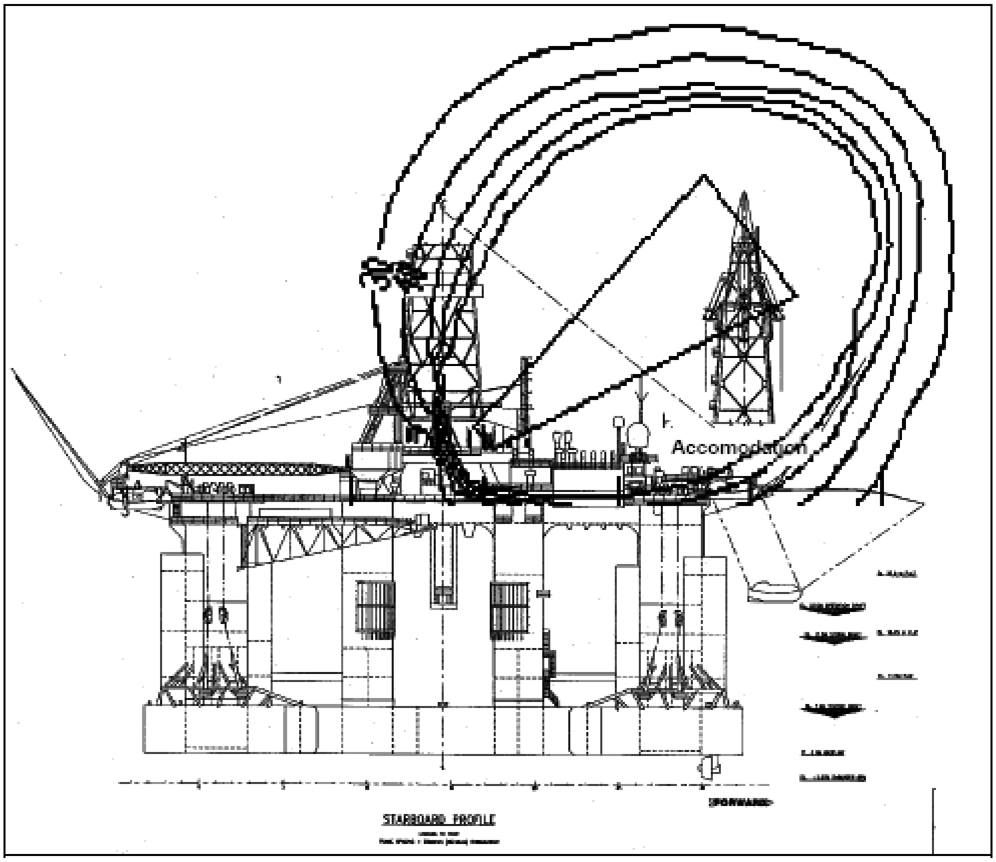


Figure B3: 50kg/s Vertical Drillfloor Blowout with 10m/s Wind Towards Accommodation (Contours in kW/m2)

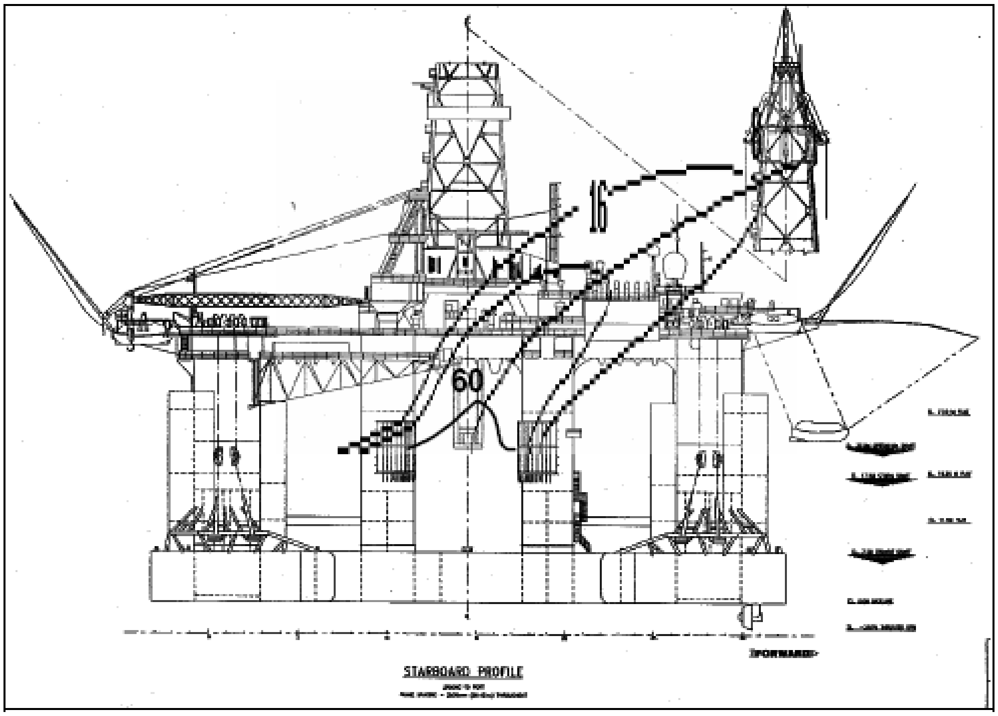


Figure B4: Deep Reservoir Blowout Sea Surface Fire Smoke Dispersion, 5m/s Wind Towards Accommodation, MODU at Operational Draft

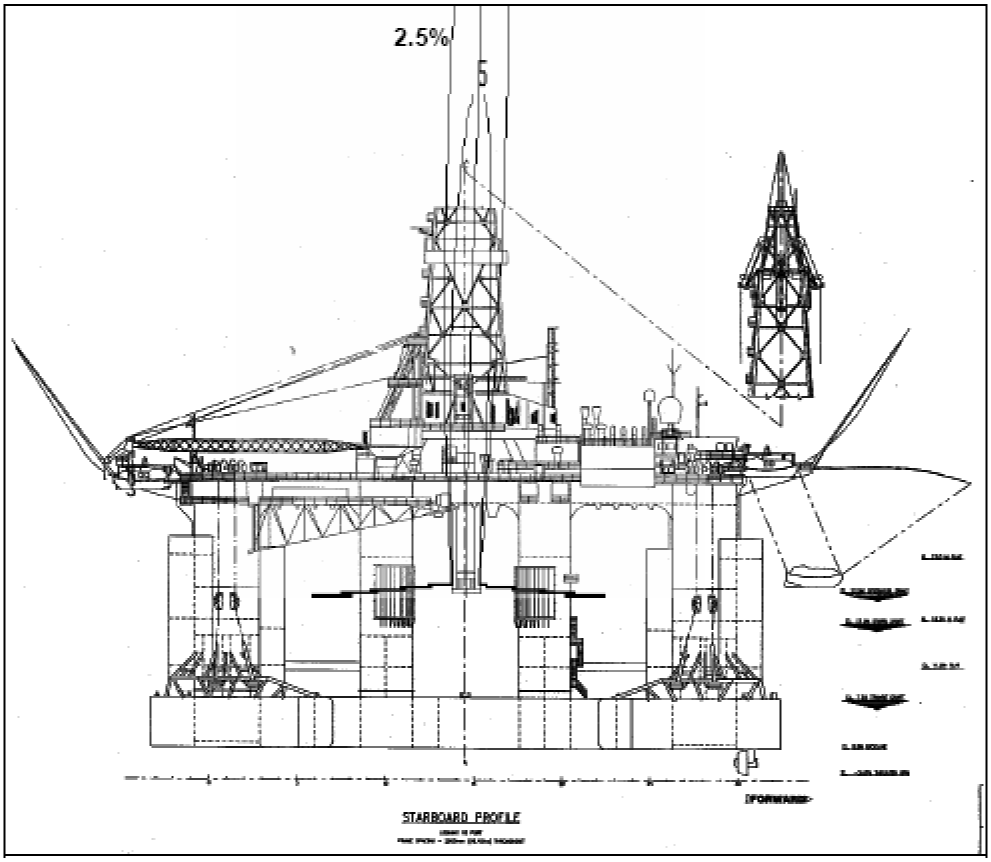


Figure B5: Shallow Gas Blowout Sea Surface Gas Dispersion, 0m/s Wind Towards Accommodation, MODU at Operational Draft

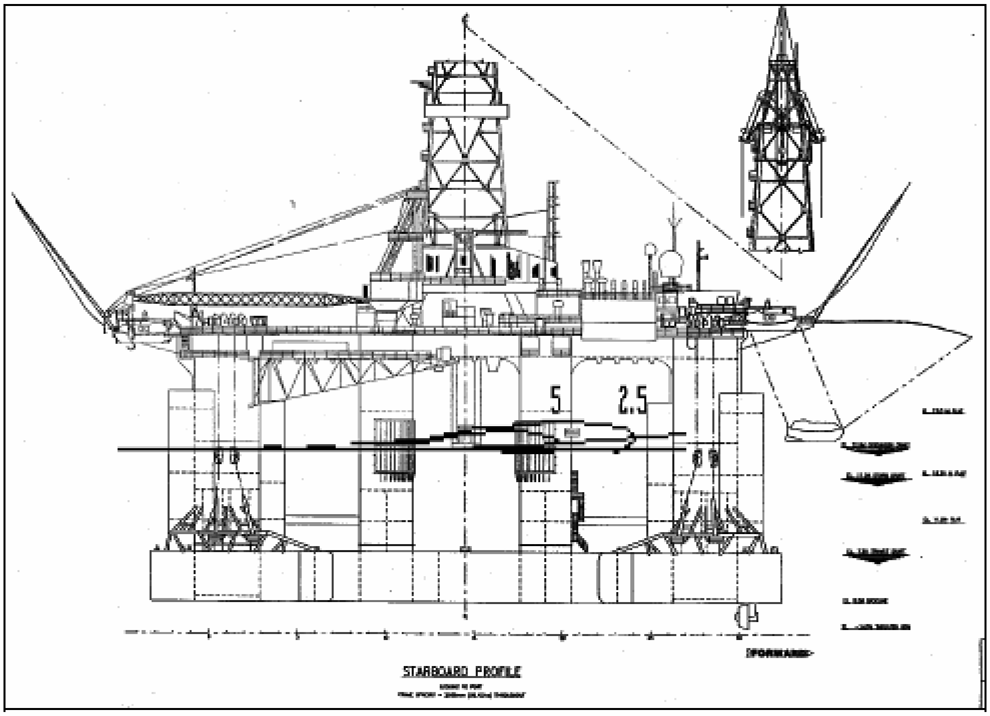


Figure B6: Shallow Gas Blowout Sea Surface Gas Dispersion, 5m/s Wind Towards Accommodation, MODU at Operational Draft

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