FREQUENCY ANALYSIS OF ACCIDENTAL OIL RELEASES FROM FPSO OPERATIONS IN THE GULF OF MEXICO

PREPARED FOR

ECOLOGY & ENVIRONMENT, INC.
Tallahassee, Florida

UNDER CONTRACT TO

MINERALS MANAGEMENT SERVICE
GULF OF MEXICO OCS REGION
NEW ORLEANS, LOUISIANA

MMS CONTRACT 1435-01-99-CT-30962

FINAL REPORT

JANUARY 2001

Det Norske Veritas, Inc.
Houston, Texas

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FINAL REPORT

Project Manager:____________________________
Jeremiah B. Spires

MANAGEMENT SUMMARY

The MMS is investigating the potential impact of the operation of Floating Production, Storage and Offloading installations (FPSOs) in the Gulf of Mexico. One of the concerns of the MMS is the potential negative effect on the environment from accidental oil releases, and in connection with this they have contracted Ecology and Environment to conduct an environmental impact study. Ecology and Environment will calculate the consequences of oil releases on the marine and coastal resources and combine these findings with estimated frequencies of accidental releases. The work to estimating the frequency of accidental oil releases from FPSO operations has been sub-contracted to DNV. This report presents DNV's findings.

Scope of Work

DNV's scope of work includes predicting the frequency of unique accidental releases from operation of a generic FPSO in the GoM. The specification for the FPSO is taken from the "Scenario Report, Environmental Impact Statement on Floating, Production, Storage, and Offloading Systems on the Gulf of Mexico Outer Continental Shelf" which provides an outline description of the FPSO and its operation. Where insufficient details are provided in the Scenario Report DNV has used judgement and experience of earlier FPSO risk analyses to supplement the information given. Good practice has been generally assumed.

The scope of the study includes:

- All aspects of operation of the FPSO from the wellheads, through oil and gas production to export of the oil by shuttle tanker, and the gas by pipeline to shore.
- Shuttle tanker transit risks to a shore terminal.
- The various utilities provided by the FPSO required for operation and support of the people manning the installation.
- External and environmental risk factors are also assessed.

The study does not include construction, installation commissioning and decommissioning of the FPSO, nor does it include drilling or workover of the wells. These were specifically excluded from the scope of work by MMS.

In addition to the basecase, the Scenario Report identifies options for the FPSO and its operation that may affect the environmental risk presented. These options have been qualitatively assessed to consider what impact, if any, they have on the overall risk. Also, DNV has identified a number of mitigation measures to reduce the risk due to accidental oil releases.

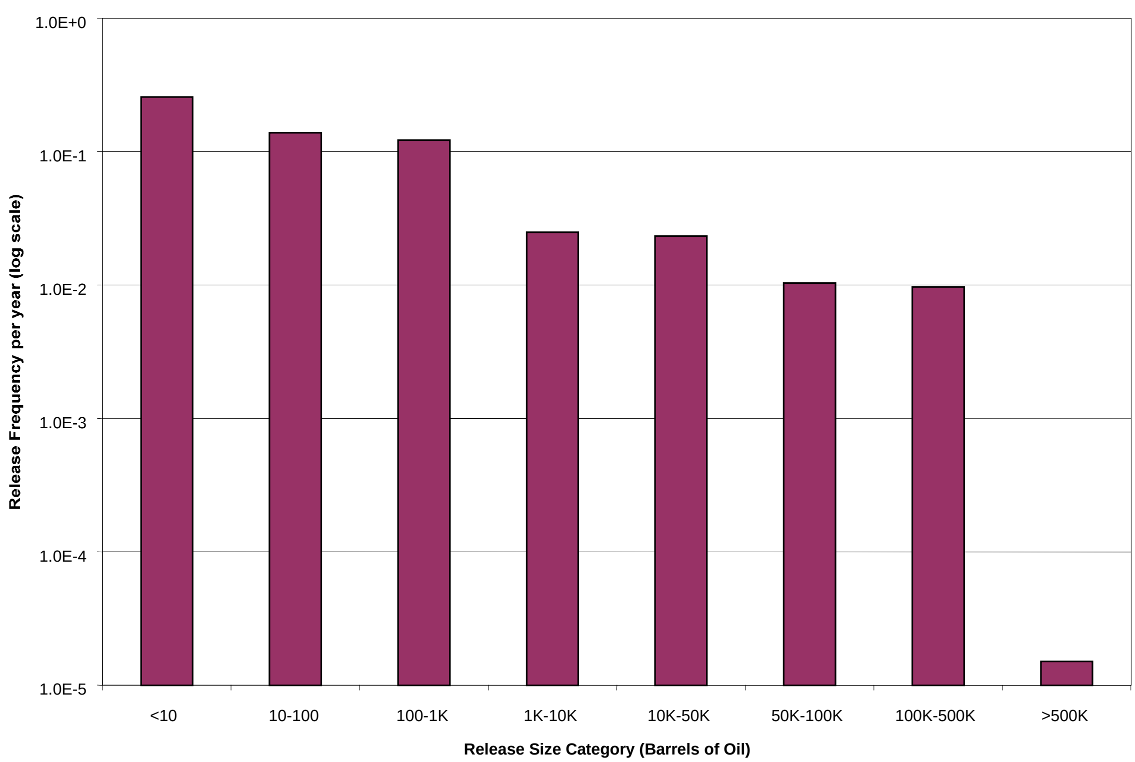
Results Summary

The table and figure below presents a summary of the overall results for the basecase.

Frequency of Oil Releases due to Unique FPSO Accidents

Barrels of Oil Released	FPSO	Offloading	Shuttle Tankers	Frequency (per year)
less than 10	1.3×10^{-2}	2.4×10^{-1}	0	2.6×10^{-1}
10-100	1.7×10^{-2}	1.2×10^{-1}	0	1.4×10^{-1}
100-1,000	7.9×10^{-5}	1.2×10^{-1}	0	1.2×10^{-1}
1,000-10,000	6.9×10^{-5}	0	2.5×10^{-2}	2.5×10^{-2}
10,000-50,000	6.7×10^{-4}	0	2.3×10^{-2}	2.3×10^{-2}
50,000-100,000	6.1×10^{-4}	0	9.7×10^{-3}	1.0×10^{-2}
100,000-500,000	5.9×10^{-4}	0	9.1×10^{-3}	9.7×10^{-3}
More than 500,000	1.6×10^{-5}	0	0	1.6×10^{-5}

Frequency of Accidental Releases by Release Size



The results show that for those risks unique to FPSO operation:

- The frequency of FPSO-unique oil releases greater than 1000 barrels is 0.037 per billion barrels produced for FPSO-related failures, and 1.2 per billion barrels for shuttle tanker-related failures. (The production rate is 150,000 barrels of oil per day.)
- Approximately 94.4 percent of the volume of potential FPSO-unique spills is likely to be due to the transfer of oil from the FPSO to the shuttle tanker and from the shuttle tanker transit to shore.
- 53.6 percent of the volume of potential FPSO-unique spills is likely to be from shuttle tankers near port.
- 39 percent of the volume of potential FPSO-unique spills is likely to be from shuttle tankers in transit to port.
- 1.8 percent of the volume of potential FPSO-unique spills is likely to be from the transfer from the FPSO to the shuttle tanker. However, these are all smaller spill sizes.
- For events on the FPSO, the dominant FPSO-unique risk is from accidents that escalate to the cargo area. The frequency of these events is of the order of 1×10^{-3} per year.
- Process releases are the largest FPSO-unique risk for releases on the FPSO.
- Passing merchant vessel collisions are low frequency events, but account for 1.2 percent of all the FPSO-unique oil released due to the potential for large volume spills.

A conclusion that can be drawn from the results is that any effort to reduce the risk of oil spill from oil production on FPSOs should firstly concentrate on the operation of shuttle tankers. This is particularly true for the significant fraction of shuttle tanker spills that occur closer to shore, where there is likely to be a greater threat of environmental damage.

Measures that protect against escalation to the cargo area are likely to be the most beneficial means of reducing the risk of oil spills from the FPSO itself. Measures that protect against passing merchant vessel collisions are also likely to be beneficial in reducing oil spill risk, as are measures that prevent or control process releases.

Finally, the following points should be noted to put the study results in perspective;

- FPSO-unique spill risk is low. Of spill risk on the FPSO itself, excluding offloading and shuttle tanker transport, FPSO-unique spill risk makes up only 5% of the total. The remaining 95% of spills are non-unique and would be equally likely and have similar outcomes on a TLP or other deepwater alternative.
- Spill risk during offloading from the FPSO to the shuttle tanker is low. This risk is similar to that for lightering operations in the GoM, where there is a history of low spill frequency and small spill volumes.

- Shuttle tanker transport spills should be compared with pipeline spills. Based on analysis of MMS's database of oil spills in US waters (ref. 2) it is expected that for pipeline transport there will be 1.32 spills greater than 1000 bbls per billion bbls transported, and for tanker transport there will be 1.21 spills greater than 1000 bbls per billion bbls transported. Therefore, the oil spill risk for shuttle tanker transport is comparable to and arguably better than pipeline transport.
- The risk of shuttle tanker transport spills used in this assessment was derived from a database of tanker spills in U.S. waters with incidents extending back to the 1970s. This incident database covers a large range of years and provides a wide experience base for determining what the historic risk of tanker transport spills has been. However, the large range of years covered also means that recent regulatory and other risk-reducing measures are not well represented in the predicted risk of tanker transport spills. It is expected that these corrective actions should result in improved tanker performance in the future over the performance predicted using this database as has been observed over the last eight years. Therefore, the risk of shuttle tanker transport spills predicted in this assessment may well be conservative (overstated).
- The assessments of oil spill risk performed in this study should be regarded as generic to the concept of the use of FPSOs in deep water. More detailed analysis would accompany the evaluation of specific FPSO permit applications. At that time, the location of a proposed FPSO and associated tanker routes would be more defined, and the risk from transportation routes closer to shore would be evaluated.

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1 INTRODUCTION

The MMS is investigating the potential impact of the operation of Floating Production, Storage and Offloading installations (FPSOs) in the Gulf of Mexico. One of the concerns of the MMS is the potential negative effect on the environment from accidental oil releases, and in connection with this they have contracted Ecology and Environment to conduct an environmental impact study. Ecology and Environment will calculate the consequences of oil releases on the marine and coastal resources and combine these findings with estimated frequencies of accidental releases. The work to estimating the frequency of accidental oil releases from FPSO operations has been sub-contracted to DNV. This report presents DNV's findings.

1.1 Scope of Work

DNV's scope of work includes predicting the frequency of accidental releases from operation of a generic FPSO in the GoM. The specification for the FPSO is taken from "Scenario Report, Environmental Impact Statement on Floating, Production, Storage, and Offloading Systems on the Gulf of Mexico Outer Continental Shelf" (Ref. 1) which provides an outline description of the FPSO and its operation. Where insufficient details are provided in the Scenario Report, DNV has used judgement and experience of earlier FPSO risk analyses to supplement the information given. Good practice has been generally assumed.

The scope of the study includes:

- All aspects of operation of the FPSO from the wellheads, through oil and gas production to export of the oil by shuttle tanker, and the gas by pipeline to shore.
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- External and environmental risk factors are also assessed.

The study does not include construction, installation commissioning and decommissioning of the FPSO, nor does it include drilling or workover of the wells. These were specifically excluded from the scope of work by MMS.

The releases are categorized according to the following ranges:

- less than 10 barrels of oil
- 10 to 100 barrels of oil
- 100 to 1,000 barrels of oil
- 1000 to 10,000 barrels of oil
- 10,000 to 50,000 barrels of oil
- 50000 to 100,000 barrels of oil
- 100,000 to 500,000 barrels of oil
- more than 500, 000 barrels of oil

These ranges were chosen to correspond to the oil spill sizes considered by Ecology and Environment in their assessment of the impact on the environment from oil accidentally released.

The MMS is particularly concerned that the study calculates the differences in environmental risk from FPSOs compared to production technologies for deepwater currently accepted and operating in the GoM.

In addition to the basecase, the Scenario Report identifies options for the FPSO and its operation that may affect the environmental risk presented. These options have been qualitatively assessed to consider what impact, if any, they have on the overall risk. DNV has identified a number of mitigation measures to reduce the environmental risk.

1.2 Report Structure

DNV has identified a broad range of hazards associated with the FPSO with the potential to cause an accidental release of oil to the environment, either directly or through escalation. The risks of accidental releases for each hazard have been calculated to provide the overall risk of oil spill.

Section 2 of the report describes the methodology used to calculate the oil spill risks.

Section 3 of the report presents the results including overall results for all accidents and a summary of the results for each of the identified hazards.

Appendix I gives the detailed risk analyses for each of the hazards identified.

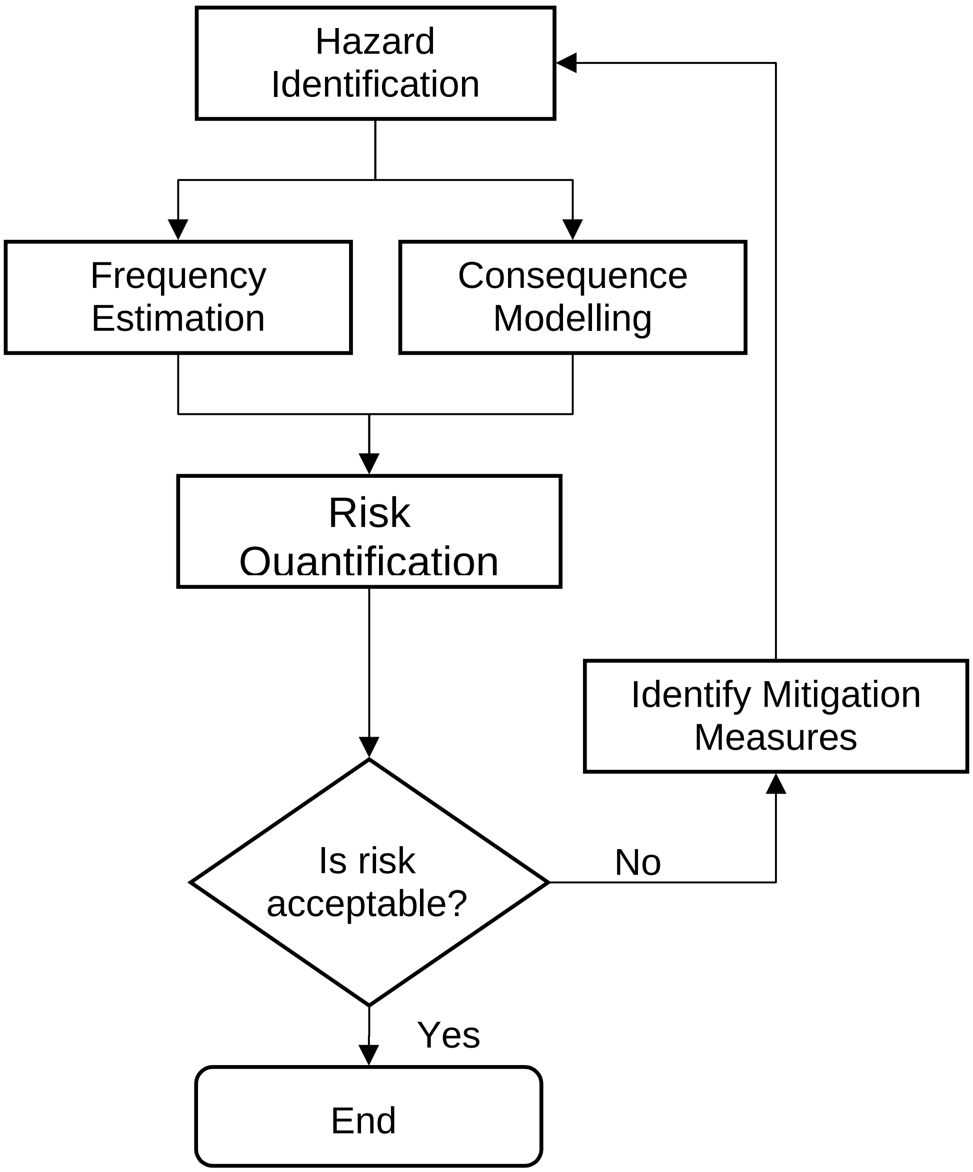
Appendix II is a qualitative assessment of the impact of the proposed design options on the oil spill risks calculated.

Appendix III is a qualitative assessment of potential risk mitigation measures

2 METHODOLOGY

DNV has applied a standard approach to risk analysis to quantify the risk of accidental releases of oil from the FPSO. The methodology is shown graphically in Figure 2.1. Each of the steps in the analysis methodology is described below.

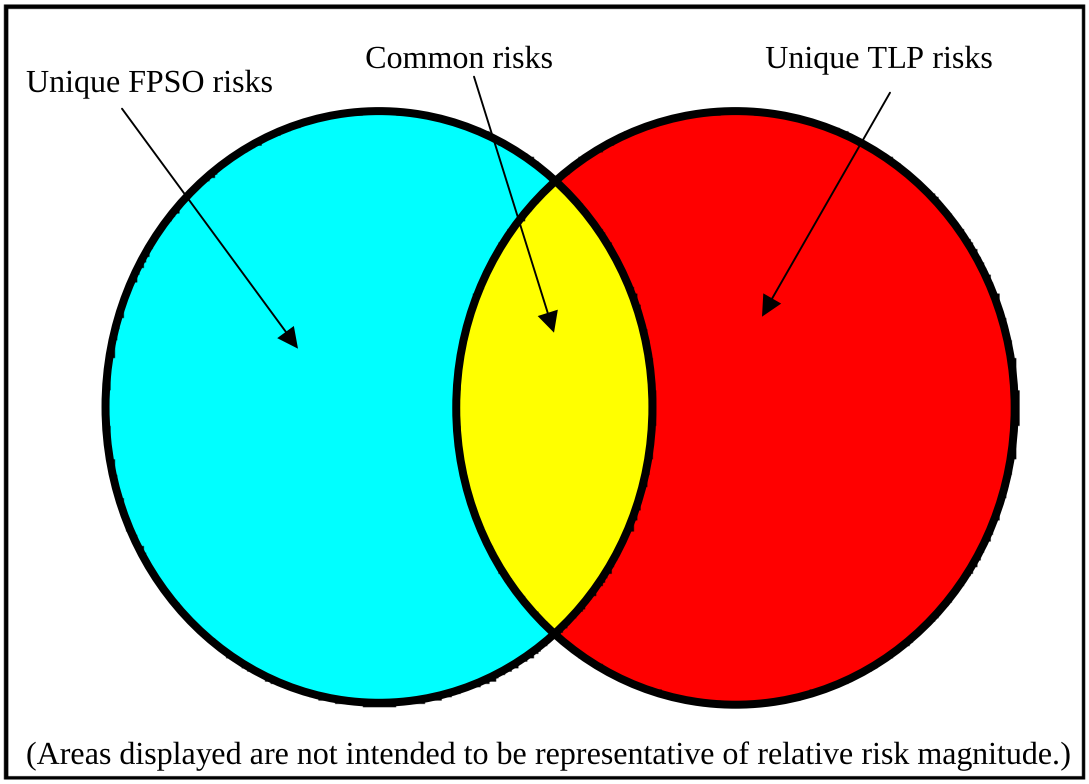
Figure 2.1: Risk Analysis Methodology



The risks from FPSO operation have been compared to accepted solutions for oil extraction in order to identify risk factors unique to FPSO operation. The identified FPSO risk factors have been compared against those known for tension leg platform (TLP), taken to be representative of accepted deep water technology for the GOM OCS. This comparison is shown graphically in Figure 2.2. From the figure, this study has quantified unique FPSO risks (blue area), but has not quantified the common risks (yellow area) or the unique TLP risks (red area).

Figure 2.2: Risks Quantified

2.1 Hazard Identification



The Hazard Identification seeks to identify all those potential sources of an accidental release of oil to the environment and characterize them in terms of the accident causes and those measures that help to prevent, detect, control or mitigate the potential accident scenarios. In addition, the hazard identification assesses the direct consequences of accidents and the potential for escalation.

Hazard identification is a formal activity to examine all aspects of the operation under consideration using a pro-forma approach. It depends on the quality of the input data available and is typically performed as a table-top exercise lead by an experienced facilitator and with participation by representatives covering the full range of design and operational expertise for the system under consideration.

This is a process that relies to a large extent on past experience and so it is important to consult as broad a range of expert sources as possible. Due to the conceptual nature of the design the generic FPSO addressed in the project, the level of detail is not available to perform this level of hazard identification. A specific hazard identification workshop would be unlikely to provide consideration beyond those already identified by DNV. Therefore, such a workshop is not appropriate to this project. Instead this project has extracted the combined experience from several previous studies carried out by DNV for similar developments. Typically, these studies included formal "hazard identification" workshops carried out with project engineers and operators and so the combination of these data sources represents actual experience and is the most appropriate source for this project available to DNV.

The hazard identification has considered a total of 11 different hazard categories that will be present during the production phase of the development. Each of the 11 hazard categories has been sub-divided into a number of more specific hazards characteristic of FPSO operation.

The hazards considered were categorized as listed below. In most categories, sub-divisions of hazards were identified and examined.

Hazard Categories

1. Blowout
2. Riser and Pipeline Leaks
3. Process Leak
4. Non-Process Fire and Explosions
5. Cargo Storage Events
6. Marine Accidents on the FPSO
7. Offloading Accidents
8. Tanker Transport
9. Non-Process Spills
10. Ship Collisions
11. Transportation (supply vessels and helicopters)

Each of the hazard sub-divisions were qualitatively described according to the following characteristics:

Consequences	direct impact of an accident
Escalation potential	routes to escalation of the event
Escalation consequences	impact of the escalated events
Accident causes	human or hardware failures that would realize the accident
Accident prevention	features of the development that will prevent an accident from occurring
Accident detection	measures to detect an accident
Accident control	measures to limit the extent of an accident
Mitigation measures	measures to prevent escalation from occurring or to limit the extent of escalation

This information collected was tabulated and has been used to develop the frequency and consequence calculations.

2.2 Frequency Calculation

Accident event frequencies were calculated for each of the identified hazards. This indicates the likelihood (per year) that a hazard will be realized calculated from a statistical analysis of available experience based data.

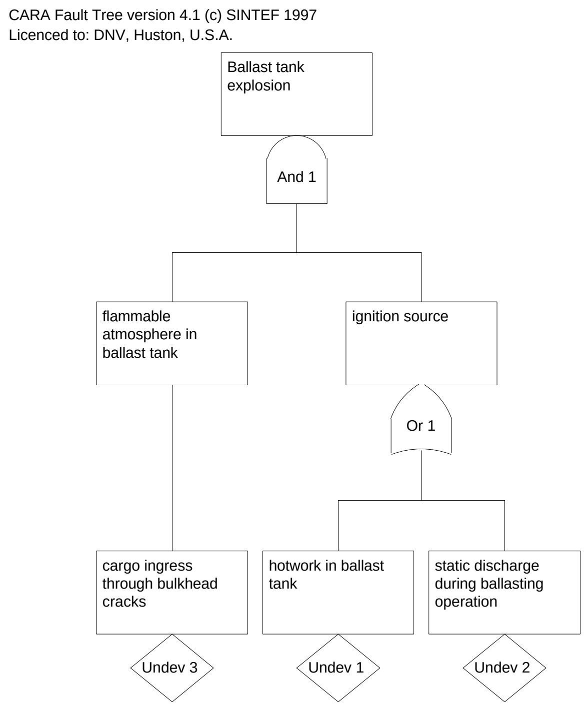
The accident frequencies were determined by a combination of the presence of accident causes, and the effectiveness of the appropriate preventative measures. Accident causes include those that are present continuously (e.g. fatigue loading), and those that arise spuriously (e.g. dropped objects). To be effective, a preventative measure must address the specific hazard and be reliable (in an operable condition when required).

The contribution of accident causes and preventative measures for each of the hazards are represented in “fault trees”. A fault tree is a graphical technique for showing the combinations of undesirable events that result in the specified accident (denoted the “top event”). The undesirable events represent each of the accident causes and failures of preventative measures identified by the hazard identification exercise. Evaluation of the fault trees involves the analytic combination of the likelihood that each of the undesirable events occurs.

The fault trees have been evaluated where appropriate. However for this project there are many instances where the quality of the available data for the frequency of the top events is as good as, or better than, the data quality for the frequency of contributing undesirable events. In such cases the top event frequencies are taken directly from the available data sources and the fault trees used to present the contributors to the accident and for the assessment of further risk reducing measures.

An example fault tree is shown below.

Figure 2.3: Fault Tree Example



2.3 Consequence Calculation

Consequence calculations are used to quantify how each of the accidents can develop and so result in the loss of oil into the sea.

For each accident event, the consequence calculations will take credit for the effectiveness and reliability of measures to detect the accident, to control it once detected, and to mitigate against escalation. The calculations also consider the likelihood of escalation if mitigation is unsuccessful. The various combinations of successful detection, control, mitigation, and escalation result in several possible different outcomes. The likely oil spill has been predicted for each outcome using judgement.

The likelihood of each of the possible outcomes were calculated using event trees. This is a graphical form of binary tree which allows the development of an accident to be shown and quantified. The initiating event forms the root of the tree, and the event tree is developed using a succession of branches, each representing success or failure of a specific detect, control, mitigation, and escalation response.

Progression along each of the various branches to the “end events” thus represents a unique combination of such responses. Each end event represents a possible development of the accident. Together, all the end events are representative of all possible accident outcomes.

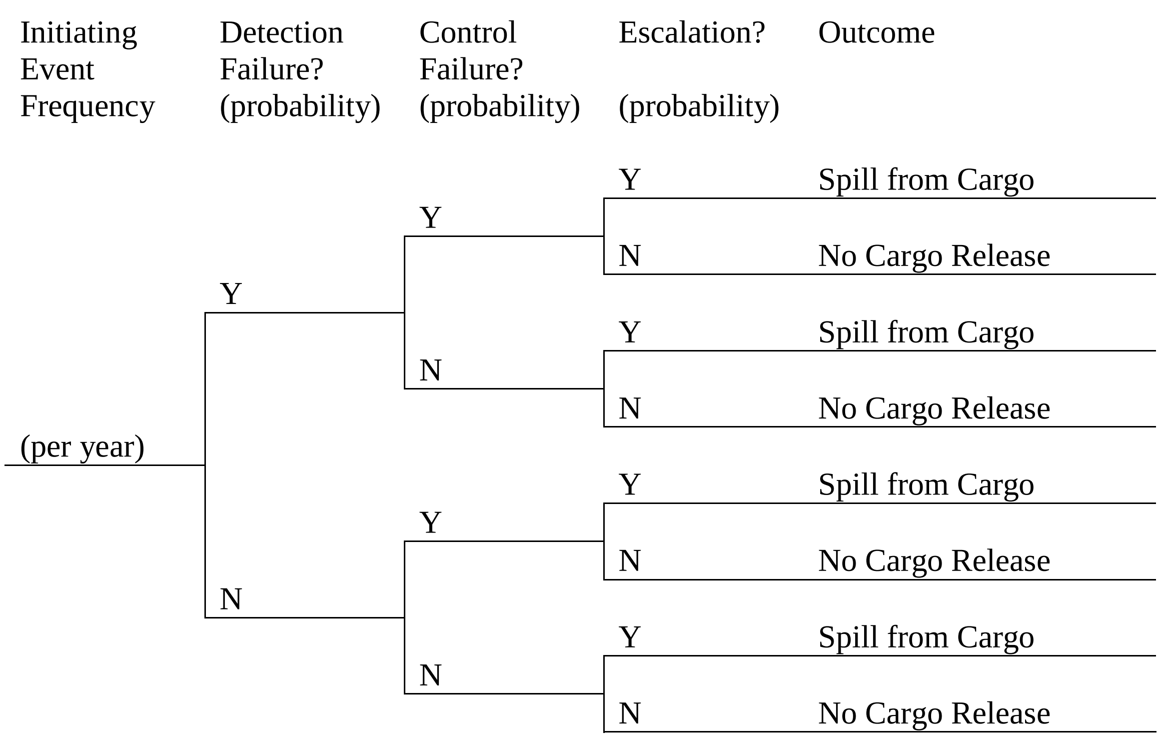
The initiating event is assigned a frequency and each branch node is assigned a value denoting the probability of successful operation of the response represented, and conversely the probability of failure in that operation (The sum of the probabilities of success and failure equals 1.0). Evaluation of an event tree involves multiplication of the initiating event frequency and the probabilities assigned to the decision branches to give a frequency for each end event. All end event frequencies are evaluated in this way.

End events are assigned specific consequences. In this project this is the volume of oil spilled, assessed by consideration of the potential route that oil may be released to the marine environment. The risk for each end event is quantified by assigning the end event frequency to the specific consequences. The total risk for that accident is calculated by summing the contribution from all end events.

Event trees have been produced and evaluated for each of the significant undesirable events produced by the hazard identification. Initiating event frequencies are taken from the results of the fault tree evaluation (see above). Branch probability data for each event tree has been taken from data sources available to DNV. The size of oil release represented by each branch outcome were calculated on the basis of rulesets. The rule sets are fully traceable and are based on DNV's experience of consequence calculations.

An example event tree is shown below.

Figure 2.4:   Event Tree Example



2.4 Data Sources

The analysis is greatly dependent on the quality of the input data. This section describes the data sources used. All data used in the fault trees and event trees are described in the data sheets in the appendix to this report which presents the analysis of individual events.

Due to the conceptual nature of the design of the generic FPSO addressed in the project, information on FPSOs, their configuration, operation, hazards and risks has been taken from DNV's experience from previous analyses. Use of this information has provided additional detail and efficiency to this analysis than would otherwise have been possible. These previous analyses include confidential proprietary information belonging to other clients of DNV. The proprietary nature of these information sources prevents full references to the data from being included here. Additionally, DNV proprietary information has been used as input data to the risk assessment.

The specification for the FPSO and its operation is provided in the Scenario Report (Reference 1). This is a concept level description of a generic FPSO for deepwater operation. The high level description of its systems means that specific details required for the analysis have been drawn from DNV's experience of similar developments.

Input data for the risk analysis of shuttle tanker transport operations is extracted from an analysis of the MMS's tanker oil spill database for tankers operating in US waters by Anderson and LaBelle (Reference 2) as well as DNV's ARF Technical Note 14 (Reference 3).

Input data for the offshore offloading operation from the FPSO to the shuttle tanker is taken from the Marine Board's tanker lightering study commissioned by Coast Guard (Reference 4) and from MMS' lease sale EISs (i.e., MMS 1997b and MMS 1998a) as well as from a client-confidential DNV study conducted for an existing FPSO operating in the North Sea.

Input data for the risk analysis of FPSO operations is taken from DNV's ARF manual (Reference 5), which is a key internal reference document for risk assessment in DNV, and forms part of DNV's documented management system. DNV's ARF manual is a constantly updated compendium of DNV's offshore risk assessment experience. The ARF manual describes good modern practice in offshore QRA, and addresses all major aspects of this subject. The ARF manual includes a selection of recommended data as well as recommended analytical techniques and data sources. The ARF manual is used within DNV both as a reference book and as a training manual. The ARF manual requires a significant effort on DNV's part to update and maintain, and is a proprietary commercial asset to DNV.

Input data for FPSO operations has also been taken from DNV's experience on FPSO projects for other clients, including comprehensive assessments for 6 specific FPSO development projects in the North Sea and North Atlantic, as well as a deep water Gulf of Mexico development project. These assessments include confidential proprietary information, which prevents full referencing of the data. As a general rule, these FPSO developments are considered by DNV to represent good practice amongst the industry, and therefore the data used is considered applicable to this study.

3 RESULTS

This section presents the overall results of the analysis for the basecase as defined in the Scenario Report.

Appendix 1 contains details of the analysis for all the events considered, including:

- definition of the hazards from the hazard identification,
- the fault trees representing the accident frequencies and causes, and
- the event trees showing the development of each event through to the calculation of the accidental risk of oil release to the marine environment

Appendix 1 also identifies those events that were considered but not evaluated because they were judged to pose only a negligible risk of accidental oil spill.

Results Summary

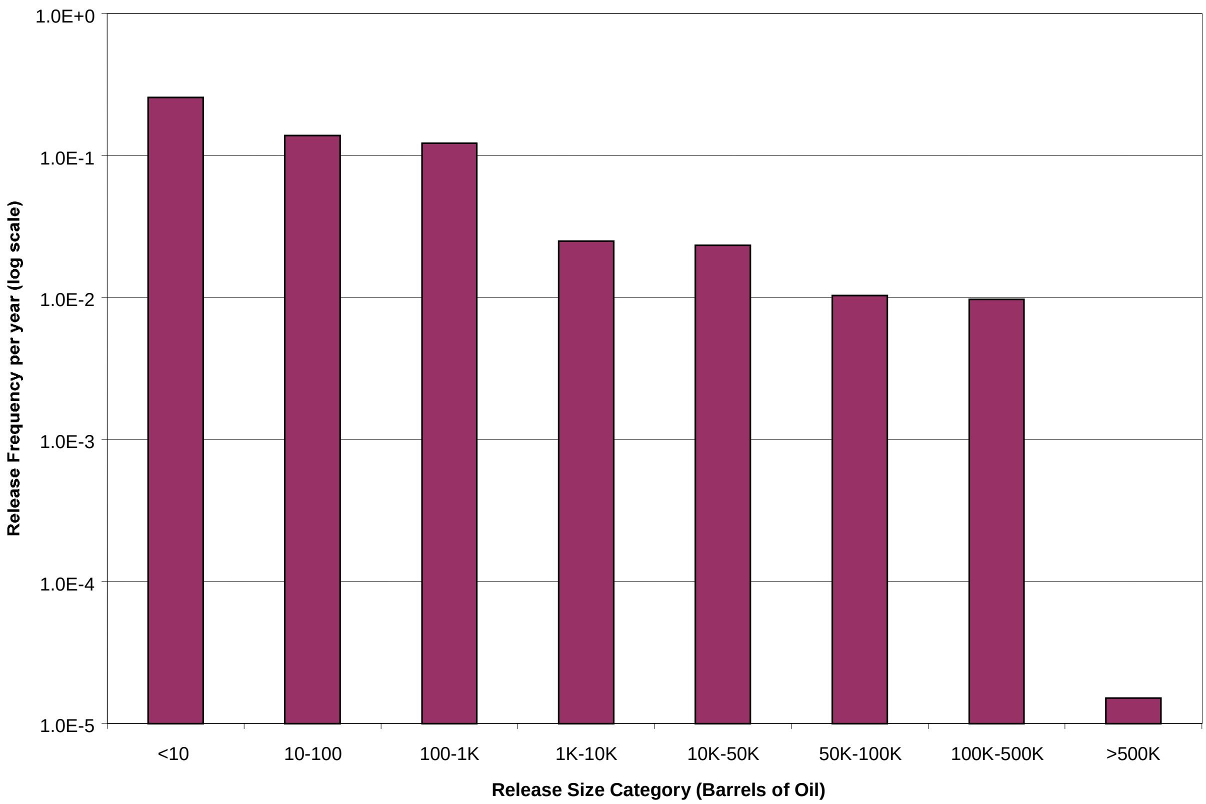
Table 3.1 presents a summary of the overall results for the basecase.

Table 3.1: Oil Releases due to Unique FPSO Accidents

Barrels of Oil Released	FPSO	Offloading	Shuttle Tankers	Frequency (per year)
Less than 10	1.3×10^{-2}	2.4×10^{-1}	0	2.6×10^{-1}
10-100	1.7×10^{-2}	1.2×10^{-1}	0	1.4×10^{-1}
100-1,000	7.9×10^{-5}	1.2×10^{-1}	0	1.2×10^{-1}
1,000-10,000	6.9×10^{-5}	0	2.5×10^{-2}	2.5×10^{-2}
10,000-50,000	6.9×10^{-4}	0	2.3×10^{-2}	2.3×10^{-2}
50,000-100,000	6.3×10^{-4}	0	9.7×10^{-3}	1.0×10^{-2}
100,000-500,000	5.9×10^{-4}	0	9.1×10^{-3}	9.7×10^{-3}
More than 500,000	1.6×10^{-5}	0	0	1.6×10^{-5}

Figure 3.1 shows these results graphically.

Figure 3.1: Frequency of Accidental Releases by Release Size for Unique FPSO Accidents



The results have been further analyzed to obtain a better understanding of the main issues driving the risks. Table 3.2 shows the risk of oil spill according to accidental event. DNV has assigned the upper end of each range as the representative release size for each category and used this to calculate the statistical volume of oil released annually for each accident type. This is a conservative approach. Table 3.2 has been ranked according to release volume, with the worst case events at the top. In the table, the column labeled "Vol." shows the annual volume released for that accident type as a fraction of the total released. The column labeled "Cum." shows the cumulative fraction for that accident plus the accidents above it in the table. Table 3.2 does not include those risks common to both FPSO and TLP technology.

Table 3.2: Oil Spill Frequencies per year by Accidental Event Category for Unique FPSO Risks

Scenario	Number of Spills Per Year									Vol. %	Cum. %
	<10	10-100	100-1K	1K-10K	10K-50K	50K-100K	100K-500K	> 500K	Total		
Shuttle Tanker Leak Near Port	0	0	0	1.4×10^{-2}	1.3×10^{-2}	5.6×10^{-3}	5.3×10^{-3}	0	3.8×10^{-2}	53.6%	53.6%
Shuttle Tanker Leak at Sea	0	0	0	1.0×10^{-2}	9.5×10^{-3}	4.1×10^{-3}	3.8×10^{-3}	0	2.8×10^{-2}	39.0%	92.6%
Process Leak	0	0	0	0	4.4×10^{-4}	4.4×10^{-4}	3.4×10^{-4}	0	1.2×10^{-3}	3.2%	95.8%
Transfer Hose Leak	2.4×10^{-1}	1.2×10^{-1}	1.2×10^{-1}	0	0	0	0	0	4.9×10^{-1}	1.8%	97.6%
Passing Merchant Vessel	0	0	0	6.9×10^{-5}	1.3×10^{-4}	7.1×10^{-5}	1.2×10^{-4}	1.1×10^{-5}	4.0×10^{-4}	1.2%	98.8%
Production Riser Leak	0	0	0	0	5.4×10^{-5}	5.4×10^{-5}	4.3×10^{-5}	0	1.5×10^{-4}	0.4%	99.2%
Foundering	0	0	0	0	4.5×10^{-6}	4.5×10^{-6}	3.6×10^{-5}	5.0×10^{-6}	5.0×10^{-5}	0.3%	99.5%
Cargo Tank Explosion	0	0	0	0	3.0×10^{-5}	3.0×10^{-5}	2.3×10^{-5}	0	8.3×10^{-5}	0.2%	99.7%
Swivel Leak	1.0×10^{-3}	1.3×10^{-2}	0	0	2.3×10^{-5}	2.3×10^{-5}	1.8×10^{-5}	0	1.4×10^{-2}	0.2%	99.9%
Cargo Piping Leak on Deck	1.2×10^{-2}	3.4×10^{-3}	7.9×10^{-5}	0	3.6×10^{-6}	3.6×10^{-6}	2.8×10^{-6}	0	1.6×10^{-2}	0.1%	100.0%
Process Gas Blow-by	0	0	0	0	3.3×10^{-6}	3.3×10^{-6}	2.6×10^{-6}	0	9.2×10^{-6}	0.0%	100.0%
Flowline Leak	0	0	0	0	1.1×10^{-6}	1.1×10^{-6}	9.1×10^{-7}	0	3.2×10^{-6}	0.0%	100.0%
Mooring Failure	0	0	0	0	8.3×10^{-7}	8.3×10^{-7}	7.0×10^{-7}	0	2.3×10^{-6}	0.0%	100.0%
Explosion in Turret	0	0	0	0	2.3×10^{-7}	2.3×10^{-7}	1.8×10^{-7}	0	6.4×10^{-7}	0.0%	100.0%
Ballast Tank Explosion	0	0	0	0	1.6×10^{-7}	1.6×10^{-7}	1.3×10^{-7}	0	4.5×10^{-7}	0.0%	100.0%
Gas Export Riser Leak	0	0	0	0	1.4×10^{-7}	1.4×10^{-7}	1.1×10^{-7}	0	3.8×10^{-7}	0.0%	100.0%
Gas Export Pipeline Leak	0	0	0	0	1.3×10^{-8}	1.3×10^{-8}	9.9×10^{-9}	0	3.5×10^{-8}	0.0%	100.0%
Visiting Shuttle Tanker	0	0	0	5.0×10^{-9}	7.8×10^{-9}	3.5×10^{-9}	5.8×10^{-9}	5.2×10^{-10}	2.3×10^{-8}	0.0%	100.0%
Methanol Fire	0	0	0	0	3.0×10^{-9}	3.0×10^{-9}	2.3×10^{-9}	0	8.3×10^{-9}	0.0%	100.0%
Drifting Vessel	0	0	0	0	0	0	0	0	0	0.0%	100.0%
Blowout	0	0	0	0	0	0	0	0	0	0.0%	100.0%
Wellhead or Manifold Leak	0	0	0	0	0	0	0	0	0	0.0%	100.0%
Cargo Tank Overfill	0	0	0	0	0	0	0	0	0	0.0%	100.0%
	2.6×10^{-1}	1.4×10^{-1}	1.2×10^{-1}	2.5×10^{-2}	2.3×10^{-2}	1.0×10^{-2}	9.7×10^{-3}	1.6×10^{-5}	5.9×10^{-1}		

The results show that for those risks unique to FPSO operation:

- The frequency of FPSO-unique oil releases greater than 1000 barrels is 0.037 per billion barrels produced for FPSO-related failures, and 1.2 per billion barrels for shuttle tanker-related failures. (The production rate is 150,000 barrels of oil per day.)
- Approximately 94.4 percent of the volume of potential FPSO-unique spills is likely to be due to the transfer of oil from the FPSO to the shuttle tanker and from the shuttle tanker transit to shore.
- 53.6 percent of the volume of potential FPSO-unique spills is likely to be from shuttle tankers near port.
- 39.0 percent of the volume of potential FPSO-unique spills is likely to be from shuttle tankers in transit to port.
- 1.8 percent of the volume of potential FPSO-unique spills is likely to be from the transfer from the FPSO to the shuttle tanker. However, these are all smaller spill sizes.
- For events on the FPSO, the dominant FPSO-unique risk is from accidents that escalate to the cargo area. The frequency of these events is of the order of 1×10^{-3} per year.
- Process releases are the largest FPSO-unique risk for releases on the FPSO.
- Passing merchant vessel collisions are low frequency events, but account for 1.2 percent of all the FPSO-unique oil released due to the potential for large volume spills.

A conclusion that can be drawn from Table 3.2 is that any effort to reduce the risk of oil spill from oil production on FPSOs should firstly concentrate on the operation of shuttle tankers. This is particularly true for the significant fraction of shuttle tanker spills that occur closer to shore, where there is likely to be a greater threat of environmental damage.

Measures that protect against escalation to the cargo area are likely to be the most beneficial means of reducing the risk of oil spills from the FPSO itself. Measures that protect against passing merchant vessel collisions are also likely to be beneficial in reducing oil spill risk, as are measures that prevent or control process releases.

Finally, the following points should be noted to put the study results in perspective;

- FPSO-unique spill risk is low. Of spill risk on the FPSO itself, excluding offloading and shuttle tanker transport, FPSO-unique spill risk makes up only 5% of the total. The remaining 95% of spills are non-unique and would be equally likely and have similar outcomes on a TLP or other deepwater alternative.
- Spill risk during offloading from the FPSO to the shuttle tanker is low. This risk is similar to that for lightering operations in the GoM, where there is a history of low spill frequency and small spill volumes.

- Shuttle tanker transport spills should be compared with pipeline spills. Based on analysis of MMS's database of oil spills in US waters (ref. 2) it is expected that for pipeline transport there will be 1.32 spills greater than 1000 bbls per billion bbls transported, and for tanker transport there will be 1.21 spills greater than 1000 bbls per billion bbls transported. Therefore, the oil spill risk for shuttle tanker transport is comparable to and arguably better than pipeline transport.
- The risk of shuttle tanker transport spills used in this assessment was derived from a database of tanker spills in U.S. waters with incidents extending back to the 1970s. This incident database covers a large range of years and provides a wide experience base for determining what the historic risk of tanker transport spills has been. However, the large range of years covered also means that recent regulatory and other risk-reducing measures are not well represented in the predicted risk of tanker transport spills. It is expected that these corrective actions should result in improved tanker performance in the future over the performance predicted using this database as has been observed over the last eight years. Therefore, the risk of shuttle tanker transport spills predicted in this assessment may well be conservative (overstated).
- The assessments of oil spill risk performed in this study should be regarded as generic to the concept of the use of FPSOs in deep water. More detailed analysis would accompany the evaluation of specific FPSO permit applications. At that time, the location of a proposed FPSO and associated tanker routes would be more defined, and the risk from transportation routes closer to shore would be evaluated.

4 ACRONYMS AND ABBREVIATIONS

bbls	–	Barrels
BOPD	–	Barrels of Oil Per Day
DNV	–	Det Norske Veritas
DP	–	Dynamic Positioning
dwt	–	Deadweight (tons)
ESDV	–	Emergency Shutdown Valve
FPSO	–	Floating Production, Storage, Offloading unit
GoM	–	Gulf of Mexico
HC	–	Hydrocarbons
LOOP	–	Louisiana Offshore Oil Port
MMS	–	Minerals Management Services
MJ	–	MegaJoules
MODU	–	Mobile Offshore Drilling Unit
OCS	–	Outer Continental Shelf
PFP	–	Personal Fire Protection
PLEM	–	Pipeline End Manifold
ROV	–	Remote Operated Vehicle
SBM	–	Single Buoy Mooring, Inc.
ST	–	Shuttle Tanker
TLP	–	Tension Leg Platform

5 REFERENCES

1. Ecology and Environment Inc., “Scenario Report, Environmental Impact Statement on Floating, Production, Storage, and Offloading Systems on the Gulf of Mexico Outer Continental Shelf” Working Copy, September 1999.
2. Anderson and LaBelle, “Comparative Occurrence Rates for Offshore Oil Spills”, Spill Science and Technology Bulletin 1(2), 1994
3. DNV ARF T14 Rev 1 – “ Process Equipment Failure Frequencies, Section 21 – Ships”, Confidential internal document, January 1999
4. Marine Board (1998): “Oil Spill Risks from Tank Vessel Lightering”, National Academy Press, Washington DC
5. DNV ARF C1 Rev 1 - "Guide to QRA of Offshore Installations", Confidential internal document, 1998

APPENDIX I

SCENARIO ANALYSIS DETAILS

HAZARDS

Blowout

- Blowout
- Wellhead or Manifold Leak

Riser and Pipeline Leaks

- Production Riser Leak
- Flowline Leak
- Gas Export Riser Leak
- Gas Export Pipeline Leak

Hydrocarbon Release on FPSO

- Swivel leak
- Explosion in turret
- Process Leak
- Explosion below process deck
- Liquid carryover from flare

Non-Process Fires and Explosions

- Methanol Fire
- Helifuel Fire
- Generator Explosion
- Cargo Heating Fire/Explosion
- Diesel Fire
- Accommodation Fire

Cargo Storage Events

- Cargo Tank Explosion
- Ballast Tank Explosion
- Cargo Tank Overfill
- Cargo Piping Leak on Deck
- Process Gas Blow-by

Marine Accidents on the FPSO

- Foundering

- Mooring Failure

Offloading Accidents

- Shuttle Tanker Collision During Offloading
- Transfer Hose Leak

Shuttle Tanker Accidents

- Shuttle Tanker Leak at Port
- Shuttle Tanker Leak at Sea

Non-Process Spills

- No events beyond those on existing platforms in the OCS

Transportation (supply vessels and helicopters)

- No events beyond those on existing platforms in the OCS

Ship Collisions

- Passing Merchant Vessel
- Drifting Vessel
- Visiting Supply Vessel
- Visiting Shuttle Tanker

Blowout

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Blowout	**Revision:** 0
Sub category :	Blowout	
Consequences :	Major release of oil to the sea	
Escalation :	Not applicable	
Consequences of Escalation :	Major release of oil to the sea	
Accident Causes :	Earthquake, Trawler damage, Material failure, Dropped object, Anchoring, Seabed compaction, Well intervention, Human error, Trenching operations, Trawler damage	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Flowline trenching, Fishing exclusion, Subsea layout	
Accident Detection :	Tree mounted instruments, Process upset, Visual detection, Downhole instrumentation, Periodic inspection	
Control :	Blowouts will not be controlled	
Mitigation :	FPSO is far enough away that cargo is not at risk, Intervention well, Oil spill response	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Blowout	**Revision:** 0

Subcategory: Blowout

Scenario description: A blowout releases oil from the reservoir directly to the sea. Blowouts are not unique spills to FPSOs, as they can also occur on any other existing OCS platforms. The FPSO is far enough away from the subsea wells that the cargo is not at risk.

Fault tree base events: 1.39×10^{-3} (ref. 3)

Event tree branch probabilities:

Release volumes: The following distribution of blowout duration times is presented in ref. 3:

< 10 min	10.9 %
10 – 40 min	6.9 %
40 min – 2 hr	6.9 %
2 – 12 hr	13.9 %
12 hr – 5 days	42.6 %
> 5 days	18.8 %

Based on this distribution and the assumption that a blowout will have a release rate 5 times that of the normal flow rate (ref. 3), the following distribution among the release ranges is assumed for this study:

100 – 1,000 :	10.9%
1,000 – 10,000 :	13.8%
10,000 – 50,000 :	13.9%
50,000 – 100,000 :	14.2%
100,000 – 500,000 :	28.4%
> 500,000 :	18.8%

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Blowout	**Revision:** 0
Sub category :	Wellhead or manifold leak	
Consequences :	Long duration small leak, or short duration large leak	
Escalation :	Blowout	
Consequences of Escalation :	Major release of oil to the sea	
Accident Causes :	Earthquake, Trawler damage, Material failure, Dropped object, Anchoring, Seabed compaction, Well intervention, Human error, Trenching operations, Trawler damage	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Flowline trenching, Fishing exclusion, Subsea layout	
Accident Detection :	Tree mounted instruments, Process upset, Visual detection, Downhole instrumentation, Periodic inspection	
Control :	Emergency shutdown	
Mitigation :	FPSO is far enough away that cargo is not at risk, Intervention well, Oil spill response	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Blowout	**Revision:** 0
Subcategory: Large (>30 kg/s) wellhead leak or manifold leak	
Scenario description : Large leak or rupture of manifold. Releases are assumed to be too far away from FPSO to cause escalation.	
Fault tree base events: 4.8 x 10^{-3} (per year) Leak frequency is assumed to be equivalent to surface oil manifold (1.6 x 10-2 leaks/year) (ref. 3) of which 3% are large leaks.	
Event tree branch probabilities: Probability release is directed towards FPSO: 0.125, estimated, depends on wind and current direction as well as distance from PLEM to FPSO. Detection failure: 0.01 for large leak (ref. 3) Control failure: 0.0012 shut in all three wells on connected subsea manifold, each well has 2 or more fail safe valves taken as reliability of ESD valve 0.02 so; P=(1-0.02^2)^3. This figure is conservatively in that it assumes there are 2 only fail-safe valves (subsea wellhead X-mas tree valves) for isolating any well from the risers each with individual failure probabilities of 0.02. In reality there are most likely 4 or 5 fail-safe valves counting sub-surface and manifold valves. Failure to isolate a well results in the release continuing until an alternate means of isolation is available, 14 days for ROV, (ref. 1). Successful isolation of all three wells results in shut-in of wells within 3 minutes of release. Ignition: 0 assumed not to ignite due to lack of ignition sources. Escalation: 0 it is assumed that the gas cloud will be too far away to affect the FPSO	
Release volumes: Subsea release from flowline. The representative release rate for a large leak or rupture of a single manifold is assumed to be equivalent to a rupture of a single flowline or 25,000 BOPD (i.e. 150,000 BOPD / 6 flowlines). It is assumed that 100% of the volume spilled subsea forms a pool at the surface.	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Blowout	**Revision:** 0
Subcategory: Medium (3.0 – 30 kg/s) wellhead leak or manifold leak	
Scenario description : Medium leak from manifold. Release of oil and gas mixture. Potential fire or explosion resulting in escalation to cargo tanks or FPSO.	
Fault tree base events: 1.8×10^{-3} (per year) Leak frequency is assumed to be equivalent to surface oil manifold (1.6 x 10-2 leaks/year) (ref. 3) of which 11% are medium leaks.	
Event tree branch probabilities: Probability release is directed towards FPSO: 0.125, estimated, depends on wind and current direction as well as distance from PLEM to FPSO. Detection failure: 0.01 for medium leak (ref. 3) Control failure: 0.0012 shut in all three wells on connected subsea manifold, each well has 2 or more fail safe valves taken as reliability of ESD valve 0.02 so; P=(1-0.02^2)^3. This figure is conservatively in that it assumes there are 2 only fail-safe valves (subsea wellhead X-mas tree valves) for isolating any well from the risers each with individual failure probabilities of 0.02. In reality there are most likely 4 or 5 fail-safe valves counting sub-surface and manifold valves. Failure to isolate a well results in the release continuing until an alternate means of isolation is available, 14 days for ROV, (ref. 1). Successful isolation of all three wells results in shut-in of wells within 3 minutes of release. Ignition: 0 assumed not to ignite due to lack of ignition sources. Escalation: 0 it is assumed that the gas cloud will be too far away to affect the FPSO.	
Release volumes: Subsea release from manifold. The representative release rate for medium leaks is 10 kg/s (~0.09 barrels/sec). It is assumed that 100% of the volume spilled subsea forms a pool at the surface.	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Blowout	**Revision:** 0
Subcategory: Small (0.3 – 3.0 kg/s) wellhead leak or manifold leak	
Scenario description : Small leak from manifold. Release of oil and gas mixture. Potential fire or explosion resulting in escalation to cargo tanks or FPSO.	
Fault tree base events: 1.4×10^{-2} (per year) Leak frequency is assumed to be equivalent to surface oil manifold (1.6 x 10-2 leaks/year) (ref. 3) of which 86% are small leaks.	
Event tree branch probabilities: Probability release is directed towards FPSO: 0.125, estimated, depends on wind and current direction as well as distance from PLEM to FPSO. Detection failure: 0.02 for small leak (ref. 3) Control failure: 0.0012 shut in all three wells on connected subsea manifold, each well has 2 or more fail safe valves taken as reliability of ESD valve 0.02 so; P=(1-0.02^2)^3. This figure is conservatively in that it assumes there are 2 only fail-safe valves (subsea wellhead X-mas tree valves) for isolating any well from the risers each with individual failure probabilities of 0.02. In reality there are most likely 4 or 5 fail-safe valves counting sub-surface and manifold valves. Failure to isolate a well results in the release continuing until an alternate means of isolation is available , 14 days for ROV, (ref. 1). Successful isolation of all three wells results in shut-in of wells within 3 minutes of release. Ignition: 0 assumed not to ignite due to lack of ignition sources. Escalation: 0 it is assumed that the gas cloud will be too far away to affect the FPSO.	
Release volumes: Subsea release from manifold. The representative release rate for small leaks is 1 kg/s (~0.009 barrels/sec). It is assumed that 100% of the volume spilled subsea forms a pool at the surface.	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Riser and Pipeline Leaks

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Riser and pipeline leaks	**Revision:** 0
Sub category :	Production riser leak	
Consequences :	Pipeline and riser contents releases to the sea	
Escalation :	Unisolated release may result in blowout, Ignited riser release may escalate to shuttle tanker	
Consequences of Escalation :	Uncontrolled wellfluid release or possible loss of FPSO due to long duration ignited leak	
Accident Causes :	Earthquake, Trawler damage, Material failure, Dropped object, Anchoring, Seabed compaction, Well intervention, Human error, Trenching operations, Riser on riser impact, Operation outside design conditions, Turret lock-up, Mooring failure, Extreme vessel motion, Riser on riser impact, Over-bending, Cyclic loading, Seabed disturbance, Single mooring line fails and damages riser	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Flowline trenching, Fishing exclusion, Subsea layout, Cathodic protection, Anchor exclusion corridor, Redundancy in the riser buoyancy system, Inspection, Bending restrictors	
Accident Detection :	Process upset, Visual detection, Gas detection on vessel, Periodic inspection	
Control :	Emergency shutdown	
Mitigation :	Procedures, Process shutdown, Oil spill contingency, Cargo tank integrity, Double hull (FPSO and shuttle tanker, Deluge cooling of process and cargo decks	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Riser and Pipeline Leaks	**Revision:** 0
Subcategory: Large production riser leak	

Scenario description : Large leak or rupture of production riser. Release of oil and gas mixture. Potential fire or explosion resulting in escalation to cargo tanks or FPSO.

Fault tree base events: 2.5 x 10^{-3} (per year) – 1.63 x 10^{-3} x 26% x 6 production risers (ref. 12)
Impacts:
<500m: 1.2 x 10-4/km-yr
>500m: 5.9 x 10-7/km-yr
Total riser length is estimated to be 2.16 km, of which 1.13 km is within 500 m of FPSO and 1.03 km is outside of 500 m.
Corrosion: 6.9 x 10-4/km-yr
Total: 1 x (6.9 x 10-4 x 2.16 + 1.2 x 10-4 x 1.13 + 5.9 x 10-7 x 1.03) = 1.63 x 10-3/yr

Hole Size Distribution:	Small:	58% (<20 mm)
	Medium:	16% (20-80 mm)
	Large:	26% (>80 mm)

Event tree branch probabilities: Detection failure: 0.01 for large leak (ref. 3)

Control failure: 0.0012 shut in all three wells on connected subsea manifold, each well has 2 or more fail safe valves taken as reliability of ESD valve 0.02 so;
P=(1-0.02^2)^3
Ignition: 0.3 for large gas leak (ref. 3)
Escalation due to major explosion: 0.075 probability of major explosion due to gas dispersing from sea surface to deck of FPSO and igniting in confined/congested area. (ref. 4)
Escalation due to fire, control fails: 0.5 estimated based on failure to isolate at least one well and continued large fire.
Escalation due to fire, control works: 0.0018 (ref. 13) calculated as 0.6 x 0.003

Release volumes: Release of inventory in production riser and flowline, 1750 x 2 (piggable loop) = 3500 barrels
Duration: isolation subsea occurs within 3 minutes unless there is an isolation failure, in which case it may take as long as 14 days (ROV) to isolate the release. Release rate is assumed to the production rate of one well, 16,700 barrels/day. 100% of the volume of oil released subsea is assumed to form a pool at the surface. If the release is ignited, the volume is reduced to 25% (i.e. 75% of the volume is lost in burning).

If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**	
10,000-50,000	0.36	
50,000-100,000	0.36	
100,000-500,000	0.28	
>500,000	0.00	
Total	1.00	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Riser and Pipeline Leaks	**Revision:** 0
Subcategory: Medium production riser leak	
Scenario description : Medium leak from production riser. Release of oil and gas mixture. Potential fire or explosion resulting in escalation to cargo tanks or FPSO.	
Fault tree base events: 1.6 x 10^{-3} (per year) – 1.63 x 10^{-3} x 16% x 6 production risers (ref. 12) (see large production riser leak)	
Event tree branch probabilities: Detection failure: 0.01 for medium leak (ref. 3) Control failure: 0.0012 shut in all three wells on connected subsea manifold, each well has 2 or more fail safe valves taken as reliability of ESD valve 0.02 so; P=(1-0.02^2)^3 Ignition: 0.1 for medium gas leak 5-25 kg/s (ref. 3) Escalation due to major explosion: 0 (ref. 4) Escalation due to fire, control fails: 0.25 estimated based on failure to isolate release from one or more wells, and continued medium fire. Escalation due to fire, control works: 0.0018 (ref. 13) calculated as 0.6 x 0.003	

Release volumes: Release of inventory in production riser and flowline, 1750 x 2 (piggable loop) = 3500 barrels
Duration: isolation subsea occurs within 3 minutes unless there is an isolation failure, in which case it may take as long as 14 days (ROV) to isolate the release. The representative release rate for a medium leak is 10 kg/second. 100% of the volume of oil released subsea is assumed to form a pool at the surface. If the release is ignited, the volume is reduced to 25% (i.e. 75% of the volume is lost in burning).

If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Riser and Pipeline Leaks	**Revision:** 0
Subcategory: Small production riser leak	
Scenario description : Small leak from production riser. Release of oil and gas mixture. Potential fire or explosion resulting in escalation to cargo tanks or FPSO.	
Fault tree base events: 5.7 x 10^{-3} (per year) – 1.63 x 10^{-3} x 58% x 6 production risers (ref. 12) (see large production riser leak)	
Event tree branch probabilities: Detection failure: 0.02 for small leak (ref. 3) Control failure: 0.0012 shut in all three wells on connected subsea manifold, each well has 2 or more fail safe valves taken as reliability of ESD valve 0.02 so; P=(1-0.02^2)^3 Ignition: 0 Release is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and ignite. Escalation due to major explosion: 0 Release is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and explode. Escalation due to fire, control fails: 0 Release is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and explode or otherwise escalate to the FPSO or cargo tanks. Escalation due to fire, control works: 0 Release is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and explode or otherwise escalate to the FPSO or cargo tanks.	
Release volumes: Release of inventory in production riser and flowline, 1750 x 2 (piggable loop) = 3500 barrels Duration: isolation subsea occurs within 3 minutes unless there is an isolation failure, in which case it may take as long as 14 days (ROV) to isolate the release. The representative release rate for a small leak is 1 kg/second. 100% of the volume of oil released subsea is assumed to form a pool at the surface.	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Riser and pipeline leaks	**Revision:** 0
Sub category :	Flowline leak	
Consequences :	Pipeline and riser contents releases to the sea	
Escalation :	Unisolated release may result in blowout, Ignited riser release may escalate to shuttle tanker	
Consequences of Escalation :	Uncontrolled wellfluid release or possible loss of FPSO due to long duration ignited leak	
Accident Causes :	Earthquake, Trawler damage, Material failure, Dropped object, Anchoring, Seabed compaction, Well intervention, Human error, Trenching operations, Riser on riser impact, Operation outside design conditions, Turret lock-up, Mooring failure, Extreme vessel motion, Riser on riser impact, Over-bending, Cyclic loading, Seabed disturbance, Single mooring line fails and damages riser	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Flowline trenching, Fishing exclusion, Subsea layout, Cathodic protection, Anchor exclusion corridor, Redundancy in the riser buoyancy system, Inspection, Bending restrictors	
Accident Detection :	Process upset, Visual detection, Gas detection on vessel, Periodic inspection	
Control :	Emergency shutdown	
Mitigation :	Procedures, Process shutdown, Oil spill contingency, Cargo tank integrity, Double hull (FPSO and shuttle tanker, Deluge cooling of process and cargo decks	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Riser and Pipeline Leaks	**Revision:** 0
Subcategory: Large flowline leak	

Scenario description : Large leak or rupture of flowline. Potential fire or explosion resulting in escalation to cargo tanks or FPSO. Analysis considers first kilometer of flow-line only. Releases past the first kilometer are assumed to be too far away from FPSO to cause escalation.

Fault tree base events: 1.1×10^{-3}/year – $6.91 \times 10^{-4} \times 26\% \times 6$ flowlines (ref. 12)
Impact Failures: 5.9×10^{-7}/km-yr
Corrosion Failures: 6.9×10^{-4}/km-yr
Total Frequency: 6.91×10^{-4}/yr = $1 \times (6.9 \times 10^{-4} \times 1 + 5.9 \times 10^{-7} \times 1)$

Hole Size Distribution:	Small:	58% (<20 mm)
	Medium:	16% (20-80 mm)
	Large:	26% (>80 mm)

Event tree branch probabilities:

Probability release is directed towards FPSO: 0.125, estimated, depends on wind and current direction as well as distance from PLEM to FPSO.

Detection failure: 0.01 for large leak (ref. 3)

Control failure: 0.0012 shut in all three wells on connected subsea manifold, each well has 2 or more fail safe valves taken as reliability of ESD valve 0.02 so;
P=(1-0.02^2)^3

Ignition, directed towards FPSO: 0.3 for large gas leak 25-200 kg/s (ref. 3)

Ignition, directed away from FPSO: 0 assumed not to ignite due to lack of ignition sources.

Escalation due to major explosion: 0.075 probability of major explosion due to gas dispersing from sea surface to deck of FPSO and igniting in confined/congested area. (ref. 4)

Escalation due to fire, control fails: 0.5 estimated based on failure to isolate release from one or more wells, and continued large release.

Escalation due to fire, control works: 0.0018 (ref. 13) calculated as 0.6 x 0.003

Release volumes: Subsea release from flowline. The representative release rate for a large leak or rupture of a single flowline is 25,000 BOPD (i.e. 150,000 BOPD / 6 flowlines). It is assumed that 100% of the volume spilled subsea forms a pool at the surface. If the release is ignited, the volume spilled is reduced to 25% (i.e. 75% is lost in burning).

If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Riser and Pipeline Leaks	**Revision:** 0
Subcategory: Medium flowline leak	
Scenario description : Medium leak from flowline. Release of oil and gas mixture. Potential fire or explosion resulting in escalation to cargo tanks or FPSO.	
Fault tree base events: 6.6 x 10-4 (per year) - 6.91 x 10-4 x 0.16 x 6 production flowlines (see large flowline leak)	
Event tree branch probabilities: Probability release is directed towards FPSO: 0.125, estimated, depends on wind and current direction as well as distance from PLEM to FPSO. Detection failure: 0.01 for medium leak (ref. 3) Control failure: 0.0012 shut in all three wells on connected subsea manifold, each well has 2 or more fail safe valves taken as reliability of ESD valve 0.02 so; P=(1-0.02^2)^3 Ignition: 0 Release originating at 5000' subsea is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and ignite. Escalation due to major explosion: 0 Release originating at 5000' subsea is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and explode. Escalation due to fire, control fails: 0 Release originating at 5000' subsea is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and escalate. Escalation due to fire, control works: 0 Release originating at 5000' subsea is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and escalate.	
Release volumes: Subsea release from flowline. The representative release rate for medium leaks is 10 kg/s (~0.09 barrels/sec). It is assumed that 100% of the volume spilled subsea forms a pool at the surface.	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Riser and Pipeline Leaks	**Revision:** 0

Subcategory: Small flowline leak

Scenario description :

Small leak from flowline. Release of oil and gas mixture. Potential fire or explosion resulting in escalation to cargo tanks or FPSO.

Fault tree base events: 2.4 x 10-3 (per year) - 6.91 x 10-4 x 0.58 x 6 production flowlines (see large flowline leak)

Event tree branch probabilities:

Probability release is directed towards FPSO: 0.125, estimated, depends on wind and current direction as well as distance from PLEM to FPSO.

Detection failure: 0.02 for small leak (ref. 3)

Control failure: 0.0012 shut in all three wells on connected subsea manifold, each well has 2 or more fail safe valves taken as reliability of ESD valve 0.02 so;
P=(1-0.02^2)^3

Ignition: 0 Release originating at 5000' subsea is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and ignite.

Escalation due to major explosion: 0 Release originating at 5000' subsea is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and explode.

Escalation due to fire, control fails: 0 Release originating at 5000' subsea is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and explode or otherwise escalate to the FPSO or cargo tanks.

Escalation due to fire, control works: 0 Release originating at 5000' subsea is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and explode or otherwise escalate to the FPSO or cargo tanks.

Release volumes: Subsea release from flowline. The representative release rate for small leaks is 1 kg/s (~0.009 barrels/sec). It is assumed that 100% of the volume spilled subsea forms a pool at the surface.

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Riser and pipeline leaks	**Revision:** 0
Sub category :	Gas export riser leak	
Consequences :	Gas releases are outside of this scope	
Escalation :	Ignited riser release may escalate to FPSO	
Consequences of Escalation :	Potential loss of cargo to the environment	
Accident Causes :	Earthquake, Trawler damage, Material failure, Dropped object, Anchoring, Seabed compaction, Well intervention, Human error, Trenching operations, Riser on riser impact, Operation outside design conditions, Turret lock-up, Mooring failure, Extreme vessel motion, Riser on riser impact, Over-bending, Cyclic loading, Seabed disturbance, Single mooring line fails and damages riser	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Flowline trenching, Fishing exclusion, Subsea layout, Cathodic protection, Anchor exclusion corridor, Redundancy in the riser buoyancy system, Inspection, Bending restrictors	
Accident Detection :	Process upset, Visual detection, Gas detection on vessel, Periodic inspection	
Control :	Emergency shutdown	
Mitigation :	Procedures, Process shutdown, Oil spill contingency, Cargo tank integrity, Double hull (FPSO and shuttle tanker, Deluge cooling of process and cargo decks	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Riser and Pipeline Leaks	**Revision:** 0

Subcategory: Large gas export riser leak

Scenario description :

Large leak or rupture of gas export riser. Potential fire or explosion resulting in escalation to cargo tanks or FPSO.

Fault tree base events: 6.0×10^{-5} (per year) – 2.29×10^{-5} x 26% x 1 gas export riser (ref. 12)

Impact Failures: <500m from FPSO: 1.2 x 10-4/km-yr
>500m from FPSO: 5.9 x 10-7/km-yr

Total riser length is estimated to be 2.16 km, of which 1.13 km is within 500 m (horizontal distance) of FPSO and 1.03 km is outside of 500 m.

Corrosion Failures: 4.3×10^{-5}/km-yr

Total Leak Frequency: 2.29×10^{-4}/yr = $1x(4.3 \times 10^{-5}x2.16+1.2x10^{-4}x1.13+5.9x10^{-7}x1.03)$

Hole Size Distribution:		
	Small:	58% (<20 mm)
	Medium:	16% (20-80 mm)
	Large:	26% (>80 mm)

Event tree branch probabilities:

Detection failure: 0.01 for large leak (ref. 3)

Control failure: 0.02 (for ESD failure of single isolatable section) (ref. 3) Control failure results in failure to isolate leaking gas export riser from pipeline to shore and prolonged release duration.

Ignition: 0.3 for large gas leak 25-200 kg/s (ref. 3)

Escalation due to major explosion: 0.075 probability of major explosion due to gas dispersing from sea surface to deck of FPSO and igniting in confined/congested area. (ref. 4)

Escalation due to fire, control fails: 0.5 estimated based on failure to isolate release from gas export pipeline to shore and continued large fire.

Escalation due to fire, control works: 0.0018 (ref. 13) calculated as 0.6 x 0.003

Release volumes:
In the event of escalation due to fire, loss of FPSO in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	Probability
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Riser and Pipeline Leaks	**Revision:** 0

Subcategory: Medium gas export riser leak

Scenario description :Medium leak from gas export riser. Potential fire or explosion resulting in escalation to cargo tanks or FPSO.

Fault tree base events: 3.7×10^{-5} (per year) – 2.29×10^{-4} x 16% x 1 gas export riser (ref. 12) (see large gas riser leak)

Event tree branch probabilities:

Detection failure: 0.01 for medium gas leak (ref. 3)

Control failure: 0.02 (for ESD failure of single isolatable section) (ref. 3) Control failure results in failure to isolate leaking gas export riser from pipeline to shore and prolonged release duration.

Ignition: 0.1 for medium gas leak 5-25 kg/s (ref. 3)

Escalation due to major explosion: 0 (ref. 4)

Escalation due to fire, control fails: 0.25 estimated based on failure to isolate riser leak from gas export pipeline and continued medium fire.

Escalation due to fire, control works: 0.0018 (ref. 13) calculated as 0.6 x 0.003

Release volumes:
In the event of escalation due to fire, loss of FPSO in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Riser and Pipeline Leaks	**Revision:** 0

Subcategory: Small gas export riser leak

Scenario description: Small from gas export riser. Potential fire or explosion resulting in escalation to cargo tanks or FPSO.

Fault tree base events: 1.3×10^{-4} (per year) – $2.29 \times 10^{-4} \times 58\% \times 1$ gas export riser (ref. 12) (see large gas export riser leak)

Event tree branch probabilities:

Detection failure: 0.02 for small gas leak (ref. 3)

Control failure: 0.02 (for ESD failure of single isolatable section) (ref. 3) Control failure results in failure to isolate leaking gas export riser from pipeline to shore and prolonged release duration.

Ignition: 0.04 for small gas leak 0.5-5 kg/s (ref. 3)

Escalation due to major explosion: 0 Leak would be too small to disperse from sea-surface and collect in any confined areas on the deck of the FPSO. Escalation due to explosion is not likely (ref. 4)

Escalation due to fire, control fails: 0 (as for explosions)

Escalation due to fire, control works: 0 (as for explosions)

Release volumes: Gas release, but no oil spill

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Riser and pipeline leaks	**Revision:** 0
Sub category :	Gas export pipeline leak	
Consequences :	Gas releases are outside of this scope	
Escalation :	Ignited riser release may escalate to FPSO	
Consequences of Escalation :	Potential loss of cargo to the environment	
Accident Causes :	Earthquake, Trawler damage, Material failure, Dropped object, Anchoring, Seabed compaction, Well intervention, Human error, Trenching operations, Riser on riser impact, Operation outside design conditions, Turret lock-up, Mooring failure, Extreme vessel motion, Riser on riser impact, Over-bending, Cyclic loading, Seabed disturbance, Single mooring line fails and damages riser	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Flowline trenching, Fishing exclusion, Subsea layout, Cathodic protection, Anchor exclusion corridor, Redundancy in the riser buoyancy system, Inspection, Bending restrictors	
Accident Detection :	Process upset, Visual detection, Gas detection on vessel, Periodic inspection	
Control :	Emergency shutdown	
Mitigation :	Procedures, Process shutdown, Oil spill contingency, Cargo tank integrity, Double hull (FPSO and shuttle tanker, Deluge cooling of process and cargo decks	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Riser and Pipeline Leak	**Revision:** 0

Subcategory: Large gas export pipeline leak

Scenario description: Large leak or rupture of from gas export pipeline. Release of gas. Potential fire or explosion resulting in escalation to cargo tanks or FPSO. Analysis only considers the first kilometer of pipeline. Release past first kilometer are assumed to be too far away to escalate to FPSO.

Fault tree base events: 1.1 x 10^{-5} /year – 4.36 x 10^{-5} x 26% x 1 gas export pipeline (ref. 12)

Impact Failures: 5.9 x 10^{-7}/km-yr

Corrosion Failures: 4.3 x 10^{-5}/km-yr

Total Leak Frequency: 4.36 x 10^{-5}/yr = 1 x (4.3 x 10^{-5} x 1 + 5.9 x 10^{-7} x 1)

Hole Size Distribution:	Small:	58% (<20 mm)
	Medium:	16% (20-80 mm)
	Large:	26% (>80 mm)

Event tree branch probabilities: Probability release is directed towards FPSO: 0.125, estimated, depends on wind and current direction as well as distance from PLEM to FPSO.

Detection failure: 0. 01 for large leak (ref. 3)

Control failure: 0.02 (for ESD failure of single isolatable section) (ref. 3) Control failure results in failure to isolate leaking gas export riser from pipeline to shore and prolonged release duration.

Ignition, directed towards FPSO: 0.3 for large gas leak (ref. 3)

Ignition, directed away from FPSO: 0 assumed not to ignite due to lack of ignition sources.

Escalation due to major explosion: 0.075 probability of major explosion due to gas dispersing from sea surface to deck of FPSO and igniting in confined/congested area. (ref. 4)

Escalation due to fire, control fails: 0.5 estimated based on control failure and continued fire

Escalation due to fire, control works: 0.0018 (ref. 13) calculated as 0.6 x 0.003

Release volumes: In the event of escalation due to fire, loss of FPSO in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis		18 October 1999
Hazard: Riser and Pipeline Leaks		**Revision:** 0
Subcategory: Medium gas export pipeline leak		
Scenario description : Medium leak from gas export pipeline. Release of gas. Potential fire or explosion resulting in escalation to cargo tanks or FPSO.		
Fault tree base events: 7.0 x 10^{-6}/ year – 4.36 x 10^{-5} x 0.16 x 1 export pipeline (see large gas export pipeline leak)		
Event tree branch probabilities: Probability release is directed towards FPSO: 0.125, estimated, depends on wind and current direction as well as distance from PLEM to FPSO. Detection failure: 0.01 for medium leak (ref. 3) Control failure: 0.02 (for ESD failure of single isolatable section) (ref. 3) Control failure results in failure to isolate leaking gas export riser from pipeline to shore and prolonged release duration. Ignition: 0 Release originating at 5000' subsea is assumed to be too small to disperse onto the deck of the FPSO and ignite. Escalation due to major explosion: 0 Release originating at 5000' subsea is assumed to be too small to disperse onto the deck of the FPSO and explode. Escalation due to fire, control fails: 0 Release originating at 5000' subsea is assumed to be too small to disperse onto the deck of the FPSO, ignite, and cause escalation. Escalation due to fire, control works: 0 Release originating at 5000' subsea is assumed to be too small to disperse onto the deck of the FPSO, ignite and cause escalation.		
Release volumes: Gas release from pipeline, but no oil spill anticipated.		
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Riser and Pipeline Leaks	**Revision:** 0
Subcategory: Small gas export pipeline leak	
Scenario description : Small leak from gas export pipeline. Release of gas. Potential fire or explosion resulting in escalation to cargo tanks or FPSO.	
Fault tree base events: 2.5 x 10^{-5}/year – 4.36 x 10^{-5} x 0.58 x 1 gas export pipeline (see large gas export pipeline leak)	
Event tree branch probabilities: Probability release is directed towards FPSO: 0.125, estimated, depends on wind and current direction as well as distance from PLEM to FPSO. Detection failure: 0.02 for small leak (ref. 3) Control failure: 0.02 (for ESD failure of single isolatable section) (ref. 3) Control failure results in failure to isolate leaking gas export riser from pipeline to shore and prolonged release duration. Ignition: 0 Release originating at 5000' subsea is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and ignite. Escalation due to major explosion: 0 (ref. 4) Release originating at 5000' subsea is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and explode. Escalation due to fire, control fails: 0 Release originating at 5000' subsea is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and explode or otherwise escalate to the FPSO or cargo tanks. Escalation due to fire, control works: 0 Release originating at 5000' subsea is assumed to be too small to disperse from the sea surface onto the deck of the FPSO and explode or otherwise escalate to the FPSO or cargo tanks.	
Release volumes: Gas release from pipeline, but no oil spill anticipated.	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Hydrocarbon Release on FPSO

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Hydrocarbon Release on FPSO	**Revision:** 0
Sub category :	Swivel leak	
Consequences :	Direct release of spilled oil to the sea, Fire at the swivel, Explosion at swivel.	
Escalation :	Damage to cargo area	
Consequences of Escalation :	Loss of some or all cargo to the sea	
Accident Causes :	Swivel seizure, Material defects, Human error, Dropped object, Tall structure collapse, Helicopter crash, Rotating equipment failure, Structural support failure, Excessive vessel motion, Green water, Hydrates, Process upset, Various ignition sources, Poor maintenance, Maintenance induced failure, Gas weepage from cargo area	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Process layout, Natural ventilation, inspection and maintenance, Operator competency, Passive fire protection, Corrosion protection, Dropped object protection, Protection against greenwater, Process control, Pressure relief, Ignition control Minimal hydrocarbon equipment, Helideck well clear from process area	
Accident Detection :	Process upset, Process control and instrumentation, Manual detection, Fire and gas detection	
Control :	Emergency shutdown, blowdown, process segregation	
Mitigation :	Deluge and foam, PFP, Limited ignition sources, open ventilation, full flow drainage, Main deck plate strength, Deck camber, Sealed deck penetrations, fire and blast walls, Electrical isolation, Inert gas in cargo tanks,	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Hydrocarbon Release on FPSO	**Revision:** 0
Subcategory: Large (>30 kg/s) swivel leak	
Scenario description : Production fluid or export gas release at swivel with potential results including spill to sea, fire or explosion, and escalation to cargo tanks or FPSO.	
Fault tree base events: 0.01 large swivel leak per year. Overall leak frequency for swivel is 0.1 leak per year with hole size distribution as follows suggested by Turret Manufacturer SBM (based on their past experience); Small: 0.90 Medium: 0.09 Large: 0.01	
Event tree branch probabilities: Detection failure: 0.01 for HC gas detection (ref. 3) Control failure: 0.02 for ESD (ref. 3). The probability of isolation failure assumes a typical section of pipework using 2 ESDVs. Ignition: 0.3 for large gas/oil release (ref. 3) Probability of escalation due to explosion: 0.075 (ref. 4) Escalation due to fire, control works: 0.0102 (ref. 13) calculated as 0.6 x 0.017 Escalation due to fire control fails: 0.0315 (ref. 13) calculated as 0.9 x 0.035 Probability of spill to sea: 0.9 Release is assumed to have a high potential to overflow the containment area due to high pressure and high release rate.	
Release volumes: Potential for hydrocarbon release off deck and directly to sea. If the release overflows the containment area it is assumed that 50% of the spill volume is released to sea. If the spill is ignited it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Representative release rate for large leak is 45 kg/second. Duration: Detection is assumed to occur in 1 minute, otherwise the release is assumed to be detected after 10 minutes. Control (i.e. ESD) is assumed to occur rapidly. The leak is then assumed to continue for 5 minutes until it deinventories the isolatable section. If control fails, the release is extended by 5 minutes relieving inventory from additional equipment. In the event of escalation due to fire, loss of FPSO in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to	

circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	Probability
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Hydrocarbon Release on FPSO	**Revision:** 0
Subcategory: Medium (3.0 – 30 kg/s) swivel leak	
Scenario description : Hydrocarbon release at swivel with potential results including spill to sea, fire or explosion, and escalation to cargo tanks or FPSO.	
Fault tree base events: 0.009 medium swivel leak per year. Overall leak frequency for swivel is 0.1 leak per year with size distribution as follows suggested by Turret Manufacturer SBM small: 0.90 medium: 0.09 large: 0.01	
Event tree branch probabilities: Detection failure: 0.01 for HC gas detection (ref. 3) Control failure: 0.02 for ESD (ref.3). The probability of isolation failure assumes a typical section of pipework using 2 ESDVs. Ignition: 0.1 for medium gas/oil release (ref. 3) Probability of escalation due to explosion: 0 (ref. 4) Escalation due to fire, control works: 0.0102 (ref. 13) calculated as 0.6 x 0.017 Escalation due to fire control fails: 0.0315 (ref. 13) calculated as 0.9 x 0.035 Probability of spill to sea: 0.5	

Release volumes: Potential for hydrocarbon release off deck and directly to sea. If the release overflows the containment area it is assumed that 50% of the spill volume is released to sea. If the spill is ignited it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Representative release rate for medium leak is 10 kg/second.

Duration: Detection is assumed to occur in 1 minute, otherwise the release is assumed to be detected after 10 minutes. Control (i.e. ESD) is assumed to occur rapidly. The leak is then assumed to continue for 15 minutes until it deinventories the isolatable section. If control fails, the release is extended by an additional 15 minutes relieving inventory from additional equipment.

In the event of escalation due to fire, loss of FPSO in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Hydrocarbon Release on FPSO	**Revision:** 0
Subcategory: Small (0.3 – 3.0 kg/s) swivel leak	
Scenario description : Hydrocarbon release at swivel with potential results including spill to sea, fire or explosion, and escalation to cargo tanks or FPSO.	
Fault tree base events: 0.09 small swivel leak per year. Overall leak frequency for swivel is 0.1 leak per year with size distribution as follows suggested by Turret Manufacturer SBM small: 0.90 medium: 0.09 large: 0.01	
Event tree branch probabilities: Detection failure: 0.02 for HC gas detection (ref. 3) Control failure: 0.02 for ESD (ref. 3). The probability of isolation failure assumes a typical section of pipework using 2 ESDVs. Ignition: 0.04 for small gas/oil release (ref. 3) Probability of escalation due to explosion: 0 (ref. 4) Escalation due to fire, control works: 0.0077 (ref. 13) calculated as 0.45 x 0.017 Escalation due to fire control fails: 0.0245 (ref. 13) calculated as 0.7 x 0.035 Probability of spill to sea: 0.1	

Release volumes: Potential for hydrocarbon release off deck and directly to sea. If the release overflows the containment area it is assumed that 50% of the spill volume is released to sea. If the spill is ignited it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Representative release rate for small leak is 1 kg/second.

Duration: Detection is assumed to occur in 1 minute, otherwise the release is assumed to be detected after 10 minutes. Control (i.e. ESD) is assumed to occur rapidly. The leak is then assumed to continue for 15 minutes until it deinventories the isolatable section. If control fails, the release is extended by an additional 15 minutes relieving inventory from additional equipment.

In the event of escalation due to fire, loss of FPSO in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Hydrocarbon Release on FPSO	**Revision:** 0
Sub category :	Explosion in turret	
Consequences :	Damage to the hull	
Escalation :	Release from cargo area	
Consequences of Escalation :	Loss of some or all cargo to the sea	
Accident Causes :	Material defects, Human error, Dropped object, Tall structure collapse, Helicopter crash, Rotating equipment failure, Structural support failure, Excessive vessel motion, Green water, Hydrates, Process upset, Various ignition sources, Poor maintenance, Maintenance induced failure, Gas weepage from cargo area	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Process layout, Natural ventilation, inspection and maintenance, Operator competency, Passive fire protection, Corrosion protection, Dropped object protection, Protection against greenwater, Process control, Pressure relief, Ignition control Minimal hydrocarbon equipment, Helideck well clear from process area	
Accident Detection :	Process upset, Process control and instrumentation, Manual detection, Fire and gas detection	
Control :	Emergency shutdown, blowdown, process segregation	
Mitigation :	Deluge and foam, PFP, open ventilation, Main deck plate strength, Sealed deck penetrations, fire and blast walls, Electrical isolation, Inert gas in cargo tanks,	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Hydrocarbon Release on FPSO	**Revision:** 0

Subcategory: Explosion in turret

Scenario description:

An explosion in the turret may lead to a leak in the cargo tank or could escalate to the process area and the cargo tanks.

Fault tree base events: 1 x 10^{-5} (per year) – ref. 6

Event tree branch probabilities:

Probability of failure to detect explosion: 0. The probability of detection of an explosion in the turret is assumed to be 100% (engineering judgement).

Probability of explosion causing a leak in the cargo tank: 0. Because of the multiple barriers between the turret and the cargo tanks and the fact that the turret should be designed to withstand any explosions within it, a 0% probability is assumed for the breaching of a cargo tank (engineering judgement).

Probability of escalation to process equipment (i.e. riser): 0.0644. For this study, the escalation probability of explosions in the turret is assumed to be the same as a referenced FPSO. A 6.44% probability of cargo tank escalation is assumed for this study (ref. 1).

Release volumes: If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Hydrocarbon Release on FPSO	**Revision:** 0
Sub category :	Process leak (pool fire or jet fire)	
Consequences :	Limited fire,	
Escalation :	Escalation to other process equipment, process deck collapse,	
Consequences of Escalation :	Release from cargo area , Loss of some or all cargo to the sea	
Accident Causes :	Material defects, Human error, Dropped object, Tall structure collapse, Helicopter crash, Rotating equipment failure (generator explosion), Structural support failure, Excessive vessel motion, Green water, Hydrates, Process upset, Various ignition sources, Poor maintenance, Maintenance induced failure, Gas weepage from cargo area	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Process layout, Natural ventilation, inspection and maintenance, Operator competency, Passive fire protection, Corrosion protection, Dropped object protection, Protection against greenwater, Process control, Pressure relief, Ignition control Minimal hydrocarbon equipment, Helideck well clear from process area	
Accident Detection :	Process upset, Process control and instrumentation, Manual detection, Fire and gas detection	
Control :	Emergency shutdown, blowdown, process segregation	
Mitigation :	Deluge and foam, PFP, Limited ignition sources, open ventilation, full flow drainage, Main deck plate strength, Deck camber, Sealed deck penetrations, fire and blast walls, Electrical isolation, Inert gas in cargo tanks, Plated process deck	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Hydrocarbon Release on FPSO	**Revision:** 0
Sub category :	Process leak (explosion)	
Consequences :	Over-pressure and missiles. Probably followed by process fire.	
Escalation :	Escalation to other process equipment, process deck collapse,	
Consequences of Escalation :	Release from cargo area , Loss of some or all cargo to the sea	
Accident Causes :	Material defects, Human error, Dropped object, Tall structure collapse, Helicopter crash, Rotating equipment failure (generator explosion), Structural support failure, Excessive vessel motion, Green water, Hydrates, Process upset, Various ignition sources, Poor maintenance, Maintenance induced failure, Gas weepage from cargo area	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Process layout, Natural ventilation, inspection and maintenance, Operator competency, Passive fire protection, Corrosion protection, Dropped object protection, Protection against greenwater, Process control, Pressure relief, Ignition control Minimal hydrocarbon equipment, Helideck well clear from process area	
Accident Detection :	Process upset, Process control and instrumentation, Manual detection, Fire and gas detection	
Control :	Emergency shutdown, blowdown, process segregation	
Mitigation :	Deluge and foam, PFP, Limited ignition sources, open ventilation, full flow drainage, Main deck plate strength, Deck camber, Sealed deck penetrations, fire and blast walls, Electrical isolation, Inert gas in cargo tanks, Plated process deck	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Marine Accident on FPSO	**Revision:** 0
Subcategory: Large (> 30 kg/s) Process Leak	
Scenario description : Large process leak and subsequent ignition results in escalation to cargo tanks or otherwise causes loss of FPSO. A leak from this location will be production fluid, which will consist of both gas and oil.	
Fault tree base events: 0.045 large process leaks per year. Based on 1.5 process leaks per year of which 3% are large.	
Event tree branch probabilities: Detection failure: HC gas detection system reliability for large leak 0.01 (ref. 3). Detection assumed to occur within 1 minute or within 10 minutes for detection failure. Control failure: Process ESD reliability 0.02 (ref. 3). This is the probability that the isolatable section where the release is originating will be isolated from the rest of the process, assuming a typical section of pipework using 2 ESDVs. Release is assumed to end within 5 minutes with isolation and in 10 minutes in the case of control failure due to double the inventory (i.e. releasing contents of two isolatable sections rather than one) or delayed closure of valves. Ignition: 0.3 per large gas release (ref. 3) Escalation due to major explosion: 0.075 (ref. 4) Escalation due to fire, control fails: 0.063 (ref. 13) calculated as 0.9 x 0.07 Escalation due to fire, control works: 0.0018 (ref. 13) calculated as 0.6 x 0.003 Spill to sea: 0.9	

Release volumes: Potential for hydrocarbon release off deck and directly to sea. If the release overflows the containment area it is assumed that 50% of the spill volume is released to sea. If the spill is ignited it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Representative release rate for large leak is 45 kg/second.

Duration: Detection is assumed to occur in 1 minute, otherwise the release is assumed to be detected after 10 minutes. Control (i.e. ESD) is assumed to occur rapidly. The leak is then assumed to continue for 5 minutes until it deinventories the isolatable section. If control fails, the release is extended by an additional 5 minutes relieving inventory from additional equipment.

If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Hydrocarbon Release on FPSO	**Revision:** 0
Area concerned: Medium (3.0 – 30 kg/s) Process Leak	
Scenario description: Medium process leak and subsequent ignition results in escalation to cargo tanks or otherwise causes loss of FPSO. A leak from this location will be production fluid, which will consist of both gas and oil.	
Fault tree base events: 0.165 medium process leaks per year. Based on 1.5 process leaks per year of which 11% are medium.	
Event tree branch probabilities: Detection failure: HC gas detection system reliability for medium leak 0.01 (ref. 3). Detection assumed to occur within 1 minute or within 10 minutes for detection failure. Control failure: Process ESD reliability 0.02 (ref. 3). This is the probability that the isolatable section where the release is originating will be isolated from the rest of the process, assuming a typical section of pipework using 2 ESDVs. Release is assumed to end within 15 minutes with isolation and in 30 minutes in the case of control failure due to double the inventory (i.e. releasing contents of two isolatable sections rather than one) or delayed closure of valves. Ignition: 0.1 per medium gas release (ref. 3) Escalation due to major explosion: 0 (ref. 4) Escalation due to fire, control fails: 0.063 (ref. 13) calculated as 0.9 x 0.07 Escalation due to fire, control works: 0.0018 (ref. 13) calculated as 0.6 x 0.003 Spill to sea: 0.5	

Release volumes: Potential for hydrocarbon release off deck and directly to sea. If the release overflows the containment area it is assumed that 50% of the spill volume is released to sea. If the spill is ignited it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Representative release rate for medium leak is 10 kg/second.

Duration: Detection is assumed to occur in 1 minute, otherwise the release is assumed to be detected after 10 minutes. Control (i.e. ESD) is assumed to occur rapidly. The leak is then assumed to continue for 15 minutes until it deinventories the isolatable section. If control fails, the release is extended by an additional 15 minutes relieving inventory from additional equipment.

If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Hydrocarbon Release on FPSO	**Revision:** 0
Area concerned: Small (0.3 – 3.0 kg/s) Process Leak	
Scenario description: Small process leak and subsequent ignition results in escalation to cargo tanks or otherwise causes loss of FPSO. A leak from this location will be production fluid, which will consist of both gas and oil.	
Fault tree base events: 1.3 small process leaks per year. Based on 1.5 process leaks per year of which 86% are small.	
Event tree branch probabilities: Detection failure: HC gas detection system reliability for small leak 0.02 (ref. 3). Detection assumed to occur within 1 minute or within 10 minutes for detection failure. Control failure: Process ESD reliability 0.02 (ref. 3). This is the probability that the isolatable section where the release is originating will be isolated from the rest of the process, assuming a typical section of pipework using 2 ESDVs. Release is assumed to end within 15 minutes with isolation and in 30 minutes in the case of control failure due to double the inventory (i.e. releasing contents of two isolatable sections rather than one) or delayed closure of valves. Ignition: 0.04 per small gas release (ref. 3) Escalation due to major explosion: 0 Release is assumed to be too small to result in escalation to cargo tanks. (ref. 4) Escalation due to fire, control fails: 0.049 (ref. 13) calculated as 0.7 x 0.07 Escalation due to fire, control works: 0.00135 (ref. 13) calculated as 0.45 x 0.003 Spill to sea: 0.1	

Release volumes: Potential for hydrocarbon release off deck and directly to sea. If the release overflows the containment area it is assumed that 50% of the spill volume is released to sea. If the spill is ignited it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Representative release rate for small leak is 1 kg/second.

Duration: Detection is assumed to occur in 1 minute, otherwise the release is assumed to be detected after 10 minutes. Control (i.e. ESD) is assumed to occur rapidly. The leak is then assumed to continue for 15 minutes until it deinventories the isolatable section. If control fails, the release is extended by 15 minutes relieving inventory from additional equipment.

If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	Probability
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Hydrocarbon Release on FPSO	**Revision:** 0
Sub category :	Explosion below process deck	
Consequences :	Over-pressure and missiles. Probably followed by process fire. Structural damage to main and process deck. An explosion under the process deck is one of the possible outcomes of a process leak. To avoid double counting, it is addressed under the process leak subcategory and is not analyzed separately.	
Escalation :	Escalation to other process equipment, process deck collapse,	
Consequences of Escalation :	Release from cargo area , loss of some or all cargo to the sea	
Accident Causes :	Material defects, Human error, Dropped object, Tall structure collapse, Helicopter crash, Rotating equipment failure, Structural support failure, Excessive vessel motion, Green water, Hydrates, Process upset, Various ignition sources, Poor maintenance, Maintenance induced failure, Gas weepage from cargo area	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Process layout, Natural ventilation, inspection and maintenance, Operator competency, Passive fire protection, Corrosion protection, Dropped object protection, Protection against greenwater, Process control, Pressure relief, Ignition control Minimal hydrocarbon equipment, Helideck well clear from process area	
Accident Detection :	Process upset, Process control and instrumentation, Manual detection, Fire and gas detection	
Control :	Emergency shutdown, blowdown, process segregation	
Mitigation :	Deluge and foam, PFP, Limited ignition sources, open ventilation, full flow drainage, Main deck plate strength, Deck camber, Sealed deck penetrations, fire and blast walls, Electrical isolation, Inert gas in cargo tanks, Plated process deck	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Hydrocarbon Release on FPSO	**Revision:** 0
Sub category :	Liquid carry over from flare	
Consequences :	Small amount of oil released directly to the sea. Liquid carry over from the flare could occur on other existing OCS platforms, and would not cause an oil spill unique to an FPSO, and is not analyzed further.	
Escalation :	None	
Consequences of Escalation :		
Accident Causes :		
Prevention :		
Accident Detection :		
Control :		
Mitigation :		
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Non-Process Fires and Explosions

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Non-process fires and explosions	**Revision:** 0
Sub category :	Methanol fire	
Consequences :	Limited fire,	
Escalation :	Escalation to other process equipment, process deck collapse,	
Consequences of Escalation :	Release from cargo area , Loss of some or all cargo to the sea	
Accident Causes :	Material defects, Human error, Dropped object, Tall structure collapse, Helicopter crash, Rotating equipment failure, Structural support failure, Excessive vessel motion, Green water, Hydrates, Process upset, Various ignition sources, Poor maintenance, Maintenance induced failure, Gas weepage from cargo area	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Process layout, Natural ventilation, inspection and maintenance, Operator competency, Passive fire protection, Corrosion protection, Dropped object protection, Protection against greenwater, Process control, Pressure relief, Ignition control Minimal hydrocarbon equipment, Helideck well clear from process area	
Accident Detection :	Process upset, Process control and instrumentation, Manual detection, Fire and gas detection	
Control :	Emergency shutdown, blowdown, process segregation	
Mitigation :	Deluge and foam, PFP, Limited ignition sources, open ventilation, full flow drainage, Main deck plate strength, Deck camber, Sealed deck penetrations, fire and blast walls, Electrical isolation, Inert gas in cargo tanks, Plated process deck	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Non-Process Fires and Explosions	**Revision:** 0

Subcategory: Methanol spill

Scenario description :

A methanol spill from the storage tank ignites and escalates to the process equipment and cargo tanks. Methanol is used for well injection purposes and the environmental risk posed by the methanol itself is not a hazard unique to an FPSO.

Fault tree base events: 1.5 x 10^{-4} (per year), ref. 3.

Event tree branch probabilities:

Failure to detect: 0.01. The methanol spill is assumed the same detection probability as a medium sized hydrocarbon release. A detection failure probability of 1% is used for this scenario (ref. 3).

Failure to deluge: 0.011. If the deluge system for the methanol area is effective, it is assumed that the methanol will be diluted and drained, thus not posing a hazard. The reliability of the deluge system for this study is assumed to be 1.1% (ref. 3).

Ignition probability: 0.08. (ref. 3)

Probability of escalation to process area: 0.063. For this study, the escalation probability is assumed to be the same for methanol leaks as large uncontrolled process leaks. A 6.3% probability of cargo tank escalation is assumed for this study (ref. 13).

Release volumes: If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Non-process fires and explosions	**Revision:** 0
Sub category :	Helifuel fire	
Consequences :	Limited fire. A helifuel fire could occur on other existing OCS platforms, and would not cause a spill that is unique to an FPSO, and is not further analyzed.	
Escalation :	None	
Consequences of Escalation :	None	
Accident Causes :	Material failure, impact damage, handling errors	
Prevention :	Material failure, impact damage, handling errors	
Accident Detection :	Visual	
Control :	limited inventory, isolation,	
Mitigation :	Drainage, bunding, PFP, deluge, pressure relief on tanks	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Non-process fires and explosions	**Revision:** 0
Sub category :	Generator explosion	
Consequences :	Over-pressure and missiles. Probably followed by process fire. A generator explosion is one of the initiating events for a process leak and fire and explosion. To avoid double counting, generator explosion is addressed under process leaks and is not analyzed separately.	
Escalation :	Escalation to other process equipment, process deck collapse,	
Consequences of Escalation :	Release from cargo area , Loss of some or all cargo to the sea	
Accident Causes :	Material defects, Human error, Dropped object, Tall structure collapse, Helicopter crash, Rotating equipment failure, Structural support failure, Excessive vessel motion, Green water, Hydrates, Process upset, Various ignition sources, Poor maintenance, Maintenance induced failure, Gas weepage from cargo area	
Prevention :	Hydrocarbon boundary integrity, Impact protection, Good design, Process layout, Natural ventilation, inspection and maintenance, Operator competency, Passive fire protection, Corrosion protection, Dropped object protection, Protection against greenwater, Process control, Pressure relief, Ignition control Minimal hydrocarbon equipment, Helideck well clear from process area	
Accident Detection :	Process upset, Process control and instrumentation, Manual detection, Fire and gas detection	
Control :	Emergency shutdown, blowdown, process segregation	
Mitigation :	Deluge and foam, PFP, Limited ignition sources, open ventilation, full flow drainage, Main deck plate strength, Deck camber, Sealed deck penetrations, fire and blast walls, Electrical isolation, Inert gas in cargo tanks, Plated process deck	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Non-process fires and explosions	**Revision:** 0
Sub category :	Cargo heating (e.g. boiler) fire / explosion	
Consequences :	Potential fire and explosion. Cargo heating equipment is not specified in the scenario report. It is not clear that cargo heating would be required. Therefore, the potential for oil spills associated with cargo heating are not analyzed further.	
Escalation :		
Consequences of Escalation :		
Accident Causes :		
Prevention :		
Accident Detection :		
Control :		
Mitigation :		
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Non-process fires and explosions	**Revision:** 0
Sub category :	Diesel fire	
Consequences :	Localized fire, large amount of smoke generated. A diesel fire could occur on other OCS platforms, and would not cause an oil spill unique to an FPSO. Therefore, diesel fires are not analyzed further.	
Escalation :		
Consequences of Escalation :		
Accident Causes :		
Prevention :		
Accident Detection :		
Control :		
Mitigation :		
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Non-process fires and explosions	**Revision:** 0
Sub category :	Accommodation fire	
Consequences :	Localized fire. An accommodations fire could occur on other existing OCS platforms an would not cause and oil spill unique to an FPSO. Therefore, accommodations fire are not analyzed further.	
Escalation :	None	
Consequences of Escalation :	None	
Accident Causes :		
Prevention :		
Accident Detection :		
Control :		
Mitigation :		
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Cargo Storage Events

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Cargo Storage Events	**Revision:** 0
Sub category :	Cargo tank explosion	
Consequences :	Structural damage, Possible loss of vessel	
Escalation :	Even if the vessel is not lost, there may be a major cargo fire	
Consequences of Escalation :	Major spill into the sea	
Accident Causes :	Poor maintenance, human error, IG failure, hot work, other ignition sources, submerged pumps running in empty tank whilst O2 present	
Prevention :	Inert gas, procedures, control of ignition sources,	
Accident Detection :	oxygen detectors,	
Control :		
Mitigation :	Vessel strength, double hull, fire-fighting	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Cargo Storage Events	**Revision:** 0

Subcategory: Cargo tank explosion

Scenario description :

An explosion in the cargo tank ruptures the hull sinking the ship or damages the top deck to an extent that will split the FPSO in two.

Fault tree base events: 2.02 x 10^{-3} (per year) – ref. 3.

Event tree branch probabilities:

Probability of ruptured tanks leading to loss of FPSO stability: 0.04. It is assumed that there is a 4% probability of structural collapse following an explosion in a ballast tank (ref. 4).

Probability of loss of structural integrity due to top deck damage: 0.001. If the explosion does not immediately cause a structural collapse of the FPSO, the explosion may cause enough damage to the top deck of the FPSO that might cause a delayed collapse. A probability of 0.1% is assumed for this study (engineering judgement).

Release volumes: If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Cargo Storage Events	**Revision:** 0
Sub category :	Ballast tank explosion	
Consequences :	Structural damage, Possible loss of vessel	
Escalation :	Even if the vessel is not lost, there may be a major cargo fire	
Consequences of Escalation :	Major spill into the sea	
Accident Causes :	Poor maintenance, human error, IG failure, hot work, other ignition sources, submerged pumps running in empty tank whilst O2 present	
Prevention :	Inert gas, procedures, control of ignition sources,	
Accident Detection :	gas detectors,	
Control :		
Mitigation :	Vessel strength, double hull, fire-fighting	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Cargo Storage Events	**Revision:** 0

Subcategory: Ballast tank explosion

Scenario description :

An explosion in the ballast tank ruptures the hull sinking the ship or damages the top deck to an extent that will split the FPSO in two.

Fault tree base events: 1.1 x 10^{-5} (per year) – ref. 3.

Event tree branch probabilities:

Probability of ruptured tanks leading to loss of FPSO stability: 0.04. It is assumed that there is a 4% probability of structural collapse following an explosion in a ballast tank (ref. 4).

Probability of loss of structural integrity due to top deck damage: 0.001. If the explosion does not immediately cause a structural collapse of the FPSO, the explosion may cause enough damage to the top deck of the FPSO that might cause a delayed collapse. A probability of 0.1% is assumed for this study (engineering judgement).

Release volumes: If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Cargo Storage Events	**Revision:** 0
Sub category :	Cargo tank overfill	
Consequences :	Structural damage	
Escalation :	Oil spill on deck over-flowing to the sea (200 kg/s), may ignite	
Consequences of Escalation :	Major spill into the sea	
Accident Causes :	Procedural error, control valve failure, instrumentation failure	
Prevention :	Crew competency, procedures, tank radar.	
Accident Detection :	High level alarm,	
Control :	Process shutdown	
Mitigation :	Vessel strength, double hull, fire-fighting	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Cargo Storage Events	**Revision:** 0

Subcategory: Cargo tank overfill

Scenario description: The cargo tank overfills, allowing oil to flow to the deck and possibly spill over to the sea.

Fault tree base events: 0.03 (per year) – ref. 3

Event tree branch probabilities: Probability of breather valve opening: 0.998. Computed from the failure rates of "failed to open" (1.34 failures per 10^6 hours) and "plugged" (0.88 failures per 10^6 hours) from a pressure reduction valve in ref 5. These failure modes are hidden failure modes, so the probability of valve failing to open is computed from the following equation: $\frac{1}{2}\lambda\tau$ (λ is the failure rate, τ is the test interval). It is assumed that there is a 3-month test interval for the breather valves. The failure probability is thus 0.2% (0.5 x 2160 hours x 2.22 x 10^{-6} failures/hr).

Probability of detection failing within 1 minute: 0.01. The cargo tank spill is assumed the same detection probability as a large hydrocarbon release. A value of 1% detection probability for a cargo tank overfill is based on the detection failure probability of a medium leak (ref. 3).

Probability of control failure: 0. Effective isolation generally requires the closure of two isolation valves (i.e. one at each end of the isolated volume). Thus, the probability of failure to isolate a typical section of pipework using 2 ESDVs is approximately 2% (ref. 3).

Ignition probability: 0.04. The ignition probability of 4% is assumed for a generic oil leak (ref. 3).

Probability of spilling to sea: 0. The probability of spilling to sea in the event of an unignited leak from cargo tanks is assumed to be 0% (engineering judgement).

Release volumes: It is assumed that the maximum flow rate from the wells is being loaded into the cargo tank (150,000 BPD or 1.74 barrels/sec).

The breather valve is for venting gas out of the cargo tank and if oil is overfilled in the tank, then the cargo tank will just become pressurized and may cause damage to the tank. It is assumed that there will be pressure and pump failure indicators upstream that will alarm if any cargo tank becomes overfilled.

Any oil that does spill through the breather valve is assumed to be < 10 barrels and it is assumed that this oil will be drained and will not pose an environmental hazard.

Thus this event will not pose any environmental hazard.

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Cargo Storage Events	**Revision:** 0
Sub category :	Cargo piping leak on deck	
Consequences :	Crude oil spill on deck	
Escalation :	Oil spill on deck, may ignite, explosion under process deck	
Consequences of Escalation :	Oil spill into the sea	
Accident Causes :	Piping failure, human error, dropped object	
Prevention :	Material selection, inspection, procedures	
Accident Detection :	Gas detection, visual	
Control :	Shutdown	
Mitigation :	Drainage, vessel strength	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Cargo Storage Events	**Revision:** 0
Subcategory: Cargo piping leak distribution	
Scenario description: Piping from the cargo tanks leaks, then ignites and escalates to the process area and cargo tanks. The cargo from the piping could also leak to the sea.	
Fault tree base events: 9.3 x 10^{-2} (per year). Cargo tank piping is estimated as 1500 meters of <11" steel piping (5.1 x 10^{-5} leaks/meter-year) in addition to an oil manifold (1.6 x 10^{-2} leaks/year) (ref. 3).	
Event tree branch probabilities: Large leak (> 30 kg/s): 0.03 Medium leak (3.0 – 30 kg/s): 0.11 Small leak (0.3 – 3.0 kg/s): 0.86 Leak size probabilities were determined from analysis of a release rate versus probability chart in ref. 3.	
Release volumes: See below.	

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Cargo Storage Events	**Revision:** 0
Subcategory: Large cargo piping leak	
Scenario description : Piping from the cargo tanks leaks, then ignites and escalates to the process area and cargo tanks. The cargo from the piping could also leak to the sea.	
Fault tree base events: 2.8 x 10^{-3} (per year)	
Event tree branch probabilities: Failure to detect: 0.01 this value for a large leak is conservatively estimated based on failure to detect medium hydrocarbon leaks (ref. 3). Failure to control leak: 0.02. Effective isolation generally requires the closure of two isolation valves (i.e. one at each end of the isolated volume). The crude oil can also be stopped by shutting off the pumps. Thus, the probability of failure to isolate a typical section of pipework using 2 ESDVs is approximately 2% (ref. 3). Ignition probability: 0.08. Ignition probability taken from the generic ignition probabilities for pool fires (ref. 3). Escalation probability: 0.063 if not controlled, 0.0018 if controlled. Escalation probabilities based on whether the ESD control fails or not. The data were taken from cargo tanks escalation probabilities from large releases in the process area of an FPSO (ref. 13). Probability of spilling to sea: 0.9. The probability of spilling to sea in the event of an unignited large leak from cargo piping is assumed to be 90% (engineering judgement).	

Release volumes: The representative release rate for a large release is 45 kg/s (~0.40 barrels/sec).

If the ESD fails, it is assumed that a manual shutoff valve will be closed 10 minutes after the start of the event (240 barrels released). If there is an initial failure to detect, it is assumed that the event will be detected after 5 minutes (120 barrels released). If the release is detected and controlled, isolation is assumed to occur 1 minute after the start of the leak (60 barrels released).

If the pool spills to sea, it is assumed that 100% of the available liquid spill to sea. If the pool ignites, it is assumed that 25% of the available pool will still be liquid when spilled to sea.

If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Cargo Storage Events	**Revision:** 0
Subcategory: Medium cargo piping leak	
Scenario description : Piping from the cargo tanks leaks, then ignites and escalates to the process area and cargo tanks. The cargo from the piping could also leak to the sea.	
Fault tree base events: 1.0 x 10^{-2} (per year)	
Event tree branch probabilities: Failure to detect: 0.01. A value of 1% detection failure probability for a medium cargo piping leak is assumed for this study (ref. 3). Failure to control leak: 0.02. Effective isolation generally requires the closure of two isolation valves (i.e. one at each end of the isolated volume). The flow can also be stopped by shutting off the pumps. Thus, the probability of failure to isolate a typical section of pipework using 2 ESDVs is approximately 2% (ref. 3). Ignition probability: 0.06. Ignition probability taken from the generic ignition probabilities for pool fires (ref. 3). Escalation probability: 0.063 if not controlled, 0.0018 if controlled. Escalation probabilities based on whether the ESD control fails or not. The data were taken from cargo tanks escalation probabilities from medium releases in the process area of an FPSO (ref. 13). Probability of spilling to sea: 0.5. The probability of spilling to sea in the event of an unignited medium leak from cargo piping is assumed to be 50% (engineering judgement).	

Release volumes: The representative release rate for a medium release is 10 kg/s (~0.09 barrels/sec).

If the ESD fails, it is assumed that a manual shutoff valve will be closed 10 minutes after the start of the event (54 barrels released). If there is an initial failure to detect, it is assumed that the event will be detected after 5 minutes (27 barrels released). If the release is detected and controlled, isolation is assumed to occur 1 minute after the start of the leak (5 barrels released).

If the pool spills to sea, it is assumed that 100% of the available liquid spill to sea. If the pool ignites, it is assumed that 25% of the available pool will still be liquid when spilled to sea.

If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	**Probability**
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Cargo Storage Events	**Revision:** 0
Subcategory: Small cargo piping leak	
Scenario description : Piping from the cargo tanks leaks, then ignites and escalates to the process area and cargo tanks. The cargo from the piping could also leak to the sea.	
Fault tree base events: 8.0×10^{-2} (per year)	
Event tree branch probabilities: Failure to detect leak: 0.02. A value of 2% detection failure probability for a small cargo piping leak is assumed for this study (ref. 3). Failure to control leak: 0.02. Effective isolation generally requires the closure of two isolation valves (i.e. one at each end of the isolated volume). The cargo flow can also be stopped by shutting off the pumps. Thus, the probability of failure to isolate a typical section of pipework using 2 ESDVs is approximately 2% (ref. 3). Ignition probability: 0.04. Ignition probability taken from the generic ignition probabilities for pool fires (ref. 3). Escalation probability: 0.049 if not controlled, 0.00135 if controlled. Escalation probabilities based on whether the ESD control fails or not. The data were taken from cargo tanks escalation probabilities from medium releases in the process area of an FPSO (ref. 13). Probability of spilling to sea: 0.1. The probability of spilling to sea in the event of an unignited small leak from cargo piping is assumed to be 10% (engineering judgement).	

Release volumes: The representative release rate for a small release is 1 kg/s (~0.009 barrels/sec).

If the ESD fails, it is assumed that a manual shutoff valve will be closed 10 minutes after the start of the event (5 barrels released). If there is an initial failure to detect, it is assumed that the event will be detected after 5 minutes (3 barrels released). If the release is detected and controlled, isolation is assumed to occur 1 minute after the start of the leak (1 barrel released).

If the pool spills to sea, it is assumed that 100% of the available liquid spill to sea. If the pool ignites, it is assumed that 25% of the available pool will still be liquid when spilled to sea.

If there is escalation to the FPSO, the entire cargo of would be lost in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the spill size distribution is derived as;

Volume (bbls)	Probability
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Cargo Storage Events	**Revision:** 0
Sub category :	Process gas blow-by	
Consequences :	Structural damage, excessive venting	
Escalation :	Oil spill on deck, may ignite or gas release beneath process deck	
Consequences of Escalation :	Structural damage to vessel	
Accident Causes :	Failure in control of process	
Prevention :	Process control, alarms	
Accident Detection :	Manual detection	
Control :	Process shutdown	
Mitigation :	Vessel strength, double hull, fire-fighting	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Cargo Storage Events	**Revision:** 0

Subcategory: Process gas blow-by

Scenario description :

Blow-by of process gas to the cargo tanks resulting in excessive venting and potential fire/explosion from tank vent.

Fault tree base events: 0.01

Event tree branch probabilities:

Detection failure: 0.02 (ref. 3, small release HC gas detection)

Control failure: 0.02 (ref. 3, ESD – process shutdown to isolate cargo tanks from process and stop gas blowby)

Ignition: 0.04 (ref. 3, small gas release, 0.5 – 5.0 kg/s)

Probability of escalation, control fails: 0.049 (ref. 13, as for small process leak)

Probability of escalation, control works: 0.00135 (ref. 13) as for small process leak)

Release volumes: Potential to overpressure and damage cargo tanks. This would be a significant capital loss but would not result in an environmental spill as structural failure of the FPSO is not anticipated.

In the event of escalation due to fire, loss of FPSO in an ignited release. Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the following spill size distribution is derived;

Volume (bbls)	Probability
10,000-50,000	0.36
50,000-100,000	0.36
100,000-500,000	0.28
>500,000	0.00
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Marine Accidents on the FPSO

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Marine accidents on FPSO	**Revision:** 0
Sub category :	Foundering (structural failure)	
Consequences :	Major damage to vessel	
Escalation :	vessel loss	
Consequences of Escalation :	major oil spill	
Accident Causes :	Severe weather, ballasting errors, poor cargo distribution	
Prevention :	Vessel strength and design, Procedures, ballast, cargo distribution, inspection	
Accident Detection :	Manual detection	
Control :	Remove cargo to shuttle tanker, ballast control, remove vessel to dock	
Mitigation :	Shutdown, oil spill response	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Marine accidents on FPSO	**Revision:** 0
Sub category :	Foundering (capsize)	
Consequences :	Loss of vessel, major oil spill	
Escalation :	n/a	
Consequences of Escalation :		
Accident Causes :	Severe weather, ballasting errors, poor cargo distribution	
Prevention :	Vessel strength and design, Procedures, ballast, cargo distribution.	
Accident Detection :	Manual detection	
Control :		
Mitigation :	oil spill response	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Marine Accidents on FPSO	**Revision:** 0
Subcategory: Foundering	
Scenario description: FPSO founders due to structural failure or capsize (severe weather, ballasting error).	
Fault tree base events: 5 x 10^{-5} per year – ref. 10.	
Event tree branch probabilities:	
Release volumes: Release volume based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. Using these figures, the following spill size distribution is derived;	

Volume (bbls)	**Probability**
10,000-50,000	0.09
50,000-100,000	0.09
100,000-500,000	0.72
>500,000	0.10
Total	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Marine accidents on FPSO	**Revision:** 0
Sub category :	Mooring failure	
Consequences :	Critical failure of two or more mooring lines resulting in vessel drifting off station	
Escalation :	riser damage	
Consequences of Escalation :	Release from risers	
Accident Causes :	Poor design, material failure, severe weather, fouling of anchor lines, turret seizure	
Prevention :	Material selection, corrosion protection, redundancy in design, inspection	
Accident Detection :	Turret sensor or visual inspection from turret	
Control :	Take vessel under tow	
Mitigation :	Shutdown, oil spill response	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Marine Accident on FPSO	**Revision:** 0

Subcategory: Mooring failure

Scenario description :

Critical failure of 2 or more mooring lines resulting in loss of station keeping and damage to risers. Potential fire and explosion hazard to FPSO and cargo tanks.

Fault tree base events: 1.0×10^{-4} – ref. 11.

Event tree branch probabilities:

Detection failures: 0 Mooring failure and loss of station keeping resulting in riser failure would be evident.

Control failures: 0.0036 Probability of failing to isolate at least one of the nine subsea wells is calculated to be 0.0036 = (1-0.02^2)^9. This figure is conservatively in that it assumes there are 2 only fail-safe valves (subsea wellhead X-mas tree valves) for isolating any well from the risers each with individual failure probabilities of 0.02. In reality there are most likely 4 or 5 fail-safe valves counting sub-surface and manifold valves. Failure to isolate a well results in the release continuing until an alternate means of isolation is available , 14 days for ROV, (ref. 1). Successful isolation of all wells results in shut-in of wells within 3 minutes of release.

Ignition: 0.3 (large gas release 25-200 kg/s)

Escalation due to major explosion: 0.075 for major explosions escalating to cargo tanks (ref. 4, as large release in process area)

Escalation due to fire, control fails: 0.5 estimated based on failure to isolate one or more well from release and continued large fire.

Escalation due to fire, control works: 0.0018 (ref. 13) as large process leak

Release volumes: Release volumes are for ignited and unignited oil releases from the risers as well as ignited releases from the cargo tanks in the event of escalation to the FPSO. The total volume of oil in the risers is 6*1750=10500 bbls. The release rate for the 6 production risers is assumed to be the production rate of 104 bbls/min (150,000 bbls/day) until isolation. The release rate for a single well is assumed to be one ninth of this value until isolated.

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Offloading Accidents

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Offloading Accidents	**Revision:** 0
Sub category :	Shuttle tanker collision during offloading	
Consequences :	Material damage. Damage to shuttle tanker hull, damage to FPSO hull. Because of the orientation of the shuttle tanker and FPSO during tandem offloading, a collision would be bow to stern, and the cargo tanks would not be expected to be impacted on either the FPSO or the shuttle tanker. Therefore, a oil spill would not be expected to occur as a direct result of the collision.	
Escalation :	Leakage from transfer hose	
Consequences of Escalation :	Refer to leakage from transfer hose event	
Accident Causes :	Bad weather, shuttle tanker power failure, fishtailing, FPSO changes heading, human error, thruster drive on failure	
Prevention :	Procedures, shuttle tanker engine & steering reliability	
Accident Detection :	Manual, radar	
Control :	Shuttle tanker maneuvering	
Mitigation :	Radar, Telemetry, oil spill response	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Offloading Accidents	**Revision:** 0
Sub category :	Transfer hose leak	
Consequences :	Oil spill into the sea	
Escalation :	Spill ignites	
Consequences of Escalation :	Risk to people	
Accident Causes :	Drive off, drift off, hawser failure, hose failure, human error, control failure	
Prevention :	Equipment design, procedures, telemetry,	
Accident Detection :	Manual, control instrumentation,	
Control :	Shutdown cargo transfer	
Mitigation :	Oil spill response	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Offloading Accidents	**Revision:** 0
Subcategory: Transfer hose leak	
Scenario description: Leak or rupture during transfer from FPSO to shuttle tanker. Spill of oil directly to sea.	
Fault tree base events: 4.88 x 10^{-1} (per year) Based on ref. 4, 4 spills will occur per 1000 offloading transfers. This compares well with ref. 2 (MMS, 1998), which cites 3-4 spills per 1000 transfers. Comparing this transfer to lightering, which is a similar operation conducted offshore between supertankers offloading to shuttle tankers, the Marine Board's study (ref. 15) cites 1.2 spills per 1000 transfers, which is also in reasonable agreement with the figure cited in reference 4.	
Event tree branch probabilities:	
Release volumes: The following release volume distribution is based on ref. 4: < 10 barrels : 0.5 10 – 100 barrels : 0.25 100 – 1000 barrels : 0.25 In ref. 2, it is noted that the average spill size during transfer to the shuttle tanker is approximately 3 barrels. In ref. 15 (Marine Board, 1998), the average spill size for lightering spills in the GoM were 150 barrels. Based on these figures, the release distribution from reference 4 should be considered reasonably conservative.	
Prepared by : Sign: Date :	
Client approval: Sign: Date:	

Shuttle Tanker Accidents

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Shuttle Tanker Accidents	**Revision:** 0
Sub category :	Shuttle tanker leak at port (harbor)	
Consequences :	Oil released in harbor.	
Escalation :	Fire in harbor area	
Consequences of Escalation :	Major accident in harbor	
Accident Causes :	Transfer hose leak, coupling failure, manual error, control failure	
Prevention :	Procedures, transfer hose testing and inspection.	
Accident Detection :	Manual, control instrumentation,	
Control :	Double hull, shutdown cargo transfer	
Mitigation :	Harbor contingency plans	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Shuttle Tanker Accidents	**Revision:** 0
Sub category :	Shuttle tanker leak near port (LOOP)	
Consequences :	Oil released into the sea	
Escalation :	Damage to offshore port	
Consequences of Escalation :	Major oil release	
Accident Causes :	Ship collision, severe weather, human error, Drive off, drift off, hawser failure, hose failure, control failure	
Prevention :	Procedures, telemetry, shuttle tanker engine & steering reliability	
Accident Detection :	Manual, control instrumentation,	
Control :	Double hull, shutdown cargo transfer	
Mitigation :	Oil spill response.	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Shuttle Tanker Accidents	**Revision:** 0

Subcategory: Shuttle tanker leak near port

Scenario description: The shuttle tanker, having loaded the cargo from the FPSO, leaks oil while at port.

Fault tree base events: 3.83×10^{-2} – 0.70 spills per 10^9 barrels of oil produced x 150,000 barrels per day x 365 days (ref. 14). This frequency refers to spills larger than 1,000 barrels. This frequency is taken from an MMS report authored by Anderson and LaBelle, which cites COE 1994 and the MMS worldwide tanker spill database as sources. This data takes into account spills in US coastal and offshore waters from 1974 to 1992.

By comparison, an internal DNV study cites a release frequency of 2.0×10^{-3} spills / year by shuttle tankers at port. As cited in that study, this figure may be optimistic based on possible under-reporting of spills in the database. Therefore, the above figure of 3.83×10^{-2} spills / year derived from Anderson and LaBelle is conservatively used in this analysis.

A review of incidents in the tanker spill databases reveals that the leading causes of tanker oil spills are;

Collision - striking or being struck by another ship, whether under way, anchored or moored. This excludes underwater wrecks

Contact - striking or being struck by an external object, but not another ship or the sea bottom. It includes striking offshore rigs/platforms, whether under tow or fixed. This is sometimes termed “impact”

Grounding - striking either the sea bed or shore, including underwater wrecks. The vessel may be either under-power or drifting when it grounds.

Fire/explosion - where fire and/or explosion occurs for reasons other than collision, contact, grounding, etc.

Foundering – loss of the vessel due to severe weather, structural failure, ballasting error or other cause, excluding collision, grounding, etc.

Hull/equipment damage - where the hull/ equipment damage is not due to other cause such as collision etc.

Transfer spills – leaks of cargo during loading and unloading, whether they occur at the transfer hose/arm, in the ship-shore pipeline, or on the ship.

Event tree branch probabilities:

Release volumes: It would be preferable to use the Anderson/LaBelle MMS report to calculate release volumes, but the report does not specifically report the data is this fashion. It does report an average release size, but it is unclear of the sizes of the vessels from which the spills occurred. Because of these reasons, the release distribution is based on an internal DNV study which compiled data from the following sources: Lloyd's Casualty Reports, LMIS database, ITOPF database, Cutter database, IOPC fund annual reports, accident investigation reports, hazardous cargo bulletins, and oil company data. This data cites oil spills from tankers at sea, in restricted waters, and at port from 1992 to 1994. The distribution used for this study is listed below.

The data from the DNV study is comparable to the MMS source, as the average spill size >1000 barrels is approximately 55,000 barrels for the DNV source and 49,000 barrels for the MMS source.

Volume (bbls)	***Probability***
1,000 – 10,000:	37.5%
10,000 – 50,000:	34.1%
50,000 – 100,000:	14.7%
100,000 – 500,000:	13.7%

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Shuttle Tanker Accidents	**Revision:** 0
Sub category :	Shuttle tanker leak at sea	
Consequences :	Oil released to sea.	
Escalation :	Fire on sea surface	
Consequences of Escalation :	Smokey fire	
Accident Causes :	Fatigue failure, collision, unintended discharge.	
Prevention :	Procedures, collision avoidance measures, and inspection.	
Accident Detection :	Manual, control instrumentation,	
Control :	Double hull	
Mitigation :	Oil spill contingency plans	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Shuttle Tanker Accidents	**Revision:** 0
Subcategory: Shuttle tanker leak at sea	
Scenario description: The shuttle tanker receives the cargo from the FPSO and leaks oil while en route to port.	
Fault tree base events: 2.79×10^{-2} spills / year – 0.51 spills per 10^{9} barrels of oil produced x 150,000 barrels per day x 365 days (ref. 14). This frequency refers to spills larger than 1,000 barrels. This frequency is taken from an MMS report authored by Anderson and LaBelle, which cites COE 1994 and the MMS worldwide tanker spill database as sources. This data takes into account spills in US coastal and offshore waters from 1974 to 1992. By comparison, an internal DNV study cites a release frequency of 2.2×10^{-3} spills / year by shuttle tankers at sea. As cited in that study, this figure may be optimistic based on possible under-reporting of spills in the database. Therefore, the above figure of 2.79×10^{-2} spills / year derived from Anderson and LaBelle is conservatively used in this analysis. A review of incidents in the tanker spill databases reveals that the leading causes of tanker oil spills are; Collision - striking or being struck by another ship, whether under way, anchored or moored. This excludes underwater wrecks Contact - striking or being struck by an external object, but not another ship or the sea bottom. It includes striking offshore rigs/platforms, whether under tow or fixed. This is sometimes termed “impact” Grounding - striking either the sea bed or shore, including underwater wrecks. The vessel may be either under-power or drifting when it grounds. Fire/explosion - where fire and/or explosion occurs for reasons other than collision, contact, grounding, etc. Foundering – loss of the vessel due to severe weather, structural failure, ballasting error or other cause, excluding collision, grounding, etc. Hull/equipment damage - where the hull/ equipment damage is not due to other cause such as collision etc. Transfer spills – leaks of cargo during loading and unloading, whether they occur at the transfer hose/arm, in the ship-shore pipeline, or on the ship.	
Event tree branch probabilities:	

Release volumes: It would be preferable to use the Anderson/LaBelle MMS report to calculate release volumes, but the report does not specifically report the data is this fashion. It does report an average release size, but it is unclear of the sizes of the vessels from which the spills occurred. Because of these reasons, the release distribution is based on an internal DNV study which compiled data from the following sources: Lloyd's Casualty Reports, LMIS database, ITOPF database, Cutter database, IOPC fund annual reports, accident investigation reports, hazardous cargo bulletins, and oil company data. This data cites oil spills from tankers at sea, in restricted waters, and at port from 1992 to 1994. The distribution used for this study is listed below.

The data from the DNV study is comparable to the MMS source, as the average spill size >1000 barrels is approximately 55,000 barrels for the DNV source and 49,000 barrels for the MMS source.

Volume (bbls)	***Probability***
1,000 – 10,000:	37.5%
10,000 – 50,000:	34.1%
50,000 – 100,000:	14.7%
100,000 – 500,000:	13.7%

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Non-Process Spills

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Non-process spills	**Revision:** 0
Sub category :	No events beyond those on existing platforms on the OCS.	
Consequences :		
Escalation :		
Consequences of Escalation :		
Accident Causes :		
Prevention :		
Accident Detection :		
Control :		
Mitigation :		
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Transportation Accidents

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Transportation Accidents (helicopters and supply vessels)	**Revision:** 0
Sub category :	No events beyond those on existing platforms on the OCS.	
Consequences :	Helicopter accidents are one of the major hazards to personnel on offshore installations, and as a minor point, could also result in small release due to fuel carried on board. However, barring hurricane abandonment which is infrequent, the frequency of helicopter transport and the likelihood of helicopter crashes are not dependent on the type of deepwater installation. Therefore, the potential for small oil spills associated with helicopter crashes is not FPSO-unique and it is not further analyzed here. Helicopter crashes impacting the FPSO are not expected to breach the cargo tanks directly, however they could potentially impact the process area causing a fire that then escalates to the cargo tanks. However, since the probability of a helicopter crashing into the process area is small relative to the probability of a process release do to other causes, it is assumed that this possibility is already factored into the failure rate data. Therefore, helicopter crashes as an initiating event for process releases are not analyzed separately. The frequency of supply boat visits and probabilities of spills from the supply boats are assumed to be the same for FPSOs as for other deepwater installations, such as TLPs. Therefore, supply boat spill are not FPSO-unique and are not further analyzed here.	
Escalation :		
Consequences of Escalation :		
Accident Causes :		
Prevention :		
Accident Detection :		
Control :		
Mitigation :		
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Ship Collisions

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Ship Collisions	**Revision:** 0
Sub category :	Passing merchant vessel	
Consequences :	Major structural damage, major oil spill.	
Escalation :	Rupture of cargo tank or loss of vessel depending on severity of collision	
Consequences of Escalation :	Single cargo tank lost to sea or all cargo lost to the sea	
Accident Causes :	Navigational error on errant vessel	
Prevention :	Good separation from shipping lanes, marked on charts	
Accident Detection :	Radar, visual	
Control :	Radio contact with the errant vessel, shutdown production	
Mitigation :	Vessel strength, double hull, transfer cargo from damaged tanks to undamaged tanks, re-ballasting, oil spill response	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Ship Collisions	**Revision:** 0
Subcategory: Passing merchant vessel	
Scenario description: A powered passing merchant vessel does not see the FPSO due to bad weather, lack of trained personnel, etc. and collides with the FPSO potentially penetrating the double hull.	

Fault tree base events: 3.88 x 10^{-3}/year. The FPSO location is not specified. Therefore, the FPSO is assumed to be exposed to an average passing merchant vessel traffic risk. This figure is based on the average shipping traffic density for the Gulf of Mexico, and a typical distribution of vessel displacements.

The powered passing vessel collision model is based on a model from ref. 7. The powered collision risk is determined from the following parameters: # of ships in the area, the probability of being on a collision course, and the probability of failing to divert from the collision course (i.e. watchkeeping failure, etc.).

The number of ships in the area is assumed to be 2.4 x 10^{-3} ships / nm^2 (ref. 3). The probability of being on a collision course is calculated from the equation L/RΠ, where L is the equivalent diameter of the FPSO and R is the distance to a basis circle surrounding the FPSO. The probability is calculated to be 0.0011 (369 ft / Π 20 mi). The probability of the vessel failing to be diverted from the collision course is assumed to be 3 x 10^{-4}(ref. 7).

With all the factors accounted for, for this study the probability that a powered merchant vessel will collide with the FPSO is 3.88 x 10^{-3} per year.

Event tree branch probabilities: Cargo tank impact: 0.64. Based on an analysis on the placement of the cargo tanks around the ship's hull.

Direct impact: 0.4. ref. 3.

Foundering: 0.141 for direct hits, 0.025 for glancing blows. Based on the distribution of sizes of merchant ships (ref. 3), there is a 14.1% probability that the original impact energy will be greater than 1000 MJ and a 2.5% probability that the original impact energy will be greater than 2500 MJ.

Rupture of one cargo tank: 0.0768 for direct hits, 0.0359 for glancing blows. Based on the distribution of sizes of merchant ships (ref. 3), there is a 7.68% probability that the original impact energy will be between 680 and 1000 MJ and a 3.59% probability that the original impact energy will be between 1700 and 2500 MJ.

Ignition: 0.58. ref. 8.

Release volumes:
The following release volume for an unignited release is based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. Using these figures, the following spill size distribution is derived for the loss of the entire FPSO and the loss of one tank;

Volume (bbls)	Probability (loss of FPSO)	Probability (loss of 1 tank)
1,000-10,000	0.00	0.18
10,000-50,000	0.09	0.72
50,000-100,000	0.09	0.10
100,000-500,000	0.72	0.00
>500,000	0.10	0.00
Total	1.00	1.00

In the event of escalation due to fire, the release volume is based on estimated volume of cargo on FPSO. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the following spill size distribution is derived for the loss of the entire FPSO and the loss of one tank;

Volume (bbls)	Probability (loss of FPSO)	Probability (loss of 1 tank)
1,000-10,000	0.00	0.72
10,000-50,000	0.36	0.28
50,000-100,000	0.36	0.00
100,000-500,000	0.28	0.00
>500,000	0.00	0.00
Total	1.00	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Ship Collisions	**Revision:** 0
Sub category :	Drifting vessel (attendant or passing vessel)	
Consequences :	Low speed collision, minor structural damage	
Escalation :	None	
Consequences of Escalation :	None	
Accident Causes :	Mechanical failure on nearby vessel (attendant or passing)	
Prevention :	Good maintenance of attendant vessels	
Accident Detection :	Radio	
Control :	shutdown production	
Mitigation :	Vessel strength, double hull	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Ship Collisions	**Revision:** 0
Sub category :	Drifting vessel (MODU)	
Consequences :	Low speed collision, minor structural damage.	
Escalation :	None	
Consequences of Escalation :	None	
Accident Causes :	MODU starts far from FPSO reducing the chance of collision	
Prevention :	Power failure on nearby MODU	
Accident Detection :	Radio contact	
Control :	shutdown production	
Mitigation :	Vessel strength, double hull	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Ship Collisions	**Revision:** 0
Subcategory: Drifting vessel	

Scenario description: An attendant or passing vessel or a MODU loses power close to the FPSO and drifts into it, potentially rupturing the hull.

Fault tree base events: 4.6×10^{-4} (per year).

The FPSO location is not specified. Therefore, the FPSO is assumed to be exposed to an average drifting vessel risk. This figure is based on the average shipping traffic density for the Gulf of Mexico, and a typical distribution of vessel displacements.

The drifting vessel risk model is based on a model created in ref 7. The drifting collision risk is determined from the following parameters: # of ships in the area, the probability of having an engine failure, the probability of being on a collision course with the FPSO, and the probability that the vessel will be deflected off course (e.g. with a tug boat, etc.).

The number of ships in the area is assumed to be 2.4×10^{-3} ships / nm^2 (ref. 3). The frequency of engine failure is assumed to be 2×10^{-5} failures / hours. The probability of being on a collision course after engine failure is calculated from the equation $L/R\Pi$, where L is the equivalent diameter of the FPSO and R is the average distance between the FPSO and a vessel. The probability is calculated to be 0.0038 (369 ft / Π 5.8 mi). The probability of the vessel failing to be deflected off course is assumed to be 0.95.

With all the factors accounted for, the probability that a merchant vessel will drift into the FPSO is 3.22×10^{-4}.

For MODUs, the probability of a drifting collision is roughly calculated to be 1.35×10^{-4}. This figure is calculated using the probability (9×10^{-3}) that the MODU will be in a position to drift into the FPSO from where the wells are located (2.6 kilometers away) and the respective widths of the FPSO and the MODU and the probability that the MODU will have a station-keeping failure (1.5×10^{-2}).

The overall probability (merchant vessels plus MODUs) of a drifting collision is 4.6×10^{-4}.

Event tree branch probabilities: Cargo tank impact: 0.64. Based on an analysis on the placement of the cargo tanks around the ship's hull.

Direct impact: 0.4. ref. 3.

Foundering of FPSO: 0. (see rupture of cargo tank below)

Rupture of Cargo Tank: 0. Based on a drifting speed of 1.8 knots, the drifting vessels would have to have a weight of over 1,400,000 dwt to rupture the double hull (680 MJ impact energy). It is assumed that there is not a ship of this size in the Gulf of Mexico.

Ignition: 0.58. ref. 8.

Release volumes:

The following release volume for an unignited release is based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. Using these figures, the following spill size distribution is derived for the loss of the entire FPSO and the loss of one tank;

Volume (bbls)	Probability (loss of FPSO)	Probability (loss of 1 tank)
1,000-10,000	0.00	0.18
10,000-50,000	0.09	0.72
50,000-100,000	0.09	0.10
100,000-500,000	0.72	0.00
>500,000	0.10	0.00
Total	1.00	1.00

In the event of escalation due to fire, the release volume is based on estimated volume of cargo on FPSO. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the following spill size distribution is derived for the loss of the entire FPSO and the loss of one tank;

Volume (bbls)	Probability (loss of FPSO)	Probability (loss of 1 tank)
1,000-10,000	0.00	0.72
10,000-50,000	0.36	0.28
50,000-100,000	0.36	0.00
100,000-500,000	0.28	0.00
>500,000	0.00	0.00
Total	1.00	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Ship Collisions	**Revision:** 0
Sub category :	Visiting supply vessel	
Consequences :	Low speed collision, minor structural damage. A supply vessel collision is not expected to have enough energy to rupture the double hull, and no oil spill from the FPSO is expected to occur. There is the potential for the supply vessel to sink if there is a high impact collision, and there may be some fuel or other oil spilled from the supply boat as a result. However, such a collision and sinking of the supply boat is not unique to an FPSO, and could similarly happen with another type of deepwater structure such as an TLP. Therefore, since no FPSO-unique spill risks area foreseen, supply vessel collisions are not analyzed further.	
Escalation :	None	
Consequences of Escalation :	None	
Accident Causes :	Navigational error by supply vessel, Severe weather, power failure on supply vessel, Thruster pitch failure, bad seamanship	
Prevention :	Supply vessel procedures (no high speed collisions)	
Accident Detection :	Radar, visual	
Control :	Double hull, procedures, DP on supply vessel	
Mitigation :	Vessel strength, double hull	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Ship Collisions	**Revision:** 0
Sub category :	Visiting shuttle tanker (low speed)	
Consequences :	Low speed collision, minor structural damage. No oil spill expected to occur (see Offloading Accidents - Shuttle Tanker Collision During Offloading).	
Escalation :	None	
Consequences of Escalation :	None	
Accident Causes :	Severe weather, navigational error, power failure on ST, Thruster pitch failure, bad seamanship	
Prevention :	ST procedures, tandem offloading,	
Accident Detection :	Radar, visual	
Control :	Cargo area is not exposed to collision, double hull, structural strength	
Mitigation :	Repair in dock	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

HAZARD IDENTIFICATION

Activity :	FPSO Release Frequency Analysis	1 November 1999
Hazard :	Ship Collisions	**Revision:** 0
Sub category :	Visiting shuttle tanker (high speed)	
Consequences :	Major structural damage, major oil spill.	
Escalation :	Rupture of single cargo tanker or loss of vessel depending on the severity of collision	
Consequences of Escalation :	Single cargo tank lost to sea or loss of entire cargo to sea depending on severity of collision.	
Accident Causes :	Navigational error, steering failure on the ST, shuttle tanker should not plot course directly at FPSO	
Prevention :	ST selection and operating procedures, communication between FPSO and ST	
Accident Detection :	Radar, visual	
Control :	Radio contact with the ST	
Mitigation :	Vessel strength, double hull, transfer cargo from damaged tanks to undamaged tanks, re-ballasting, oil spill response	
Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

Activity: FPSO Release Frequency Analysis	18 October 1999
Hazard: Ship Collisions	**Revision:** 0
Subcategory: Visiting shuttle tanker (high speed)	
Scenario description: A visiting shuttle tanker loses track of position and collides with the FPSO at high speeds potentially causing a cargo tank rupture.	
Fault tree base events: 3.54 x 10^{-8} (per year). Ten percent of low-speed on arrival tanker collisions – 3.54 x 10^{-9} (ref. 7).	
Event tree branch probabilities: Cargo tank impact: 0.64. Based on an analysis on the placement of the cargo tanks around the ship's hull. Direct impact: 0.4. ref. 3. Foundering of FPSO: 1.0 for direct hit, 0.25 for glancing blow. A 100,000 dwt shuttle tanker will have an impact energy of 2100 MJ at 12 knots. A direct hit will exceed the foundering limit for the FPSO (1000 MJ). A glancing blow does not exceed the foundering limit (2500 MJ), but there is a possibility that the vessel will be traveling at a greater speed (13 knots will exceed the limit). It is assumed that there is a 25% probability that the shuttle tanker will be travelling at a speed greater than 13 knots in a full speed collision. Rupture of one cargo tank: 1 for glancing blows. For the glancing blows that do not end in a foundering, there is a 100% probability that the impact energy will exceed 1700 MJ (the impact energy required for a glancing blow to rupture one cargo tank). Ignition: 0.58. ref. 8.	

Release volumes:
The following release volume for an unignited release is based on estimated volume of cargo on FPSO. It is assumed that FPSO is operated in a cycle starting out largely empty and filling to up to 500,000 bbls (50% of capacity) before offloading to shuttle tanker. It is assumed that FPSO operates in this cycle 90% of the time, and the remaining 10% of the time it is operates between 500,000 and 1,000,000 bbls due to circumstances such as waiting on shuttle tanker or bad weather. Using these figures, the following spill size distribution is derived for the loss of the entire FPSO and the loss of one tank;

Volume (bbls)	Probability (loss of FPSO)	Probability (loss of 1 tank)
1,000-10,000	0.00	0.18
10,000-50,000	0.09	0.72
50,000-100,000	0.09	0.10
100,000-500,000	0.72	0.00
>500,000	0.10	0.00
Total	1.00	1.00

In the event of escalation due to fire, the release volume is based on estimated volume of cargo on FPSO. As this event is an escalation due to fire, it is assumed that the spill volume is reduced to 25% (i.e. 75% of volume is lost in burning). Using these figures, the following spill size distribution is derived for the loss of the entire FPSO and the loss of one tank;

Volume (bbls)	Probability (loss of FPSO)	Probability (loss of 1 tank)
1,000-10,000	0.00	0.72
10,000-50,000	0.36	0.28
50,000-100,000	0.36	0.00
100,000-500,000	0.28	0.00
>500,000	0.00	0.00
Total	1.00	1.00

Prepared by :	Sign:	Date :
Client approval:	Sign:	Date:

REFERENCES

/1/ E&E (1999): "*Scenario Report, Environmental Impact Statement on Floating Production, Storage, and Offloading Systems on the Gulf of Mexico Outer Continental Shelf*".

/2/ MMS (1998): "*Gulf of Mexico OCS Oil and Gas Lease Sales 171, 174, 177, and 180*". Environmental Impact Statement 98-0008.

/3/ DNV ARF C1 Rev 1 - "Guide to QRA of Offshore Installations", Confidential internal document, 1998.

/4/ QRA on an FPSO located in the North Sea.

/5/ OREDA (1997): "*Offshore Reliability Database*". Third Edition.

/6/ Concept Safety Evaluation of a Floating Production System in the North Sea.

/7/ DNV (1999) Report 2828 – Cost Benefit Analysis involving FPSO's.

/8/ Risk Assessment of a Marine Terminal located in the Middle East.

/9/ J P Kenny (1988): "*Study on Offshore Installations Protection Against Impact*", Department of Energy Offshore Technology Information Report ITI 88 535.

/10/ QRA on an FPSO located in the UK Sector of the Central North Sea.

/11/ Bechtel (1998): "*JIP on Risk Assessment and Reliability of a FPSO System in the Gulf of Mexico*".

/12/ QRA of a TLP located in the Gulf of Mexico.

/13/ Safety and Emergency Preparedness Study (SEPA) on an FPSO located in the North Sea.

/14/ Anderson and LaBelle, "Comparative Occurrence Rates for Offshore Oil Spills", Spill Science and Technology Bulletin 1(2), 1994

/15/ Marine Board (1998): "Oil Spill Risks from Tank Vessel Lightering", National Academy Press, Washington DC

APPENDIX II

CONSIDERATION OF DESIGN OPTIONS

II. CONSIDERATION OF DESIGN OPTIONS

The scenario report includes 3 tables of design options. This appendix contains a qualitative assessment of how each option may affect the risk of oil release.

TableII.1: FPSO Location

Number	**Component**	**Basecase**	**Option**	**Impact**
1.0	Water Depth	5,000 ft	600 – 12,500 ft	Subsea technology is currently better proven for shallower water. The amount of operational experience and failure rate data decrease with increasing water depth. Some hazards (e.g., riser and mooring failures) increase with water depth. For shallower water depths, these risks would be expected to decrease somewhat. For greater water depths, these risks would be expected to increase. It should be noted that as yet there are no floating production systems in place extending to 12,500-foot water depths. Operating production facilities in these water depths may require the use of new technologies, and greatly increase the uncertainties in estimating the risk. Increased water depth results in different wave characteristics, and this has to be considered in fatigue loading design calculations.
2.0	Location	To be determined		Location dependent risks include ship collisions, shuttle tanker operations, export pipeline risks. The passing merchant vessel collision risk (1.2% of potential basecase spills by volume) is directly impacted by the proximity of the FPSO to shipping lanes. For this analysis we have assumed an average location based on the vessel traffic in the Gulf of Mexico. Based on previous analyses, if the FPSO is located adjacent to high traffic shipping lanes the collision risk could increase by a factor of four. Conversely, if the FPSO is located far from shipping lanes the risk could drop by an order of magnitude or more. Means of reducing collision risk include collision avoidance radar, attendant vessel, thrusters, and a vessel exclusion zone around the FPSO. Proximity to other installations or shore may increase the availability of spill response equipment. Environmental impact of releases is location dependent

TableII.2: FPSO System Components

Number	Component	Basecase	Option	Impact
1.0	**Subsea System**			
1.1	Well count and drill centers	3 drill centers each with 3 wells	No options	
1.2	Subsea Trees	Horizontal	Conventional	Reduced accessibility for intervention may increase the likelihood of blowout during intervention. Risk of major oil spills would thus be greater
1.3	Flowlines	Dual insulated steel	Flexible	No impact, provided they are properly designed, constructed, installed and maintained.
			Steel	No impact, provided they are properly designed, constructed, installed and maintained.
1.4	Subsea Manifold Type	Active	Passive	A passive manifold would reduce the number of barriers for isolation between a riser release or flowline release and the wellhead. Conversely, a passive manifold would reduce the number of potential subsea manifold leak sources.
1.5	Umbilicals	Single multiplex	Dual	There is insufficient data to suggest that use of dual subsea controls umbilicals is more reliable than use of single multiplex umbilicals. Therefore, it is assumed that provided they are properly designed, constructed, installed and maintained for the service, the type of umbilicals used should not significantly impact the risk of oil spill.
2.0	**Risers**	Steel wave risers	Flexible risers Steel caternary risers Hybrid risers	Riser technology for deepwater applications is relatively new, and as such there is a limited track record for the various types of deepwater riser systems in terms of numbers of riser failures. The current data for deepwater risers is not sufficient to differentiate amongst the options for this study. Therefore, it is assumed that provided they are properly designed, constructed, installed and maintained for the service, the type of deepwater riser used should not significantly impact the risk of oilspill.
3.0	**Vessel mooring**			
3.1	Number of moorings	Clustered (3 groups of 3 mooring lines)	Equally spaced	Equally spaced mooring lines reduces the available spacing for risers and so increases the likelihood of riser to riser collisions. There is no clear disadvantage from clustered moorings as long as they are sized for the foreseeable environmental loads.
3.2	Configuration	Caternary	Taut	Use of taut moorings may result in a reduction in the potential for mooring line/ riser interaction, but are otherwise not expected to impact the spill rate, provided there are properly designed, constructed, installed and maintained.
			Semi-taut	Use of semi-taut moorings may result in a reduction in the potential for mooring line/ riser interaction, but are otherwise not expected to impact the spill rate, provided there are properly designed, constructed, installed and maintained.

Number	Component	Basecase	Option	Impact
3.3	Material	Wire rope / chain	Polyester / chain	Polyester moorings are not expected to affect release rate provided they are properly designed, constructed, installed, and maintained.
3.4	Anchor type	Drag	Suction pile	No impact, provided they are properly designed, constructed, installed and maintained
			Driven pile	
4.0	**Turret system**			
4.1	Weathervaning	Passive	Active	FPSO could be brought about or moved somewhat off-station to avoid a collision or minimize damage, which may result in a major reduction in the potential for collision by passing merchant vessels (1.2% of potential basecase spills by volume). Reduced fatigue loading on process equipment and tall structures potentially resulting in a minor reduction in process releases (3.2% of potential basecase spills by volume). Improved station keeping during offloading, reducing the potential for “fishtailing” and leak during transfer to shuttle tanker (1.8% of potential basecase spills by volume). Possibility of reduced loads on the mooring system, which may have a minor effect in reducing the likelihood of mooring failures (<0.1% of basecase spills by volume). Additional power generation requirements and possible vulnerability to failures in the drive mechanism may partially offset the benefits.
			Passive with assist	Similar impact as for active option
4.2	Type	Permanent	Disconnectable	Increased risk of riser release (0.4% of potential basecase spills by volume) during connection and disconnection operations. Reduced risks due to foundering caused by severe weather (but this would typically be counteracted by a reduction in specification). Structural failure (foundering) accounts for 0.3% of potential basecase spills by volume. The FPSO is more vulnerable to marine hazards when disconnected (running aground, collisions while in congested waters). Disconnection is not likely to be rapid enough to protect the FPSO against ship collision or riser releases.

Number	**Component**	**Basecase**	**Option**	**Impact**
4.3	Location	Internal	External	Internal turrets are universal for FPSOs in harsh environments. The turret and swivel are located farther away from the process area and the cargo tanks, resulting in a major reduction in probability of escalation from swivel and turret releases (0.2% and <0.0% of potential basecase spills by volume, respectively). Maintenance of turret and swivel components is much harder, and so release frequency (smaller releases) would increase.
4.4	Bearing system	Roller	Bogeys / sliding	Not clear that this can significantly affect environmental risks.
5.0	**Fluid Transfer System**	Multi-pass	Drag chain	Not clear that this can significantly affect environmental risks. Using drag chain would require that the FPSO have some means of propulsion, either active or passive with an assist. See Weathervaning above.
6.0	**Hull**			
6.1	Cargo storage	1 MM bbls	2.3 MM bbls	Cargo storage should be consistent with shuttle tanker size with a contingency to allow for shuttle tanker delays. The size of the shuttle tanker depends on destination port. Larger shuttle tankers will require fewer offloading operations, thus reducing the frequency of offloading spills, but the magnitude of shuttle spills would increase (for bigger shuttle tankers). Increasing the storage on the FPSO will also tend to increase the size of FPSO spills.
6.2	Ballast capacity	Segregated	None	

Number	Component	Basecase	Option	Impact
6.3	Type	New build	Conversion	As a basis of comparison, we have assumed that a new-build FPSO and a conversion FPSO would be built to the same rules and specifications, and that both would be double-hulled (the design option of having a single-hulled FPSO is being addressed independent of the new-build/conversion design option). In comparing a new-build FPSO with a conversion FPSO relating to the risk of oil spills, the following potential differences have been identified: • Fatigue History: The uncertainty in fatigue life prediction is the same on both new-build and conversion FPSOs. In the case of a conversion FPSO there is some uncertainty as to what the fatigue history of the vessel is, and exactly how much fatigue life there is remaining. However, the fatigue assessment procedure for the conversion of oil tankers for FPSO service is generally conservative and it can be assumed that the frequency of fatigue failure for a conversion FPSO is similar to that of a new-build. Also, not all fatigue damages will result in cargo leakage if inspections occur on a regular basis. • Layout Options: For a conversion FPSO the layout options (locations of process, manifold, accommodations, etc) are somewhat constrained compared to a new-build FPSO. This is due to the accommodations, machinery spaces, and other features already being in place on a conversion. By optimizing the layout on a new-build FPSO, there is the potential to increase personnel safety (e.g. by relocating the accommodations from the stern to the bow, upwind of the process area) and to increase the protection against environmental spills (e.g. by relocating manifolds, process equipment, and cargo piping to minimize the possibility of spills to sea). Even so they both need to satisfy the same minimum requirements. • Connection Details: To account for the load of the process unit and other equipment on the main deck, the connection details of a new-build FPSO may be different than on a conversion FPSO. However, in both cases the large equipment support loads are distributed to transverse bulkheads and locally strengthened as required. For the purpose of the risk of oil spills there is likely to be little or no difference between the design options.

Number	Component	Basecase	Option	Impact
				• Frequency of Hull Cracks: The frequency of hull cracks (number of cracks per year) in tankers built after 1993 (double hull tankers) is significantly lower than for older (single hull) tankers built before 1993. If the original vessel was a single hull tanker, the frequency of hull cracks may be higher than a new-build FPSO. However, if the original vessel was a double hull tanker, the frequency of hull cracks may be the same order of magnitude as for a new-build FPSO. A conversion FPSO may potentially have a higher risk of oil spills than a new-build FPSO. Based on the current amount of historic data for FPSOs, it is difficult to quantify the difference in risk between a new-build FPSO and a conversion FPSO. Qualitatively, however, it is believed that as long as both the new-build FPSO and the conversion FPSO are built properly and to the same rules and specifications, the increased risk of oil spill for the conversion FPSO would be small. Other design options considered in this Risk Assessment (single hull FPSO, double hull width, different location of FPSO, higher production rate, etc) would have greater effects on the risk of oil spills than would use of a conversion FPSO.
			Non-ship shaped	The shape of the hull, the layout of equipment including risers, turret system (if present), the process area, cargo storage area, accommodations, etc all affect the risk of oil spill. Specifications of a proposed design would be needed in order to evaluate the effect on the risk of oil spill.
6.4	Configuration	Double hull (4 m)	2 m – 5 m double hull	The main factor determining the FPSO's resistance to cargo tank breach from a vessel collision is the width of the double hull. Passing merchant vessel collisions result in 1.2% of potential basecase spills by volume. Narrowing the double hull width to 2 meters would reduce the impact energy required to cause cargo tank breach by 50% (i.e. 50% lower vessel displacement required to cause a cargo release for a given collision speed). This would result in the passing merchant vessel releases increasing to 2.5% of potential spills by volume. Widening the double hull width to 5 meters would increase the impact energy required to breach a cargo tank by 24%. This would result in the passing merchant vessel releases decreasing to 0.8% of potential spills by volume.

Number	Component	Basecase	Option	Impact
			Single sided single bottom	Increased vulnerability to ship collision damage. Passing merchant vessel collisions result in 1.2% of potential basecase spills by volume, and would be expected to increase to 2.8% for a single sided FPSO. Much more difficult to inspect hull. Increased main deck plate thickness would reduce risk of escalation to cargo area from process leaks and other fires impacting the deck. Process leaks escalating to cargo area result in 3.2% of potential basecase spills by volume. Changed risk of oil spill following cargo tank explosion due to change in plate thickness.
			Single sided double bottom	Increased vulnerability to ship collision damage. Passing merchant vessel collisions result in 1.2% of potential basecase spills by volume, and would be expected to increase to 2.8% for a single sided FPSO. Much more difficult to inspect hull. Increased main deck plate thickness would reduce risk of escalation to cargo area from process leaks and other fires impacting the deck. Process leaks escalating to cargo area result in 3.2% of potential basecase spills by volume. Changed risk of oil spill following cargo tank explosion due to change in plate thickness.
			Double side, single bottom	Much more difficult to inspect ship's bottom. Increased main deck plate thickness would reduce risk of escalation to cargo area from process leaks and other fires impacting the deck. Process leaks escalating to cargo area result in 3.2% of potential basecase spills by volume. Changed risk of oil spill following cargo tank explosion due to change in plate thickness.
6.5	Propulsion	No propulsion	Propulsion	See weathervaning, above
			DP	See weathervaning, above
7.0	**Production**			

Number	Component	Basecase	Option	Impact
7.1	Oil production rate	150,000 bopd	300,000 bopd	The risks per barrel produced are likely to reduce as production rates increase. Releases linked to production (excluding transport and offloading) are 5.5% of basecase spills by volume. The risk per barrel offloaded or transported would remain about the same. Releases from transport by shuttle tanker at sea and in port are 53.6% and 39.0% of potential basecase spills by volume, respectively. Releases during transfer from FPSO to shuttle tanker are 1.8% of potential basecase spills by volume.
7.2	Gas production rate	200 MMSCFD	300 MMSCFD	The increase in gas throughput is likely to increase the risk of process fires, which are one of the larger contributors to the overall risk. Therefore, the risk is likely to increase.
7.3	Water production rate	70,000 BWPD	100,000 BWPD	No direct increase in the risk of accidental oil spills. However, if this required additional production risers, or additional separation equipment, the risk is liable to increase.
7.4	Trains	Single train	Dual train	The risk of process accidents would approximately double due to the increase in equipment. As the inventory in each stage is liable to be much greater than that necessary for escalation, the risk from process events is also likely to approximately double. Process events account for 3.2% of potential basecase spills by volume.
7.5	Separators	3 stage	2 stage	Reduced risk from separators due to the reduction in vessels. However, if this means there is a need to increase the number of compression stages, this may reduce or remove the risk benefit for process events. Process events account for 3.2% of potential basecase spills by volume.
7.6		Pipeline export	Injection	Shorter gas pipeline at higher pressure means that the gas pipeline risks would be affected. These are negligible in the basecase. There would be an increase in the process risks as a result of the additional compression. Process events account for 3.2% of potential basecase spills by volume. MMS has indicated that gas reinjection may be an approvable option under the condition that the operator demonstrates a solid commitment and plan to eventually produce the gas.

Number	Component	Basecase	Option	Impact
			Conversion	Not a proven offshore technology. Therefore, conversion could potentially pose unforeseen risks. Additional process plant required for conversion is likely to increase process risks. Process events account for 3.2% of potential basecase spills by volume.
			Flaring / venting	Gas compression risks eliminated (except fuel gas), resulting in reduced process risks. Process events account for 3.2% of potential basecase spills by volume. Flaring is not likely to be acceptable, long term.
7.7	Flare	Emergency flare only	None	
7.8	Produced water disposal	Discharge overboard	None	
8.0	**Offloading system**			
8.1	Offloading configuration	Tandem	Side by side	Not clear whether risks would be affected significantly. Side by side offloading would be largely similar to current lightering practice between oil tankers and shuttle tankers, which has a good safety record in the GoM. The potential for maneuvering collisions between the shuttle tanker and the FPSO are a concern with side by side offloading. Because of the low maneuvering speeds and the fact that both shuttle tanker and FPSO have double hulls it is not anticipated that a cargo spill could result from a low speed collision. However, the potential for damage to either the shuttle tanker or FPSO, potentially requiring drydock repair, could pose a significant concern.
			Buoy based offloading system	Increased risk of oil spill from additional riser / pipeline from FPSO to buoy. Reduced potential for low speed maneuvering collision between shuttle tanker and FPSO. However, low speed collisions are not expected to result in a cargo spill because of the low maneuvering speeds and the fact that the shuttle tanker and the FPSO are both double hulled. The reduction in potential for low speed maneuvering collisions would lessen the potential for damage and possible dry dock repair for the shuttle tanker or FPSO.

Number	Component	Basecase	Option	Impact
8.2	Cargo pumps	Submerged pumps	pump room	A pump room introduces an additional and significant risk of cargo area explosions. Cargo tank explosions account for 0.2% of potential basecase spills by volume. The relative scarcity of experience with submerged pumps means that the risks from their operation and maintenance are not so well understood, however the fashion is to assume that submerged pumps are lower risk than a pump room.
8.3	Offload rate	50,000 BPH	30,000 BPH	The time required for offloading would be increased, which would tend to increase the potential for offloading spills, however, the volume of potential spills would likely decrease due to the lower flow rate. Therefore, it is not clear how this would affect the risk of oil spill.
8.4	Offloading hose	Retractable	Floating	Not clear that this will affect the risks measured.
9.0	**Shuttle tanker**			
9.1	Hull configuration	Double hull	Single hull	Increased consequences in the event of grounding, contact or collision. These are three of the leading causes of shuttle tanker spills and shuttle tanker spills near and at sea already account for 53.6% and 39.0% of potential basecase spills by volume. Therefore, the single hull shuttle tanker option would represent a major increase in oil spill risk over the basecase.
			ATB	Use of ATBs (articulated tug barges) is a relatively new development and there are little data on frequency of oil spills from ATBs. There are oil spill frequency data for tankers and barges. These data indicate that the oil spill frequency for barges is approximately four times higher than for oil tankers, and the average barge spill size is about eight times smaller than for oil tankers. However, ATBs are not very similar to inland barges, which make up the majority of the vessels in the barge data quoted. ATBs are more similar in design and operation to tankers. The main functional differences are that ATBs have a lower crew size, lower top speed than tankers and some sea-state limitations on the tub-barge coupling. Therefore, it is expected that the oil spill frequency for ATBs is best estimated using oil spill rate tanker data rather than barge data.
9.2	Capacity	500,000 bbls	No options	
9.3	Station-keeping	Hawser with thruster assist	Hawser	Increased vulnerability to hawser failure, and subsequent damage to the offloading hose and release during transfer to shuttle tanker. Transfer hose leaks account for 1.8% of potential basecase spills by volume.

Number	Component	Basecase	Option	Impact
			DP	Vulnerability to DP failures, and subsequent damage to the offloading hose and release during transfer to shuttle tanker. Whether using a DP system would increase or decrease the potential for oil spills would depend on the reliability of the DP system. With a reliable DP system it would be expected that loss of station-keeping and damage to the offloading hose would be much reduced. Transfer hose leaks account for 1.8% of potential basecase spills by volume.
10	**General Lay-out**			
10.1	Quarters/flare location	Quarters stern/ flare bow	Quarters bow / flare stern	It is not clear that there will be a significant difference in the risk of oil spill between these two configurations. The flare should be well clear / upwind of any potential gas release sources. If the flare is sufficiently high, it is unlikely that it will ignite a gas release.
10.2	Living quarters capacity	70	No Options	
10.3	Life Boat Arrangements	per USCG requirements	No options	
10.4	Bow/stern Escape Tunnels	Not required	No options	
10.5	Collision Avoidance Warning System	Monitor / Alarm	Continuously manned radar watch	Reduced risk of ship collision by passing merchant vessel. Use of a continuously manned radar watch with supervision of passing vessels has been estimated to reduce collision frequency by 50-80% (ref. 3). However, this 50-80% reduction is probably too high for the basecase because there is no attendant vessel, as is assumed in this figure. Since there is no attendant vessel to act as a guard vessel, the actions of the FPSO personnel would be largely limited to trying to raise the oncoming vessel on the radio and otherwise alert them, and to prepare for collision. Passing merchant vessel collisions account for 1.2% of basecase spills by volume.
			No CAWS	Increased risk of ship collision by passing merchant vessel. Passing merchant vessel collisions account for 1.2% of basecase spills by volume.

TableII.3: FPSO Operations

Number	Component	Basecase	Option	Impact
1.0	Shuttle tanker destination	Various		Transit routes avoiding busy shipping lanes or difficult navigation passages are likely to have lower risks. Thereafter, minimizing the distance traveled reduces risk.
2.0	Offloading frequency	Every 3 days	Every day to once per ten days	More frequent offloading operations increases the risk of small leaks due to offloading, and increases the risk of shuttle tanker failures. Conversely less frequent offloading has the opposite effect.
3.0	FPSO Thruster Assist	No thrusters	Thrusters	See 4.1 and 6.5 in above table
4.0	Shuttle tanker tug assist	No tug	Tug	A tug would reduce the risk of shuttle tanker collision with the FPSO, and would also be on hand to prevent collisions by other drifting vessels in the vicinity (drifting vessels are a negligible risk)
5.0	Hurricane abandonment	No	Yes	Reduced possibility for manual mitigation of an accident were it to occur during a hurricane. The benefit of hurricane abandonment is reduced potential for loss of life in the event of a failure during a hurricane, rather than any reduction in oil spill risk. Evacuating personnel by helicopter for hurricane abandonment is not a risk free operation. Helicopter accidents are one of the major fatality risks of offshore operations. An FPSO should be so designed and constructed to ensure it is habitable and safe during all foreseeable weather conditions.

APPENDIX III

SUGGESTED RISK MITIGATION OPTIONS

III SUGGESTED RISK MITIGATION OPTIONS

HAZARD	BASE CASE	MITIGATIONS	MITIGATION EFFECT
Shuttle Tanker Leak Near Port	• Double hull vessel • Compliant with Coast Guard regulations and Jones Act • Tankers of opportunity will be used	• Inert Gas System • Firewater and foam systems • Oil spill contingency plans • Continuously manned radar watch • Contingency plans in case of loss of propulsion including availability of tug assistance and possibility of using anchor to stop drifting vessel. • Establish selection standards and inspections to ensure that shuttle tanker meets requirements for vessel safety, crew training, and emergency response preparedness. Alternatively, a dedicated shuttle tanker and crew could be used.	• To minimize the potential for damage due to fires and explosions • To minimize impacts of potential oil spills • To minimize the potential for collisions • To minimize the potential for groundings • To minimize potential for oil spills impacts
Shuttle Tanker Leak at Sea	(items listed under Shuttle Tanker Leak Near Port above also apply)	(mitigation measures and effects listed under Shuttle Tanker Near Port also apply)	

HAZARD	BASE CASE	MITIGATIONS	MITIGATION EFFECT
Process Leaks	• Fire and gas detection system to shutdown and blowdown. • Firewater deluge and foam protection to prevent escalation. • Process deck elevated above the storage tanks to prevent fire impingement onto the storage tank. • Open type process area with individual equipment area classification. • As per MMS, Coast Guard and USEPA regulatory requirements.	• Designated process area to be classified area, • Equipment arrangement to segregate ignition and fuel sources, API-RP-14J • Electrical system to conform with API-RP-14F • Two levels of process upset protection per API-RP-14C. • Piping system to conform with API-RP-14E. • Restrict crane operations over process area. Designate crane landing area. Require work permit for lifting equipment to or from process area. • Limit containment of pressurized hydrocarbon and provide automatic isolation between vessels. • Optimized equipment and piping layout to reduce congestion and in turn reduce potential explosion overpressure. • Deck drainage system to divert hydrocarbon spill and deluge water to the adequately sized drain/slop tank	• Current area classification practice emphasizes equipment coverage and does not cover catastrophic failure. By designating the whole process area together to comply with both API-RP-14F & 14J the potential for ignition would be minimized. • Lowers probability of loss of containment. • Lowers the consequences of a potential fire or explosion. • To control the consequence of liquid spill.

HAZARD	BASE CASE	MITIGATIONS	MITIGATION EFFECT
Transfer Hose Leak	• Tandem cargo offloading system. Offloading hose to be equipment with a marine breakaway coupling complete with shut-off valve. • Isolation valve to be provided at each pump discharge line to the common manifold.	• Use of high integrity hoses, valves and couplings and other offloading equipment and regular of inspection of equipment for defects. • Automated shutdown valve to be provided upstream of the hose tie-in station complete with low-pressure sensor or equivalent sensor to detect leak. • Independent low pressure sensors to be provided at each pump discharge upstream of check valve preferably located at the tie in point of the manifold to shutdown the pump and/or the automatic isolation valve. • Oil spill control procedure.	• To reduce potential for oil spills during offloading • To minimize spill size in the event of hose rupture or breakage during offloading. • To detect and shut down pump in order to minimize spill size. • To minimize pollution to the environment.
Vessel Collision	• FPSO location to be determined • Monitor/Alarm. • Navigation aids in the form of lights, shapes, and sound signal in compliance with Coast Guard Navigational Aid regulations.	• Exclusion of FPSO operations from in or near high traffic shipping lanes. • Collision avoidance radar. • Attendant vessel. • FPSO with thrusters. • Establish vessel exclusion zone around FPSO operation.	• Reduce collision risk by avoiding high traffic areas. • Provide advance warning for potential collision situation. • Provides “active” intervention for drifting vessel or other potential collision. • Reduce collision risk by excluding from the area vessels unrelated to FPSO operation.

HAZARD	BASE CASE	MITIGATIONS	MITIGATION EFFECT
Cargo Tank Explosion	• The cargo tanks will be provided with Inert Gas System (IGS) and crude oil washing (COW) system. • Double hull vessel	• Continuous monitoring of cargo tank O2 level to ensure it is maintained below 5%. • Individual venting system and a relief/vacuum valve are to be provided to each cargo tank. • Exhaust and air intake from/to the tank to be equipped with devices to prevent fire flash back.	• To minimize potential for explosion within the storage tank. • To localize potential failure. • To minimize potential for explosion within the storage tank.
Production Riser Leak	• 3 subsea well manifolds connected to the FPSO through 6 flowlines and 6 production risers, providing piggable loops. • Pressure monitoring system will be used for detection of main leaks as per API RP 14C.	• All subsea wells tied into one manifold with a single production riser and one alternative riser to provide a pigging loop. • Device to detect and alarm on no flow or loss of flow in order to indicate potential leakage. Pressure sensor may not effectively detect leakage especially for small leaks, especially if the sensor is located subsea where the external pressure may be about that of the riser or pipeline pressure.	• Reducing the number of production risers from 6 to 2 will approximately cut in one third the potential for production riser leaks (1.4% of spills by volume). • Swivel leaks (0.6% of spills by volume) would be reduced due a simpler design with less possible leak points. • Reduces the probability of undetected sub-sea leak

HAZARD	BASE CASE	MITIGATIONS	MITIGATION EFFECT
Foundering	• To satisfy IMO and global strength requirement. • Segregated ballast system. • Design for 100 years wave with associated wind and current, • Design for 100 year current with associated wave and wind.	• Central ballast control station to control and monitor the ballast and bilge system, including heel and trim monitoring. • An FPSO is unlike other oil production facilities, where insignificant amount of oil is stored or if it is stored it can be pump into the pipeline prior to the storm. Therefore, a much higher safety factor should be considered. For example, the FPSO could be “overdesigned” to withstand more extreme conditions (i.e., events greater than a 100-year storm). • Consider classification of FPSO including hull and mooring system. • Real-time monitoring of loads on the hull of the FPSO.	• To reduce the potential for human error in ballasting operation. • Reduces the risk to extreme weather conditions. • To ensure integrity of the unit against structural failure and eliminate potential design and fabrication errors.
Swivel Leak	• Adequate Ventilation, • Div 2 Area Classification, • Fire and gas detection to activate shutdown and blowdown, • Firewater, and foam system.	• Coffer or ballast tank to be provided between turret/swivel and storage tanks.	• The additional coffer dam or ballast tank would reduce the risk of escalation from the fire or explosion in the turret/swivel area.
Cargo Piping Leak on Deck	•	• Provide spill containment system similar to process area.	• To reduce the probability for piping leaks to spill to sea.