# Comparative Risk Analysis for Deepwater Production Systems

*Final Project Report*

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**Minerals Management Service**

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## EXECUTIVE SUMMARY

A quantitative risk analysis was performed to assess and compare oil spill and fatality risks for four representative deepwater production systems in the Gulf of Mexico. Three of the study system types have already been operated successfully in the Gulf of Mexico: two floating production systems in deepwater with oil pipelines, a Spar and a Tension Leg Platform (TLP); and a shallow-water jacket serving as a hub and host to deepwater production. One of the study system types has not been used in the Gulf of Mexico: a tanker-based Floating Production Storage and Offloading (FPSO) system with oil transportation to shore via shuttle tankers. The objective of this analysis was to understand and compare the risks of the FPSO with those for currently acceptable alternatives for deepwater production.

Conceptual system descriptions that are representative of existing and typical technology in the Gulf of Mexico were developed for the four systems. The scope of these descriptions included the entire production systems and operations from the wells through the transport of product to the shore.

Three risk measures were assessed and analyzed for each system: the total number of fatalities in a 20-year production life as a measure of the human safety risk, the total volume of oil spilled in a 20-year production life as a measure of the chronic environmental risk, and the maximum volume spilled in a single incident in a 20-year production life as a measure of the acute environmental risk. The process of developing the conceptual descriptions for the systems and then evaluating the risks has drawn on expertise from all facets of oil and gas production, including operators, contractors, manufacturers, class societies and regulators.

### Conclusions

The following major conclusions have been drawn from the results of this analysis:

1. There are no significant differences in the fatality risks among the four study systems.
2. There are no significant differences in the oil-spill risks among the four study systems.
3. The average total volume of oil spilled during the facility lifetime will be dominated by rare, large spills rather than frequent, small spills.
4. The major contribution to the oil spill risks for all systems is the transportation of oil from the production facility to the shore terminal by either pipelines or shuttle tankers. Spill risks for pipelines and shuttle tankers are comparable, although the frequencies and sizes of possible spills are different for pipelines versus shuttle tankers. The spill risks for pipelines are dominated by the possibility of spills between 10,000 and 100,000 bbl in size that are expected to occur once every 600 years on average. The spill risks for shuttle tankers are dominated by the possibility of spills between 100,000 and 500,000 bbl in size that are expected to occur on average once every 4,500 years.
5. The confidence intervals in predicted oil spill volumes range over about an order of magnitude, reflecting the limited quantity and quality of historical data available to estimate frequencies for rare events.

Therefore, the expected risks associated with the FPSO are comparable to those for already accepted alternatives for deepwater production, including a Spar, a TLP and a shallow-water jacket serving as a hub and a host to deepwater production.

**Recommendations**

The following recommendations have been developed from this work:

1. The results from this study should be periodically updated because they provide a valuable baseline for future analyses of risk in the Gulf of Mexico. The three measures of risk used in this study can all be readily measured and tracked for new and existing deepwater production facilities in the Gulf of Mexico.
2. The quality of existing data sets for the Gulf of Mexico should be improved so that they are of greater value in future risk analyses. First, the type and quality of data that are currently collected should be evaluated, and any changes recommended from this evaluation should be implemented in a timely manner. Second, single agencies should be responsible for tracking and compiling similar types of data. Third, all data records should be reviewed annually by the industry and regulators to improve the clarity, quality and usefulness of the information in these records. Finally, the data should be published annually in a clear and an easily accessible format.
3. Additional information about the populations of offshore facilities and operations in the Gulf of Mexico should be collected on an annual basis. Specifically, the following information from federal and state waters in the Gulf of Mexico would be valuable: the length of active pipelines operating per year, the number of tanker on-loading and off-loading events in ports and lightering zones per year, and the number of man-hours in production-related activities, supply vessel operations and tanker operations per year.
4. Uncertainty in the predicted performance for these four study systems should be considered carefully in drawing conclusions from and applying the results from this study.
5. The process used on this project to assess risks has been effective in obtaining valuable technical information from industry and regulators, and should be considered in supporting other analyses of new technology in the Gulf of Mexico.

# 1. INTRODUCTION

## 1.1 Background

To date, deepwater (more than 3,000-foot water depth) reserves in the Gulf of Mexico have been developed primarily with the following types of production systems: Spars; Tension Leg Platforms (TLP's); and Subsea Well Systems tied back to these floating systems or to shallow water jackets that may also serve as hubs for other deepwater production systems (Hub/Host Jacket). All three of these types of systems rely on pipelines to transport oil to shore. A potentially attractive alternative to these systems is a tanker-based Floating Production Storage and Offloading (FPSO) system with oil transportation to shore via shuttle tankers. Floating Production Storage and Offloading systems have been used in many areas of the world, but not the Gulf of Mexico.

The Minerals Management Service (MMS) funded the Offshore Technology Research Center (a National Science Foundation engineering research center located at Texas A&M University and The University of Texas at Austin), with EQE International, Inc. as a subcontractor, to conduct a Comparative Risk Analysis (CRA). The purpose of this study was to assess and compare the system risks for FPSO's with those for existing deepwater production systems, specifically TLP's, Spars and Hub/Host Jackets. This study was conducted concurrently with an Environmental Impact Statement study for FPSO's in the Gulf of Mexico (MMS 2000c). Information from both the Comparative Risk Analysis and the Environmental Impact Statement will be used by the MMS in developing policies concerning the use of FPSO's in the Gulf of Mexico.

## 1.2 Objectives

The primary objectives of the Comparative Risk Analysis were the following:

1. Assess and compare the system risks for FPSO's with those for existing deepwater production systems, specifically Spars, TLP's and Hub/Host Jackets; and
2. Understand the contributions to system risk by subsystems and phases of operation.

### 1.3 Organization of Report

This report is divided into five sections. Following this introduction, the approach is described in Section 2. Results are presented in Section 3 and conclusions and recommendations are given in Section 4. Acknowledgments are made in Section 5. A bibliography that includes all references cited in this report is provided in Section 6. In addition, there are six appendices with information supporting the report. A glossary of major technical terms used in this study is provided in Appendix A. Information about technical experts who participated in this study is listed in Appendix B. Detailed descriptions for the four production systems assessed in this project are contained in Appendix C. A mathematical description of the framework used in the quantitative risk assessment is provided in Appendix D. Finally, the detailed information for the fatality and oil-spill risk assessments is contained in Appendices E and F, respectively.

## 2. APPROACH

The approach used to conduct the Comparative Risk Analysis was developed with the following goals in mind:

1. Provide the MMS with information that can be used for a consistent and objective comparison of the risks associated with the four production systems;
2. Provide the MMS with a level of detail necessary to compare and understand overall system risks for typical production systems; and
3. Incorporate industry data, experience and expertise to the greatest extent possible into evaluating the risks.

The approach used to achieve these goals involved teams of experts and a series of workshops.

### 2.1 Participation of Technical Experts

The purpose of this study was to compare the risks of several deepwater production systems. Risk is a measure of failures and the consequences of those failures. Historical data on actual failures, particularly those very infrequent failures with large consequences that tend to drive overall risks, are scarce, and the risks must be estimated by other means. For this study, we chose to directly involve the expertise and experiences of engineers involved in the design and operation of these production systems. The Deepstar consortia facilitated and coordinated the participation of industry engineers in this project.

There was active participation by experienced engineers representing all segments of the industry, including oil companies, consultants, manufacturers, contractors, classification societies, as well as the regulatory agencies. They brought a detailed understanding of the nature of these risks as well as design and operational options to manage these risks. Many of the industry engineers who were involved in this study had also participated in risk studies within their companies, which are often undertaken either in the design of a specific system or to compare several systems in selecting the most appropriate system for a given project. The practical experience and perspective that these engineers brought to the study was deemed critical to the success of this study.

Separate teams were formed for each of the four production systems, the Spar, the TLP, the Hub/Host Jacket, and the FPSO. These teams were made up of invited participants from industry and representatives from the MMS and the U. S. Coast Guard (USCG), the government agencies responsible for regulating the deployment and operation of deepwater production systems. The teams were designed to include engineers with expertise and experience in the design, construction and operation of the overall systems as well as the subsystems and components that make up the systems. There was an average of about ten members per team. The companies that provided one or more participants to these system teams are listed in Table 2.1.

Table 2.1 Industry Sources for Workshop Participants

| Oil Companies | Consultants & Contractors | Classification Societies |
|---|---|---|
| BP Amoco | EQE | ABS |
| Chevron | ABB | Lloyd's Register |
| Conoco | Atlantia | DNV |
| Elf | FMC | |
| ExxonMobil | Paragon | |
| Marathon | McDermott | |
| Oxy | Navion | |
| Shell | | |
| Statoil | | |
| Texaco | | |

It is worth noting that these companies represent a large measure of the offshore industry's deepwater experience and expertise. They have been very active in the design, operation, and/or certification of deepwater production systems in the Gulf of Mexico and elsewhere. Of particular importance is their direct involvement and experience with the deepwater production systems used in this study: Spars, TLP's, Hub/Host Jackets, and FPSO's.

The teams were balanced to include members with overall systems expertise as well as those with expertise in various sub-systems, components, and operations, including:

- Platform and subsea well systems;
- Drilling and well intervention operations for both platform and subsea wells;
- Topsides (processing facilities, equipment);
- Production operations;

- Pipelines and flowlines;
- Tanker and FPSO design and operations;
- Structures (hulls, decks, mooring systems, riser systems);
- Helicopter operations (personnel transport);
- Supply boat operations (material & personnel transport); and
- Diving operations.

Thus the teams were able to focus on risks at the sub-system, component, and operational levels as well as to focus on overall system risks.

Additional contributions from industry included input on detailed hazard identifications through participation in formal specialty interview sessions, and various other interactions in which individuals provided data, input, or advice. Technical experts from the companies and organizations listed in Table 2.2 as well as from most of those listed previously in Table 2.1 contributed in these areas.

Table 2.2 Additional Industry Sources for Technical Expertise

| | |
|---|---|
| Skaugen Petrotrans | Association of Diving Contractors |
| SBM IMODCO | Oceaneering |
| Global Maritime | Cameron |
| Aker | Mentor |
| R&B Falcon | Bay Ltd. |
| Transocean SedcoForex | Spirit Energy |
| Edison Chouest | Horizon Engineering |
| Tidewater Marine | Kerr McGee |
| HSAC | Mathews Daniels |
| Air Logistics | LOOP |
| PHI | State of Louisiana |
| ERA Aviation | |

In all, over 100 of the industry's more experienced engineers directly participated in the study either through the system teams and workshops, or the specialty interview sessions. The names and affiliations of these participants are summarized in Appendix B. The average experience level for these experts was approximately 20 years.

The level of participation by the industry experts was substantial. Their direct involvement in the workshops (preparation, participation, and review) and the specialty interviews involved an estimated 5,000 man-hours. Further, these experts often sought additional input and review from colleagues in their companies, and gathered additional relevant information for the study.

## 2.2 Workshop Process

A flowchart for the workshops is shown in Fig. 2.1. Individual, one-day workshops were conducted for each system during the first three phases (Workshops #1 to #3). The final workshop was held collectively over a two-day period. The activities conducted between workshops are also indicated on Fig. 2.1.

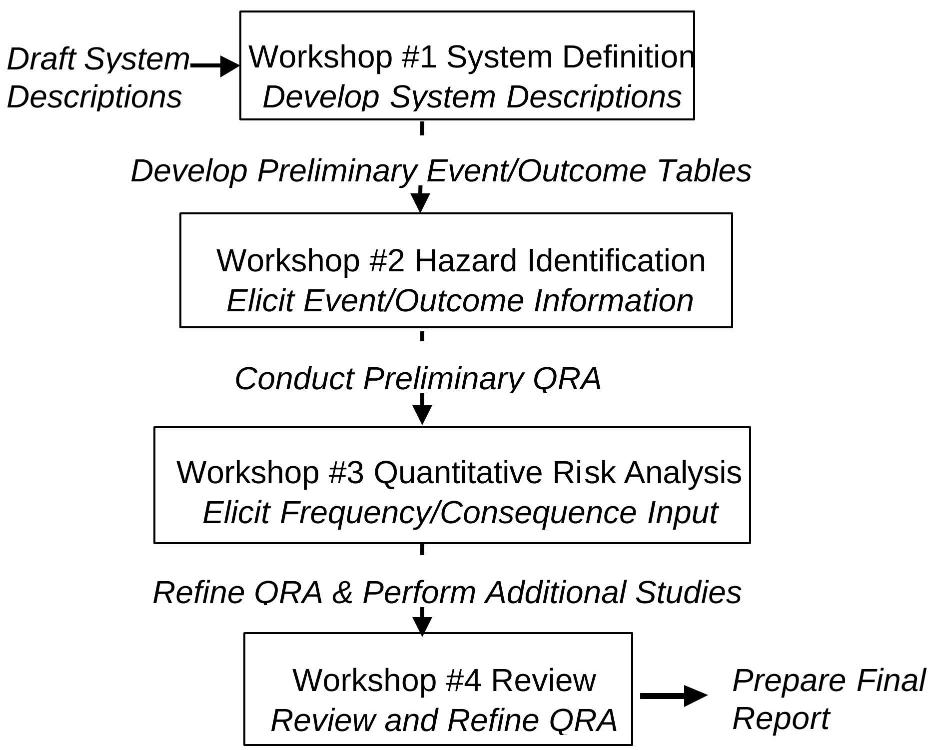


Fig. 2.1 Flowchart for Workshop Process

The objective of Workshop #1 was to develop conceptual system descriptions for the four production systems. This work included establishing study boundaries in space and time and describing the physical and operational features for each system. Draft system descriptions were distributed to the workshop participants ahead of the workshop and then used as the starting point in the workshop.

The objective of Workshop #2 was to perform hazard identifications for each system. A list of possible adverse events (or initiating events) that could contribute to risk was developed for each study system and organized by sub-system or activity. Detailed hazard identifications were developed through a series of specialty interviews with technical experts before Workshop #2. The participants and topics for these interview sessions are summarized in Appendix B. These detailed lists were then reviewed during Workshop #2 and used to develop a framework for the quantitative risk assessment.

The objective of Workshop #3 was to elicit quantitative information about frequencies and consequences for oil spills and fatalities. A preliminary quantitative risk assessment based entirely on raw data was distributed to the workshop participants before the workshop. This preliminary risk assessment was then refined during Workshop #3 and needs for additional information and studies were identified.

The objective of Workshop #4 was to review and refine the risk assessment. Information from additional studies conducted between Workshops #3 and #4 was incorporated into this review.

The general work processes used for the workshops was as follows. Preliminary information that had been distributed to the participants was reviewed and refined through an open forum process that included time for discussion and developing a consensus regarding the input on risks. The open forum approach encouraged an iterative and synergistic discussion of risks and information from different perspectives. The participation of both the industry and the regulatory agencies helped to provide balance and objectivity in the discussions and input. Consensus was generally readily achieved, but when significant disagreement occurred between participants, votes were taken to achieve a consensus and dissenters' opinions were recorded. The phased and progressive nature of the workshops provided the opportunity to seek and incorporate additional expertise and information as the study progressed and additional needs became apparent. Interim reports summarizing information from each of the first three workshops were distributed to participants after each workshop. These reports provided participants with opportunities for ongoing review and a means to ensure consistency in assumptions and approaches among the different systems. Finally, evaluations were conducted at the completion of the first three sets of workshops to continually improve the process.

## 2.3 Risk Measures

Risk measures for the study systems were developed using the following criteria:

- The measures of risk should provide relevant and useful input to MMS in their decision making process;
- The measures of risk should be tractable and quantifiable; and
- The measures of risk should be measures that are currently tracked and recorded so that (i) available data can be used to support the results of this risk analysis and (ii) future data can be used to validate and calibrate the results of this risk analysis.

From these criteria, the risk measures listed in Table 2.3 were adopted for this study. The total number of fatalities is intended to measure the human safety risk. The volume of oil spilled is intended to measure the environmental risk. The environmental effects of an oil spill are not considered directly in this study because (1) there is a correlation between the magnitude of environmental damage and the volume of oil spilled; (2) environmental effects are difficult to measure and quantify; and (3) the environmental impacts of oil spills from FPSO's are included in the scope of the Environmental Impact Statement (MMS 2000c). The total volume of oil spilled in the 20-year lifetime is intended to measure chronic environmental risks. The maximum volume of oil spilled in a single incident is intended to measure acute environmental risks. The risk measures in Table 2.3 are practical simplifications that are intended to approximately capture the multitude of risks present.

Table 2.3 Summary of Risk Measures

| Risk | Measure of Risk | Unit |
|---|---|---|
| Human Safety | Total Fatalities over Production Lifetime | Number of Fatalities |
| Environmental – Chronic | Total Volume of Oil Spilled over Production Lifetime | bbl of Oil |
| Environmental – Acute | Maximum Single Spill Volume in Production Lifetime | bbl of Oil |

These measures of risk were not discounted with time. In addition, each measure was treated separately in comparisons and no attempt was made to combine them into a single measure, such as equivalent cost.

## 2.4 Descriptions of Study Systems

The following criteria, in order of decreasing importance, were used to develop conceptual descriptions for each of the representative study systems:

1. The study systems for the Spar, TLP, and Hub/Host Jacket should be typical of existing systems and technologies that are currently being used in the Gulf of Mexico because these systems and technologies have been approved and therefore represent acceptable risks.
2. The study system for the FPSO should be comparable to that already developed for the base case in the Environmental Impact Statement (MMS 2000c) study in order to capitalize on the substantial effort devoted to developing this study basis.
3. The study systems should be as comparable to one another as possible so that differences in risks among them represent realistic differences among these types of systems and are not an unintended artifact of the study system descriptions.

As an example of how these criteria were applied, consider a Spar. In order for the study Spar to be as comparable as possible to the study FPSO (criterion 3), which has oil transport via shuttle tankers consistent with the Environmental Impact Statement (criterion 2), the Spar would also have oil storage and oil transport via shuttle tankers. However, while this type of a Spar is possible, it is not typical of existing Spars in the Gulf of Mexico (criterion 1). Therefore, the description for the study Spar did not include oil storage and has oil transport via pipeline.

The first step in the system description process was to establish a time frame for the risk assessment. The intent was to assess risks covering all aspects of offshore production including oil and gas production and processing offshore; drilling and well intervention during production; export of the oil and gas to shore; and transport of personnel to and from shore. The "lifetime" for a study system was defined to start when oil flows through the first production riser and end when the last well is shut in (Fig. 2.2). For this study, a 20-year lifetime was used. Other phases in the actual lifetime for a system, such as construction, system installation, commissioning, decommissioning and system removal, were not included in this risk analysis.

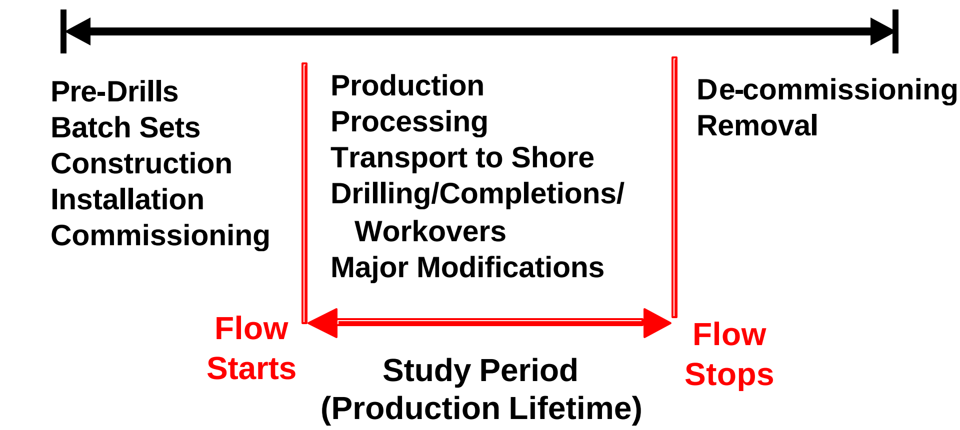


Fig. 2.2 Timeline for Study Systems

The second step in the system description process was to establish physical boundaries for the risk assessment. The study boundaries included the production facility, the pipelines and shuttle tankers used to transport oil to a shore terminal, and the supply vessels and helicopters used to support the production operations. These physical boundaries are shown schematically on Figs. 2.3 through 2.5.

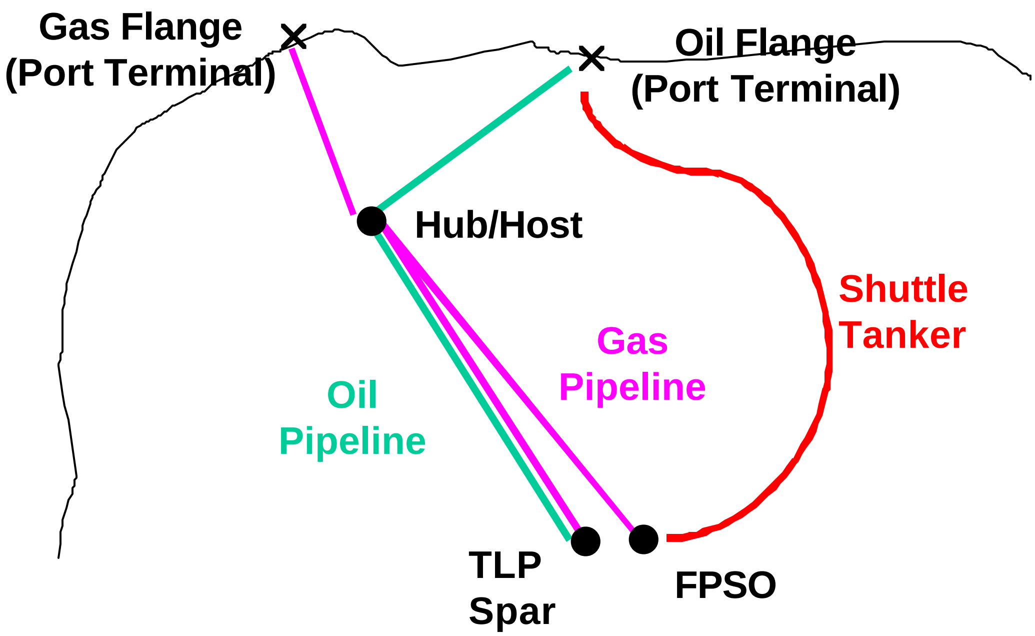


Fig. 2.3 Physical Layout for Study Systems (Plan View)

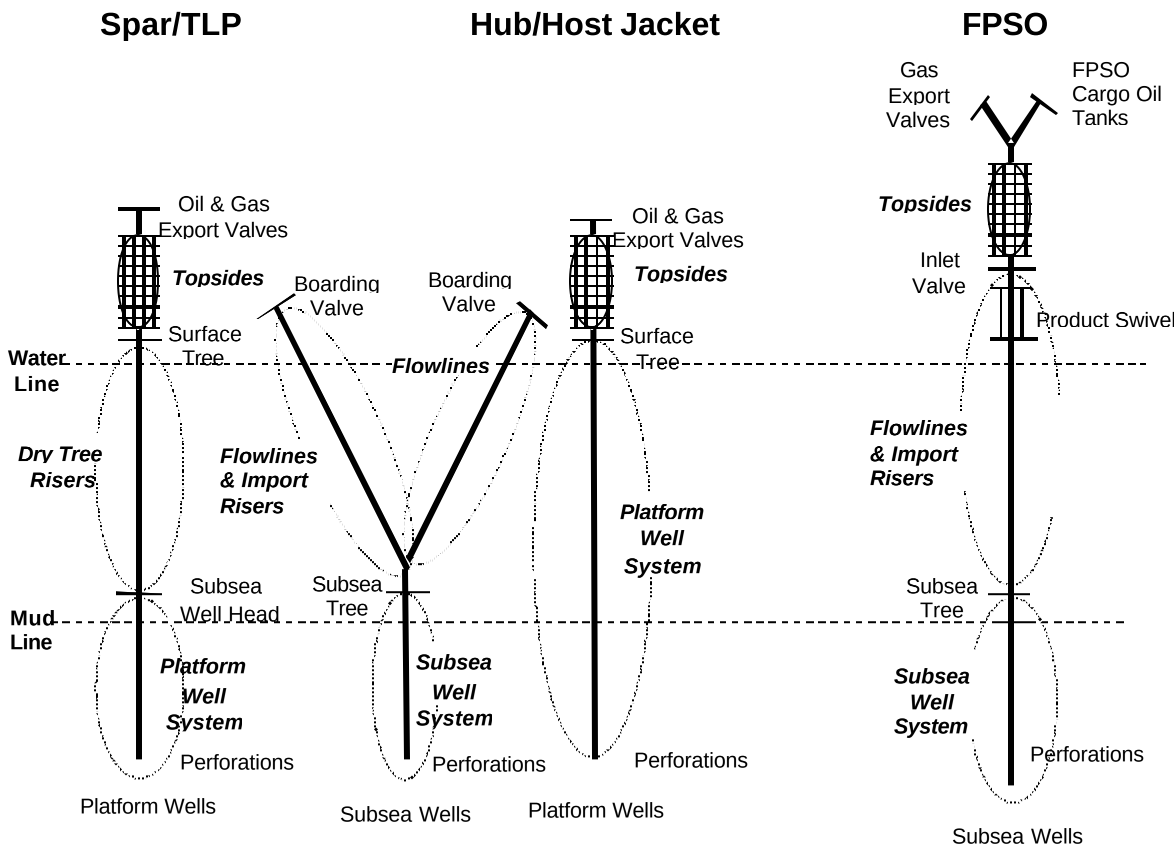


Fig. 2.4 Schematic of Production Systems for Study Systems (Flow Diagram)

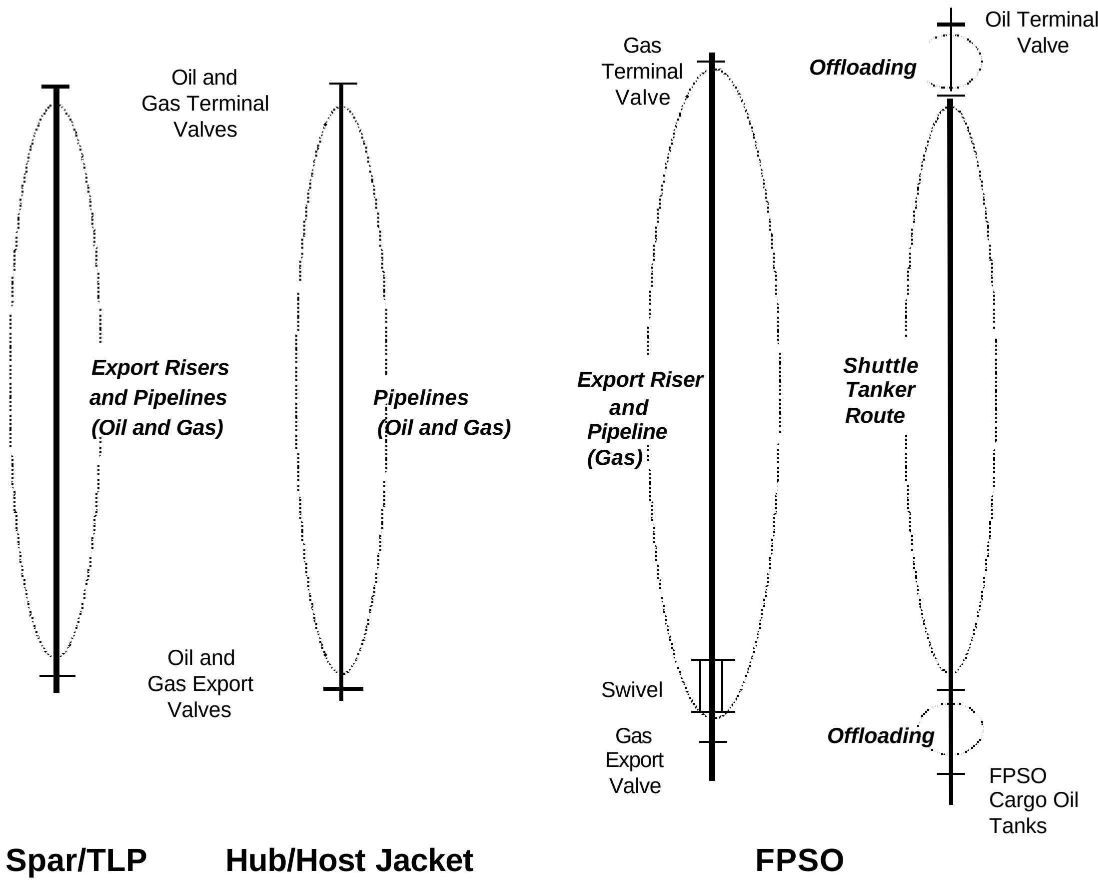


Fig. 2.5 Schematic of Transportation Systems for Study Systems (Flow Diagram)

The third step in the system description process was to define the physical and operational attributes for each system. Detailed descriptions for these attributes are contained in Appendix C, and the major attributes are summarized in Table 2.4. For the Spar, TLP and Hub/Host Jacket, operating experience from the Gulf of Mexico was directly drawn upon in developing the system descriptions. For the FPSO, experience with tanker operations in the Gulf of Mexico was used together with operating experience for FPSO's in other parts of the world, such as the North Sea and the South China Sea. It is important to note that these study systems represent typical or generic systems. Therefore, the range of risks associated with possible variations in hardware and operating practices is not captured in the results of this project.

Table 2.4 Summary of Attributes for Study Systems

| | Spar | TLP | Hub/Host Jacket | FPSO |
|---|---|---|---|---|
| Water Depth (ft) | 4,000 | 4,000 | 600 | 5,000 |
| Peak Production | | | | |
| Oil (bopd) | 150,000 | 150,000 | 50,000 | 150,000 |
| Gas (scfpd) | 200,000 | 200,000 | 50,000 | 200,000 |
| Export | | | | |
| Oil (bopd) | 150,000 | 150,000 | 250,000 | 150,000 |
| Gas (scfpd) | 200,000 | 200,000 | 550,000 | 200,000 |
| Wells | | | | |
| Pre-Drill (MODU) | 1 | 1 | 1 | 3 |
| Platform | 5 | 5 | 5 | 0 |
| Subsea (MODU) | 3 | 3 | 3 | 6 |
| Manning | | | | |
| Production | 30-45 | 30-45 | 30-45 | 30-45 |
| Marine | 6 | 6 | 0 | 10 |
| Drilling – Platform | 65 | 65 | 50 | 0 |
| Drilling MODU | 65 | 65 | 65 | 65 |

## 2.5 Quantitative Risk Assessment

The objective of the quantitative risk assessment was to quantitatively assess the risk measures listed in Table 2.3. These risk measures were quantified by estimating *representative or average values* for each study system. As an example, consider the total volume of oil spilled during the operational lifetime. If a fleet of Spars similar to the one defined in this study were installed and operated for 20 years in the Gulf of Mexico, then the total oil spill risk associated with this type of system would be the average value for the total volume of oil spilled from each Spar (that is, the sum of all the oil spilled from each Spar in its 20 year lifetime divided by the total number of Spars). Likewise, the average values for the maximum volume of oil spilled in a single incident from each Spar and the total number of fatalities on each Spar would represent the other measures of risk.

Since there is an extremely limited experience base in the Gulf of Mexico for the types of production systems being analyzed in this study, it is not possible to obtain average values directly for the total number of fatalities, the total volume of oil spilled, and the maximum volume of oil spilled in a single incident. The goal of this study was to *predict* what the average values would be (the expected value) if each study system were hypothetically installed and operated in the future in the Gulf of Mexico.

As with any prediction, there is uncertainty that the actual average value for each risk measure (obtained many years in the future) will be equal to the predicted value in this study. The range of possible values for the actual average was represented in this study by two quantities: the expected value and the standard deviation. The *expected value* represents the predicted value for the average, while the *standard deviation* represents the magnitude of uncertainty in the prediction. The expected value and standard deviation can be used to calculate confidence intervals for the prediction. For example, the 90-percent confidence intervals indicate that there is a ninety-percent probability that the actual average will be within this interval.

This section describes how the quantitative risk assessments were conducted through a process of developing preliminary assessments and then refining those assessments using the input of the technical experts (Section 2.1).

### 2.5.1 Preliminary Risk Assessments

Preliminary (or pre-workshop) quantitative risk assessments played a very important role in this project because they were used to elicit quantitative information from the technical experts during Workshops #3 and #4 (Fig. 2.1). These preliminary risk assessments were developed to be objective, consistent and complete in order to maximize the value of the information obtained from the technical experts during the workshops.

The philosophy adopted in developing the preliminary risk assessments was to extrapolate directly from historical experience in the Gulf of Mexico to predict future performance. The primary data sources were the MMS (MMS 2000a) and the USCG (USCG 1999). The methodology used to develop the preliminary risk assessments had the following steps:

1. <u>Summarize Data for Sub-Systems</u>: The data sets were first divided into sub-systems based on the hazard identification work in Workshop #2. These sub-systems are listed in Table 2.5. The data for fatalities were then summarized as the total number of fatalities in the data record for each sub-system. The data for oil spills were further sub-divided

into categories by the size of the spill, and then the number of incidents in the data record that had occurred for each spill-size category was compiled. The data for oil spills were divided into categories in order to facilitate the assessment since the range of spill volumes per incident covered five to six orders of magnitude and the frequency distribution for spill sizes was highly skewed.

2. Select Exposure Factors for Sub-Systems: The *exposure* for a risk is an indicator of the factors that influence the risk. In this way, the data can be extrapolated to each study system based on the exposure to the risk for that study system. The factors used to express the exposure for each sub-system category were selected based on the hazard identification information work in Workshop #2. These factors are listed in Table 2.5.
3. Estimate Frequencies of Occurrence for Sub-Systems: Estimates for the frequencies of occurrence for incidents (from Step 1) relative to the exposure factors (from Step 2) were developed using statistical methods that are described in Appendix D. Both the expected value and the standard deviation for these frequencies were calculated. For the oil spill frequencies, it was assumed that a spill could occur in the next largest spill-size category above the maximum spill size observed in the historical data set.
4. Determine Sub-System Exposures for Study Systems: The exposure for each sub-system was determined from the system descriptions in Appendix C.
5. Assess Sub-System Risks for Study Systems: The estimated frequencies from the historical data (from Step 3) were then combined with the exposures for the study systems (from Step 4) to assess the sub-system risks. Both an expected value and a standard deviation were calculated for each risk measure (see Appendix D for details).
6. Assess System Risks from Sub-System Risks: The final step was to combine the information for the sub-system risks (from Step 5) to assess the total system risk (see Appendix D for details).

Table 2.5 Sub-System Categories Used in Risk Assessment

| Risk Measure | Sub-System Category | | Exposure Factor |
|---|---|---|---|
| Fatalities | Production | | man-hours |
| | Drilling | | man-hours |
| | Supply Vessels | | docking calls |
| | Helicopter Transport | | passengers |
| | Tanker Operations | | docking calls |
| | Major Accident | | platform-years |
| Oil Spills | Production System | Well Systems – Platform (or Surface) | bbl produced |
| | | Well Systems – Subsea | bbl produced |
| | | Dry Tree (or Production) Risers | riser-years |
| | | Flowlines | mile-years |
| | | Import Flowline Risers | riser-years |
| | | Topsides | bbl processed |
| | | Supply Vessels | docking calls |
| | | Drilling and Intervention | man-hours |
| | Transportation System | Pipelines | mile-years |
| | | Export Pipeline Risers | riser-years |
| | | Shuttle Tanker (Offloading in Field and at Port) | docking calls |
| | | FPSO Cargo Tank | platform-years |

### 2.5.2 Final Risk Assessments

The preliminary risk assessments were then refined through the workshop process to develop final risk assessments. This process involved the following steps:

1. Start with data-based estimates that are as complete as possible (the preliminary risk assessments).
2. Evaluate the data sources and refine raw data sets as necessary so that they are relevant for predicting future performance of the study systems. As an example, the data set for oil spills from tankers in the Gulf of Mexico was limited to years after 1990 to account for the positive effects that the Oil Pollution Act of 1990 has had on recent performance and is anticipated to have on future performance.
3. Extrapolate predictions of future performance from the data set, applying corrections to the data-based estimates if necessary. As an example, the frequencies for small spills from subsea well systems were increased from the data-based estimates to account for differences between subsea well systems and the platform well systems that dominate the data set.

4. Account for all sources of uncertainty in the estimates, including the following:
   - the limited quality and quantity of relevant data records, especially for rare events;
   - the sometimes limited information available on the exposures corresponding to the data sets; and
   - the extrapolation of future performance from historical performance.
5. Document the whole process clearly and thoroughly. Appendix E contains the detailed quantitative risk assessments for fatalities and Appendix F contains the detailed quantitative risk assessments for oil spills.

## 3. RESULTS

The results from the quantitative risk assessment for fatalities (Appendix E) and oil spills (Appendix F) are presented, analyzed and discussed in this section.

### 3.1 Risks for Fatalities

Results for the average total number of fatalities are shown on Fig. 3.1 for each study system. The results indicate that the fatality risks are very similar among the four study systems (Fig. 3.1). The expected contributions to the total fatality risk are shown on Fig. 3.2.

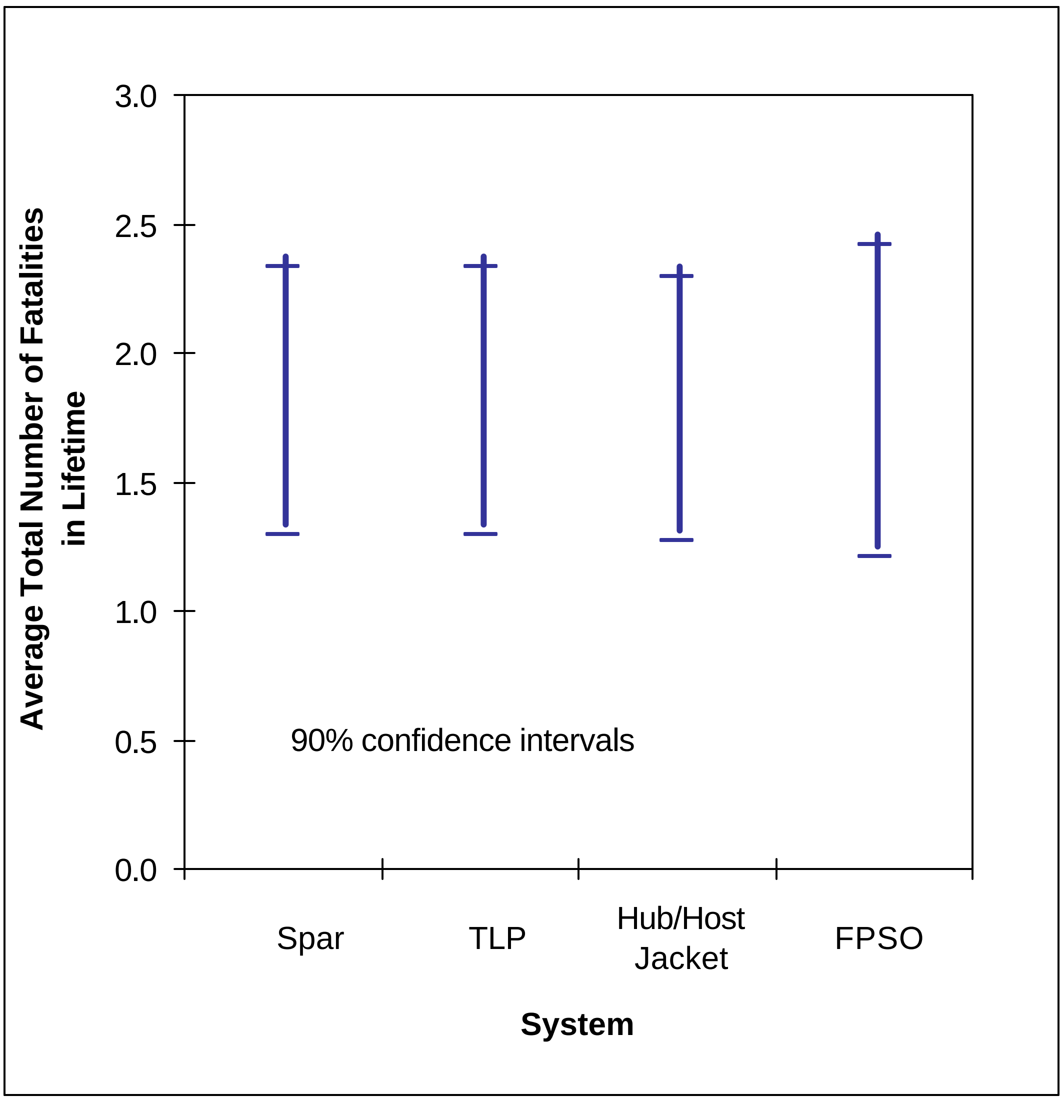


Fig. 3.1 Average Total Number of Fatalities in Lifetime

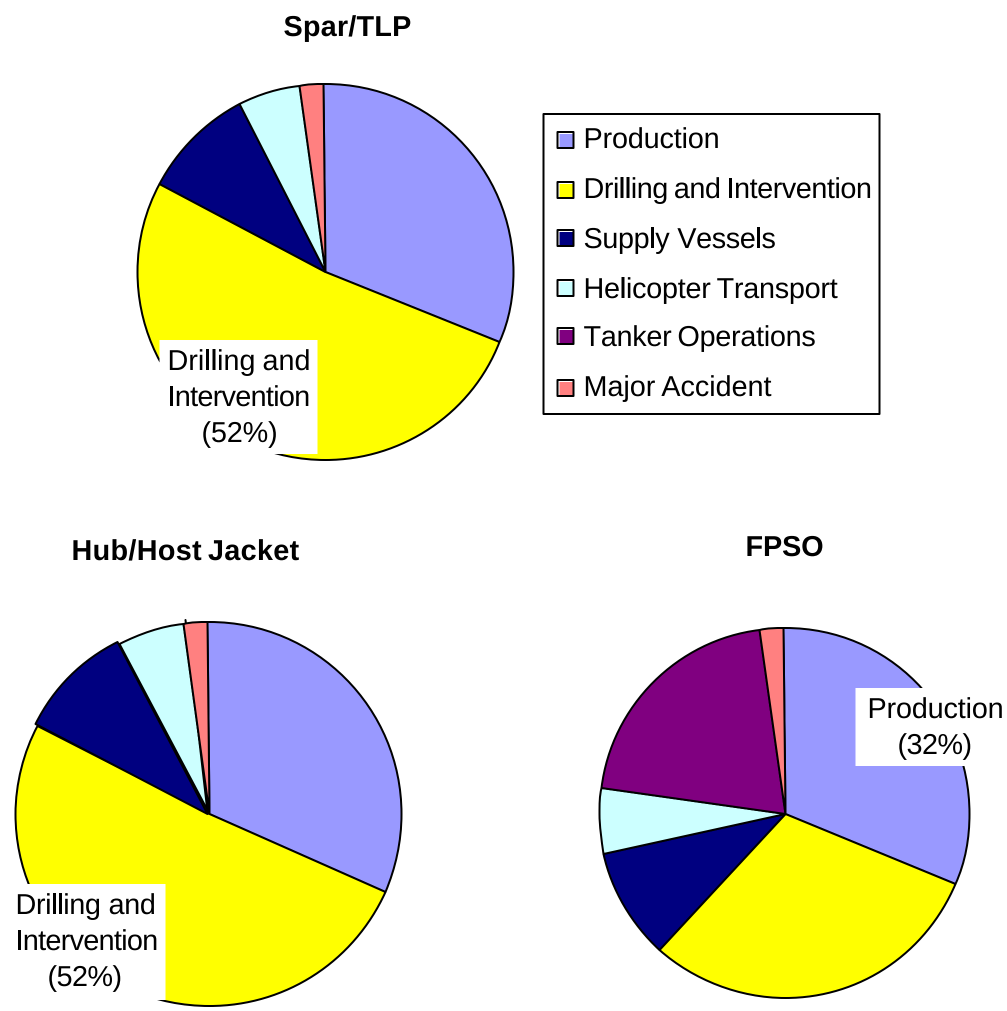


Fig. 3.2 Expected Contributions to Average Total Fatalities versus Activity

Production and drilling and well intervention activities dominate the total fatality risk for all of the study systems. This result occurs because these activities require the bulk of the man-hours over a 20-year lifetime. The contribution of drilling and intervention activities to the total fatality risk for the FPSO is not as large as for the other systems because all of the wells on the FPSO are subsea wells that are subjected to less frequent well intervention compared to platform wells. To put the production and drilling and intervention fatality risks in context, 90-percent confidence intervals for the frequency of fatalities per man-hour worked are summarized in Table 3.1. The magnitudes of these rates are comparable to those reported for common industrial activities (AIChE 1989) and for the oil and gas industry throughout the world (OGP 1999b).

Table 3.1 Summary of Fatality Rates (90-Percent Confidence Intervals)

| Activity | Fatal Accident Rate (fatalities per 100 million man-hours) | Fatal Incident Rate (fatalities per 200,000 man-hours) |
|---|---|---|
| Production | 4 to 13 | 0.0078 to 0.026 |
| Drilling and Intervention | 11 to 18 | 0.022 to 0.035 |

## 3.2 Risks for Oil Spills

The results for the oil spill risks are presented and discussed in this section. First, the frequencies for different spill sizes are addressed. Next, the average total volume of oil spilled and the maximum volume spilled in a single incident over the lifetime are addressed.

### 3.2.1 Frequencies of Spills

The frequencies of spills from production and transportation are first presented and discussed, and then the frequencies of spills from all sources are addressed.

#### 3.2.1.1 Frequencies of Production Spills

The annual frequencies for spills from production (Table 2.3) are shown on Fig. 3.3 for each of the study systems. Note that the frequency of spills tends to decrease as the spill size increases. Also, note that the relative magnitude of uncertainty in the estimated frequency increases as the spill size increases. This relative increase in uncertainty occurs because large spills are rare events, so there are few occurrences available from which to estimate frequencies.

The information on Fig. 3.3 highlights the similarities and differences among the systems regarding oil spills from production. First, the Spar and the TLP are indistinguishable. This result is reasonable in that the elements of the designs on both systems that affect the potential for oil spills from production are nearly identical on these two study systems (Fig. 2.4).

Second, the Hub/Host Jacket tends to have smaller spill frequencies from production than the Spar, TLP and FPSO for spill sizes less than 1,000 bbl (Fig. 3.3). This difference is due to the smaller indigenous production rate on the shallow-water Hub/Host Jacket versus the deepwater floating production systems (Table 2.2).

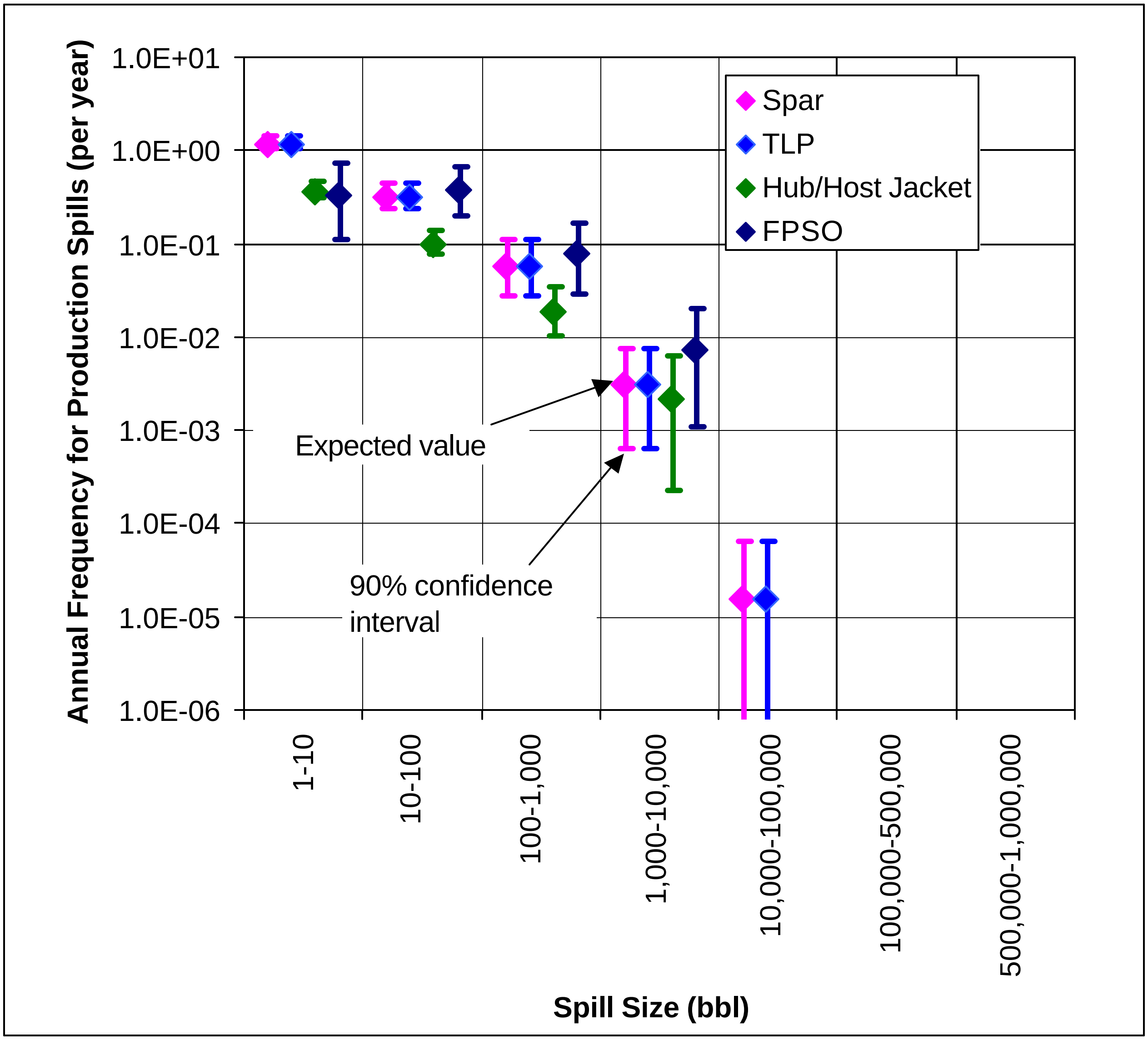


Fig. 3.3 Annual Frequency for Production Spills versus Spill Size

Third, the frequency of very small spills (less than 10 bbl) on the FPSO is less than that on the Spar and TLP, even though the production rates are similar on all of these study systems. This difference is due to the large deck area and the solid decking that exist on an FPSO; the deck would contain most small spills.

Fourth, the frequency of spills between 100 and 10,000 bbl is slightly larger for the FPSO versus the other systems. This relative difference is because the FPSO has more subsea wells than the other systems; subsea wells were considered to have a higher leak frequency than platform wells because of a greater potential for sand erosion and cutouts due to high flow rates and detection difficulties for sand. In addition, the FPSO has a greater number of flowlines and flowline risers, which both contribute to the frequency of spills between 100 and 10,000 bbl.

Fifth, the Spar and the TLP have the potential for very large spills (greater than 10,000 bbl), although the frequency for these spills is very small (Fig. 3.3). The potential source for these very large spills on the Spar and TLP is the dry tree risers. This risk does not exist on the FPSO study system because the trees that control the reservoir pressure and flow are on the seafloor (wet trees) rather than at the surface (dry trees), and it is negligible for the Hub/Host Jacket study system because of the lack of movement for this non-floating system.

A comparison with published information for the frequency of large spills from production is shown on Fig. 3.4 (note that CRA denotes this Comparative Risk Analysis). Anderson and LaBelle (1994) report a frequency for spills greater than 1,000 bbl in size. Their frequency was estimated using spill data from offshore platforms operating in the United States between the years 1974 and 1992. They report their frequency on the basis of the volume produced. In order to develop Fig. 3.4, this frequency has been converted to an annual frequency for the study systems using the total volume of oil produced in the 20-year lifetime for each system.

The estimated frequencies for the study systems are less than the values obtained from Anderson and LaBelle (Fig. 3.4). There are two reasons for this result. First, two different data sets have been used. In the CRA project, data before 1990 were discarded due to the implementation of new regulations in 1990 (API RP14C 1998), which improved operating procedures on platforms (Appendix F). The Anderson and LaBelle data set extends back to 1974. Second, the CRA study systems are not representative of conventional, shallow-water platforms in the United States, which dominate the population of platforms in the Anderson and LaBelle data set. Note that the agreement between the CRA and Anderson and LaBelle is best for the Hub/Host Jacket study system (Fig. 3.4), which is most similar to the platforms in the Anderson and LaBelle data set.

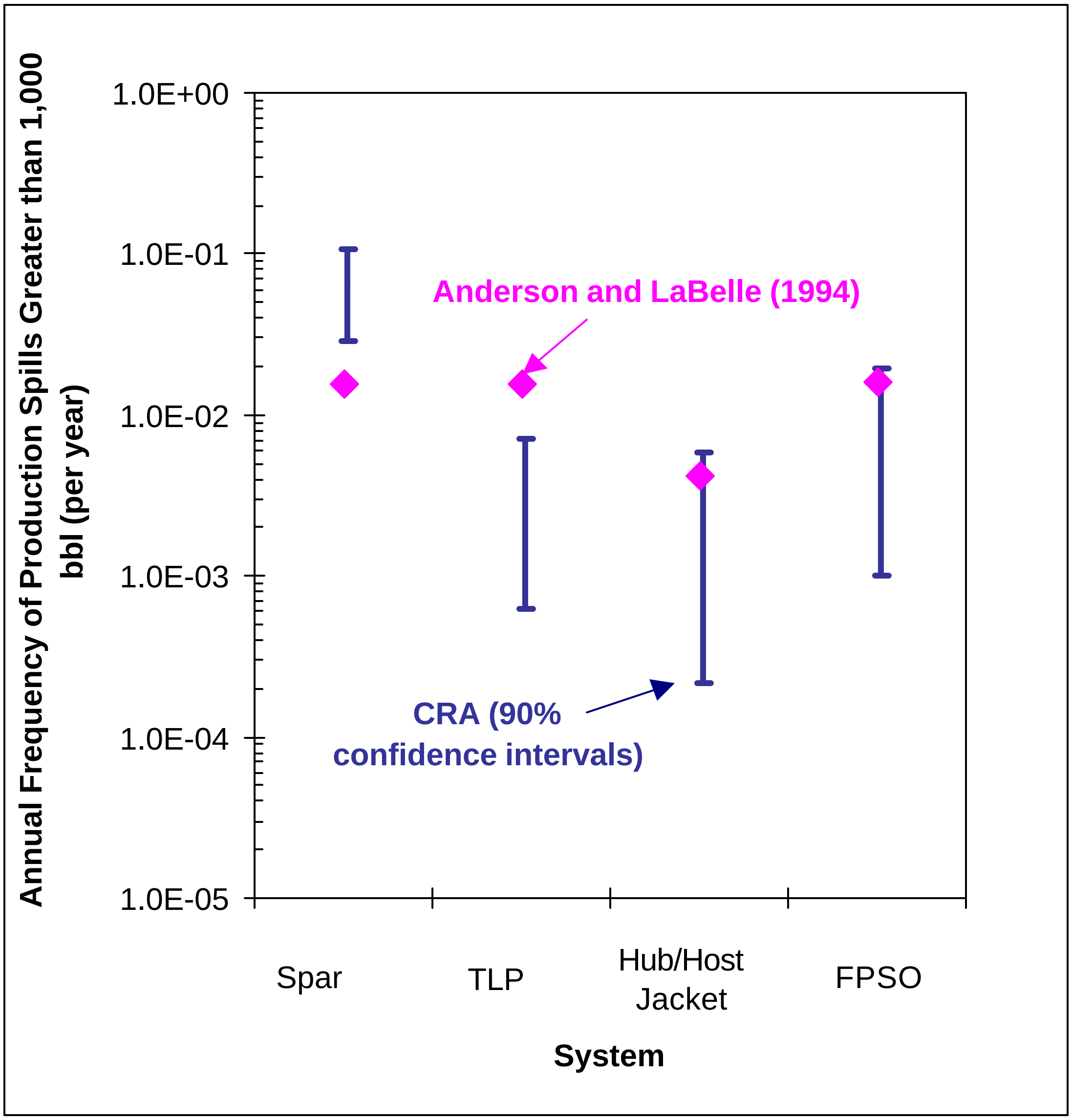


Fig. 3.4 Comparison of Production Spill (>1,000 bbl) Frequencies with Published Data

### 3.2.1.2 Frequencies of Transportation Spills

The annual frequencies for spills from transportation (Table 2.3) are shown on Fig. 3.5 for each of the study systems. The results highlight the similarities and differences among the systems regarding oil spills from transportation.

First, compare the systems with pipelines. The Spar and the TLP are indistinguishable. This result is reasonable in that the elements of the designs on both systems that affect the potential for oil spills from transportation are nearly identical on these two study systems (Fig. 2.5).

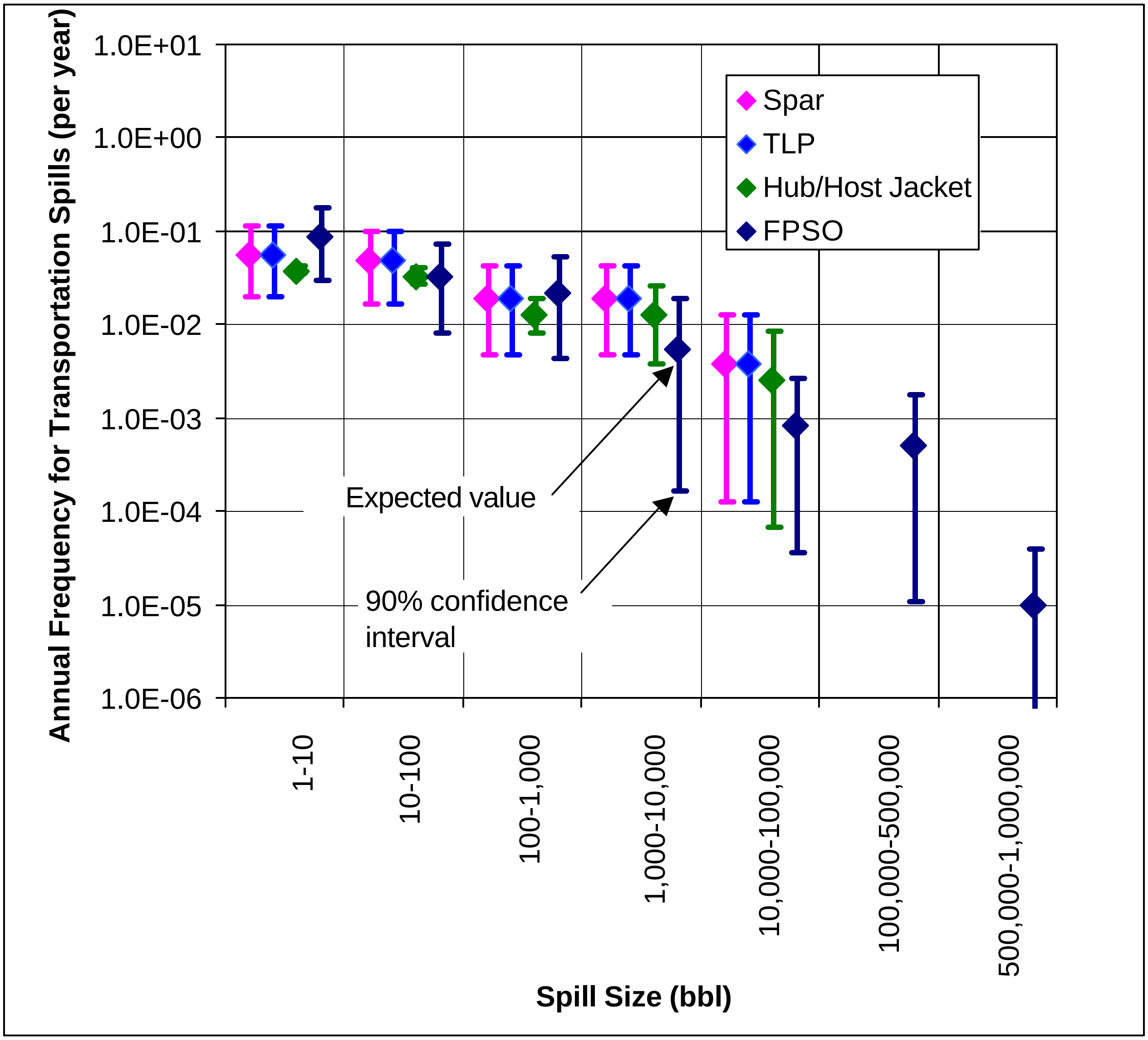


Fig. 3.5 Annual Frequency for Transportation Spills versus Spill Size

The Hub/Host Jacket has slightly smaller spill frequencies from its pipeline than the Spar and TLP (Fig. 3.5). This difference is because there is a shorter length of pipeline exposed for the Hub/Host Jacket due to the shorter distance to the shore (Fig. 2.3). In addition, there is relatively less uncertainty in the estimated spill frequencies for the Hub/Host Jacket for spills less than 1,000 bbl (Fig. 3.5). The greater uncertainty for the Spar and TLP is due to the potential for spills from the more flexible steel catenary export pipeline risers versus the more rigid risers on fixed jackets. The uncertainty for the Spar and TLP reflects that there are limited data concerning the performance of these risers in deepwater applications.

Second, compare the two different types of transportation systems. There are notable differences between the pipelines for the Spar, TLP and Hub/Host Jacket and in-field storage and shuttle tanker system for the FPSO. For very small spill sizes (less than 10 bbl), the frequency of spills for the FPSO is greater than from pipelines due to the potential for spills during offloading from hoses and valves (Fig. 3.5). For spill sizes between 1,000 and 100,000 bbl, the annual frequencies of spills for the shuttle tanker are smaller than the annual frequencies for pipelines (Fig. 3.5). One reason for this difference is that the potential for spills from the pipeline remains a constant as long as there is oil in the pipeline, regardless of the production rate. However, the potential for spills from the shuttle tanker will go down as the production rate decreases since fewer offloading events are required. Lastly, very large spill sizes (greater than 100,000 bbl) are not considered possible for pipelines due to operational and physical constraints (Appendix F), while they are possible although infrequent for the FPSO. A spill between 100,000 and 500,000 bbl represents a major loss from the shuttle tanker due to a collision or explosion. A spill greater than 500,000 bbl represents a major loss from the FPSO due to a collision or explosion.

A comparison with published information for the frequency of large spills from transportation is shown on Fig. 3.6. Anderson and LaBelle (1994) report frequencies for spills greater than 1,000 bbl in size from pipelines and tankers. Their frequencies were estimated using spill data from offshore operations in the United States between the years 1974 and 1992. They report their frequency on the basis of the volume produced. In order to develop Fig. 3.6, this frequency has been converted to an annual frequency for the study systems using the total volume of oil produced in the 20-year lifetime for each system.

The estimated frequency for the Hub/Host Jacket is comparable to that from Anderson and LaBelle (Fig. 3.6). This result is reasonable since the pipeline from the Hub/Host Jacket is representative of the conventional, shallow-water pipelines that are in the Anderson and LaBelle data set. However, the estimated frequencies for the Spar and TLP study systems are less than those obtained from Anderson and LaBelle (Fig. 3.6). The primary reason for this difference is explained with Fig. 3.7. The Anderson and LaBelle frequency for pipeline spills is proportional to the volume produced. However, the potential for spills from pipelines in the CRA study was related to the length of the pipeline and the time of exposure, not the volume of throughput.

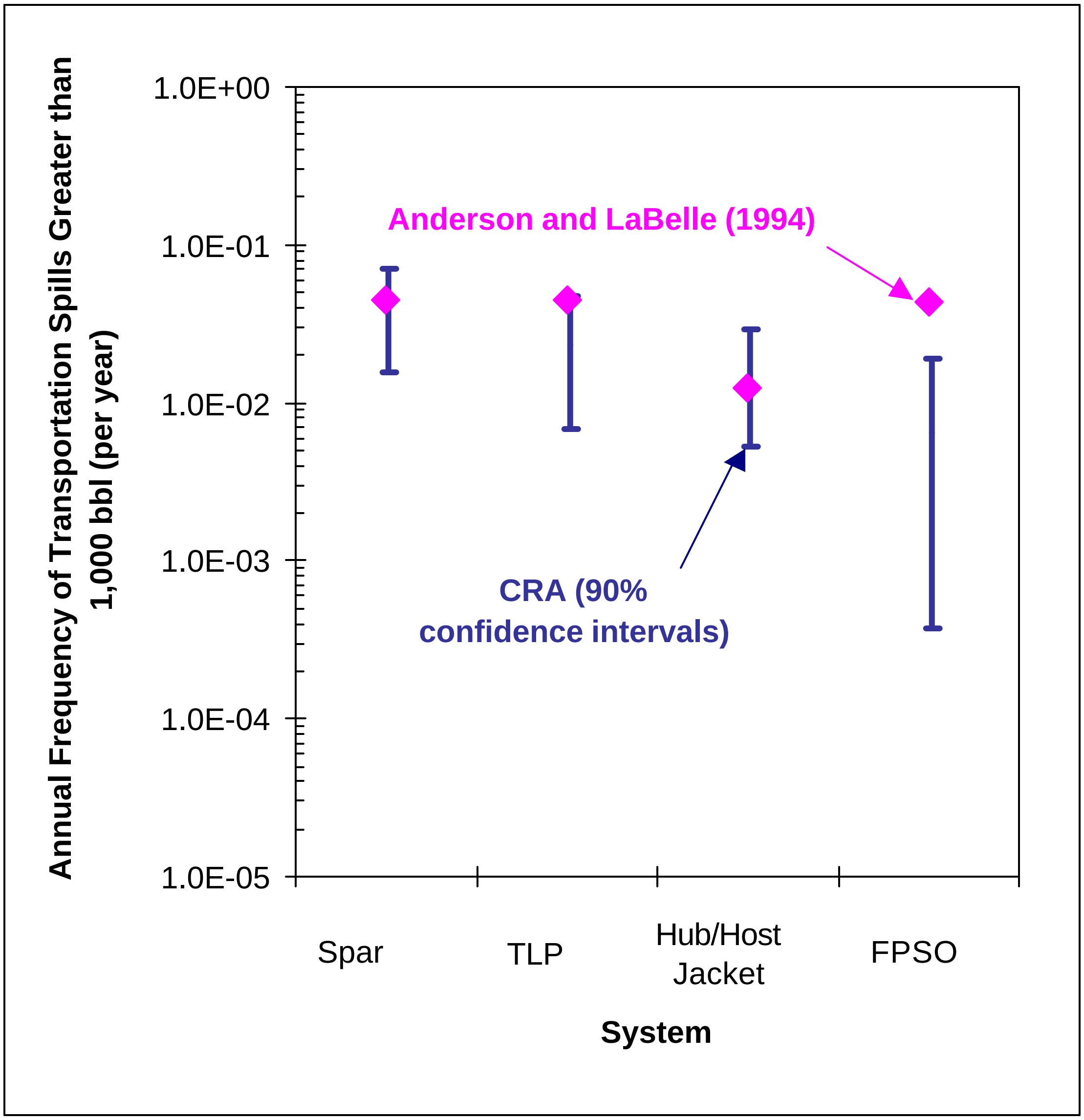


Fig. 3.6 Comparison of Transportation Spill (>1,000 bbl) Frequencies with Published Data

The estimated frequency for the FPSO is lower than that from Anderson and LaBelle (Fig. 3.6). This result is due to the different data sets used to estimate the frequency. The Anderson and LaBelle data set extends back to 1974, and includes data from all U. S. coastal and offshore waters. In the CRA project, data before 1992 were discarded due to the implementation of the Oil Pollution Act of 1990 (OPA '90), which improved operating procedures on tankers and probably reduced the frequency of spills. Data for crude oil tankers in the Gulf of Mexico are summarized in Table 3.2 to support the hypothesis that data prior to the passage of OPA '90 are not representative of existing conditions. In addition, data from outside of the Gulf of Mexico were not applied directly in the CRA project to estimate the shuttle tanker risk in the Gulf of

Mexico. An analysis of tanker spills from 1992 to 1999 indicates that frequencies of spills between 50 and 5,000 bbl and of spills greater than 5,000 bbl in the Gulf of Mexico are approximately 40 percent of those for the rest of the world (Appendix F). Tanker spills are considered to be less likely on average in the Gulf of Mexico than in the rest of the world for the following reasons, in order of importance:

1. The regulatory environment in the Gulf of Mexico is more restrictive;
2. The environmental conditions in the Gulf of Mexico are less severe;
3. The consequences of grounding are significantly less due to the lack of rocky coasts in the Gulf of Mexico;
4. Shuttle tankers used in the Gulf of Mexico have a smaller parcel size on average;
5. The Gulf of Mexico has less congested waterways on average; and
6. Newer vessels are used in the Gulf of Mexico due to recent federal regulations.

Table 3.2 Summary of Oil Spills from Crude Tankers in Gulf of Mexico

| Year | Number of Spills[1] | | | | | Volume Spilled[1] (bbl) |
|---|---|---|---|---|---|---|
| | 1-10 bbl | 10-100 bbl | 100-1,000 bbl | 1,000-10,000 bbl | 10,000-100,000 bbl | |
| **1985** | 0 | 1 | 0 | 0 | 0 | 30 |
| **1986** | 2 | 1 | 0 | 0 | 0 | 28 |
| **1987** | 4 | 0 | 0 | 0 | 0 | 5 |
| **1988** | 5 | 1 | 0 | 0 | 1 | 15,401 |
| **1989** | 3 | 1 | 2 | 0 | 0 | 1,146 |
| **1990** | 7 | 2 | 1 | 0 | 0 | 266 |
| **1991** | 5 | 0 | 0 | 0 | 0 | 17 |
| **Sub-Total** | **26** | **6** | **3** | **0** | **1** | **16,893** |
| **1992** | 0 | 0 | 0 | 0 | 0 | 0 |
| **1993** | 2 | 1 | 1 | 0 | 0 | 191 |
| **1994** | 2 | 0 | 0 | 0 | 0 | 8 |
| **1995** | 0 | 0 | 1 | 0 | 0 | 179 |
| **1996** | 0 | 0 | 0 | 0 | 0 | 0 |
| **1997** | 1 | 0 | 0 | 0 | 0 | 2 |
| **1998** | 1 | 1 | 0 | 0 | 0 | 22 |
| **1999** | 1 | 0 | 0 | 0 | 0 | 9 |
| **Sub-Total** | **7** | **2** | **2** | **0** | **0** | **411** |

[1]Note: Data from USCG (1999).

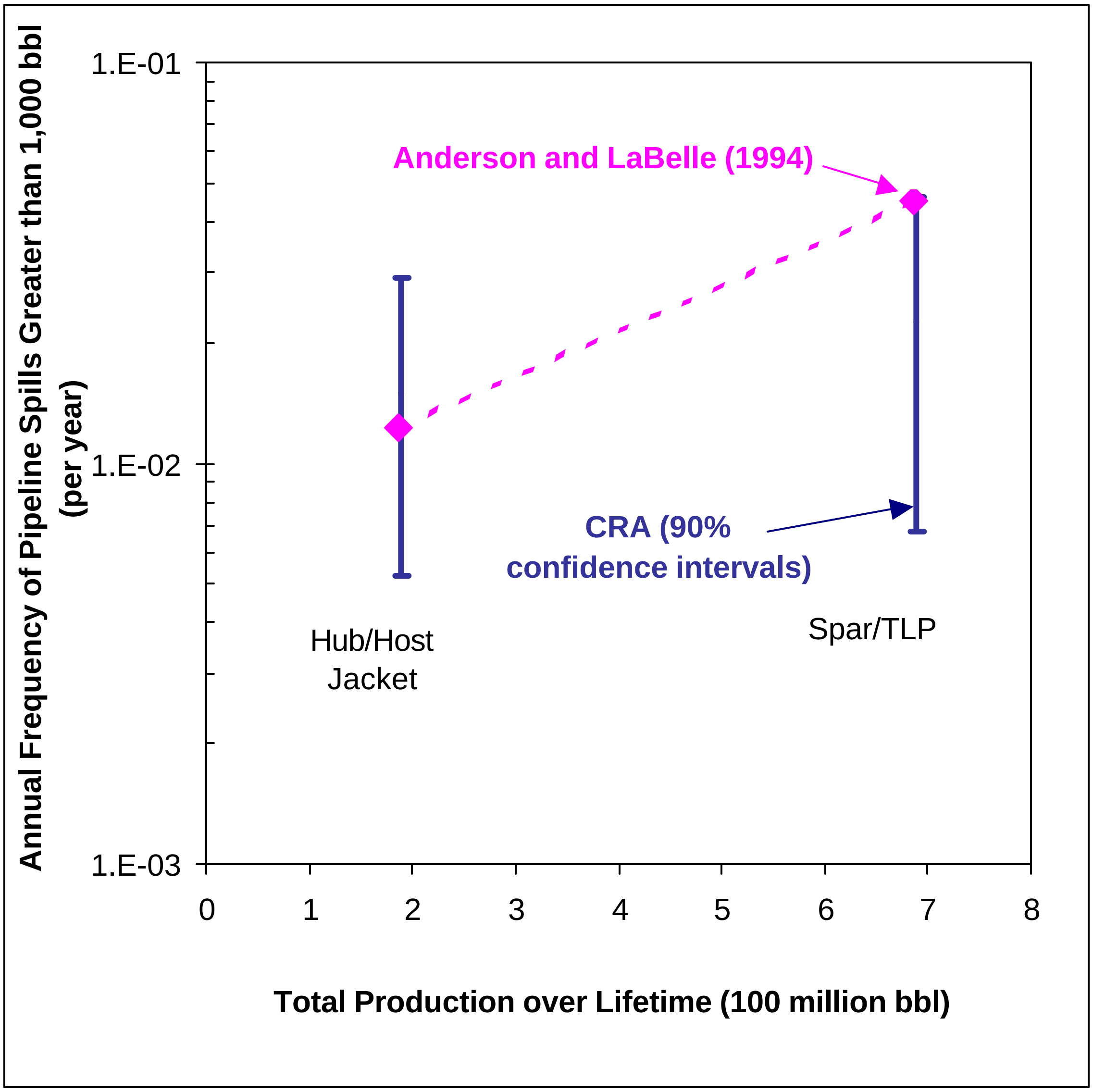


Fig. 3.7 Comparison of Pipeline Spill Frequencies with Published Data

#### 3.2.1.3 Frequencies of Spills from All Sources

The annual frequencies for spills from all sources, including production and transportation, are shown on Fig. 3.8 for each of the study systems. To help in interpreting this figure, the relative contributions of production and transportation to the total frequencies are shown on Figs. 3.9 and 3.10. The frequencies for spills are generally dominated by production-related spills for spill sizes up to 1,000 bbl and by transportation-related spills for spill sizes greater than 1,000 bbl. Therefore, the similarities and differences among the study systems are related to those for production for spills less than 1,000 bbl (Fig. 3.3) and to those for transportation for spills greater than 1,000 bbl (Fig. 3.5). Note that the Spar and TLP are indistinguishable for all spill sizes.

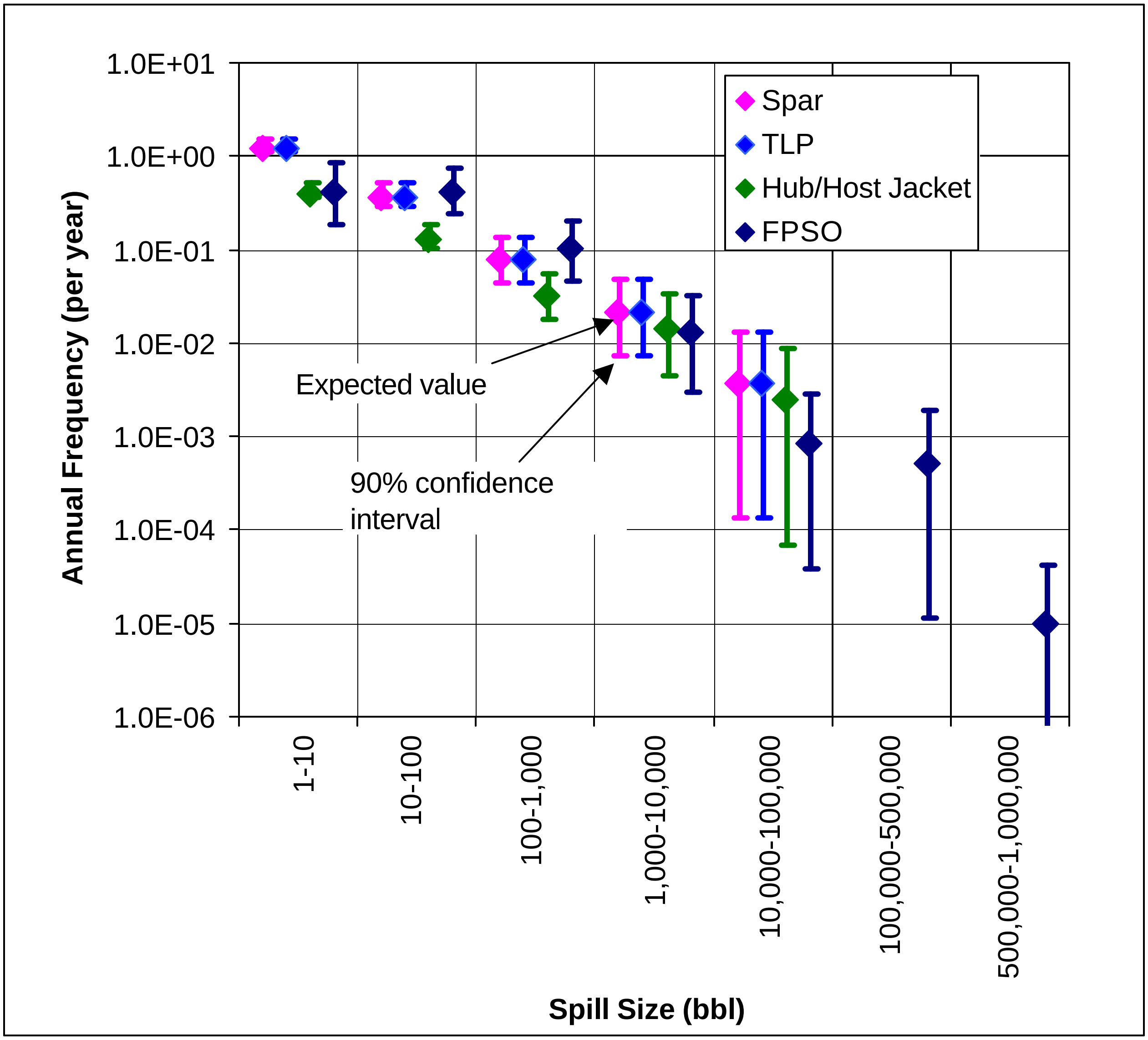


Fig. 3.8 Annual Frequency for Spills from All Sources versus Spill Size

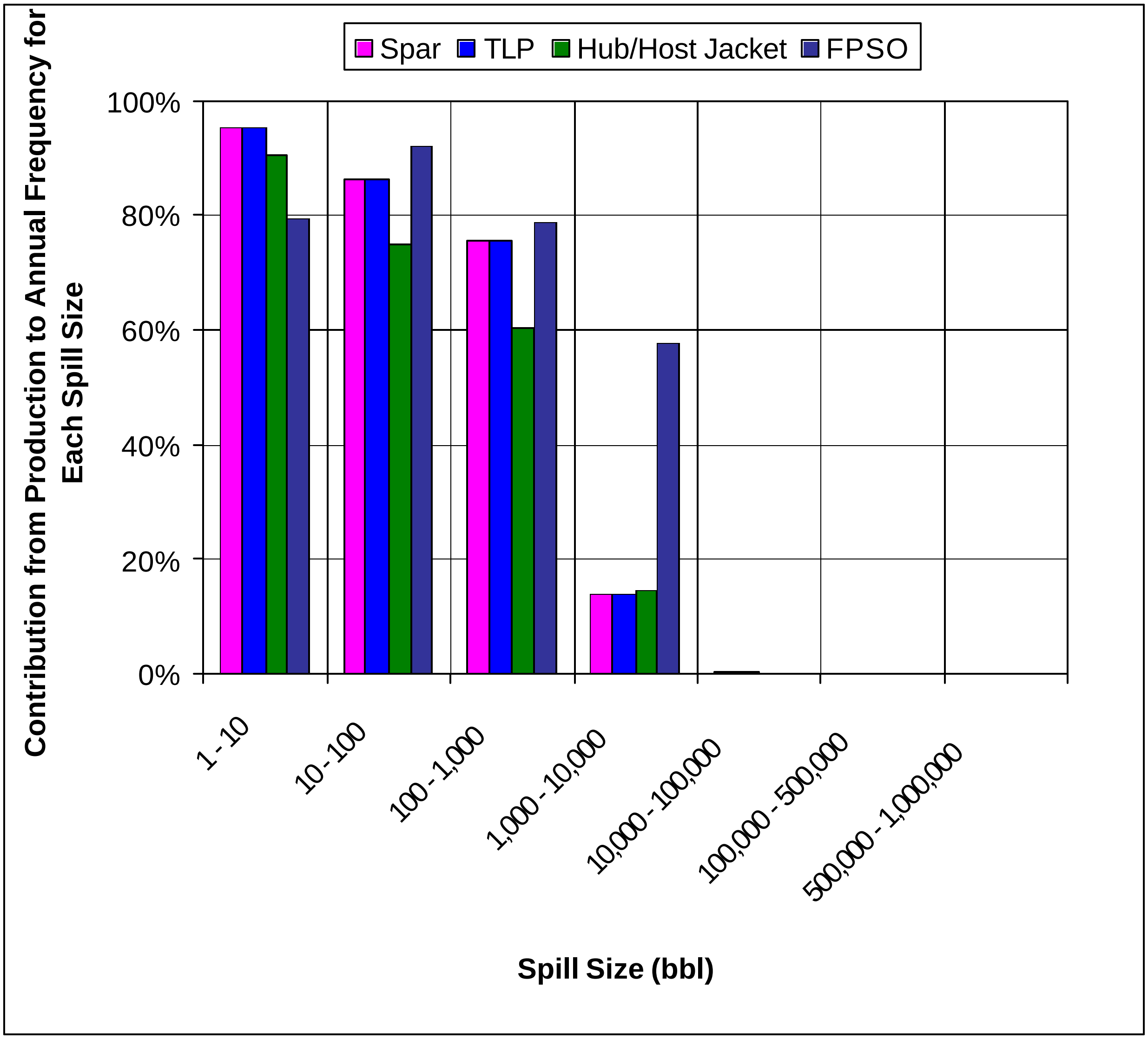


Fig. 3.9 Contribution of Production to Annual Frequency for Each Spill Size

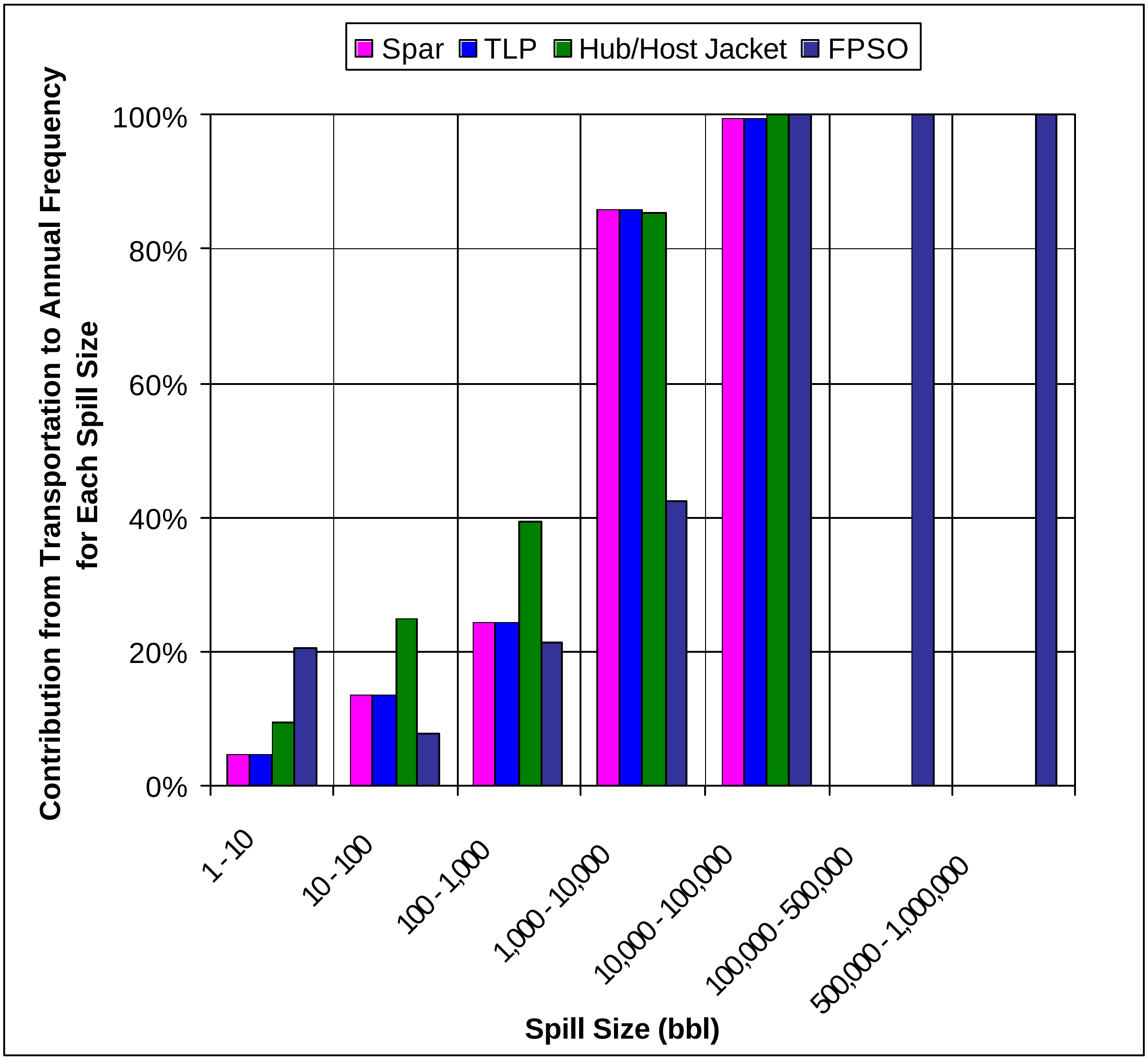


Fig. 3.10 Contribution of Transportation to Annual Frequency for Each Spill Size

### 3.2.2 Total Volume of Oil Spilled over Lifetime

Results for the average total volume are shown on Fig. 3.11 for each study system. These results indicate that the systems provide very comparable risks. The risk for the Hub/Host Jacket is slightly smaller than the risks for the other systems because it has a smaller production rate and a shorter transportation distance to the shore. The risks for all of the deepwater systems (Spar, TLP and FPSO) are nearly identical even though the frequencies for different spill sizes are not identical (Fig. 3.8). This result occurs because the risk is a measure of both frequency and consequence (spill size). While very large spills (greater than 100,000 bbl) are more likely with the FPSO than with the Spar or TLP, the annual frequencies are still small. Furthermore, the frequencies for spills less than 100,000 bbl for the FPSO are generally smaller than those for the TLP or Spar (Fig. 3.8). Therefore, the risks for the Spar, TLP and FPSO are comparable.

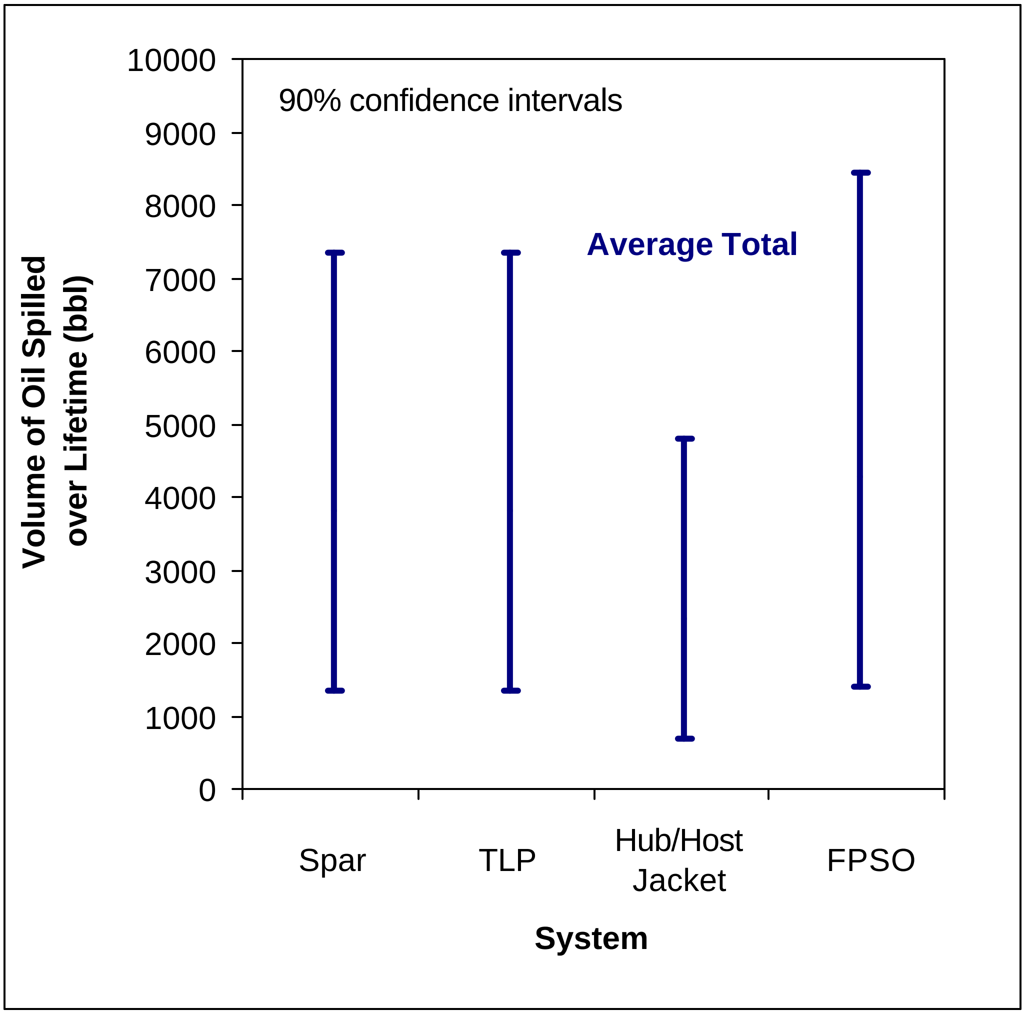


Fig. 3.11 Average Total Volume of Oil Spilled over Lifetime – All Sources

In order to facilitate interpretation of the results on Fig. 3.11, the relative contribution of each spill-category to the total volume spilled is shown on Fig. 3.12. Note that the chronic environmental risk is dominated by large spills (greater than 1,000 bbl), which are low frequency but high consequence events. Therefore, most of the systems in a fleet of study systems will have small volumes of oil spilled. Occasionally, one of the systems may have a large spill and this large spill will dominate the average for the fleet. To emphasize this point, Table 3.3 summarizes the expected time between spills of different sizes for each of the study systems. Note that most of the risk for the Spar and TLP study systems comes from spills between 10,000 and 100,000 bbl, which are only expected approximately once every 600 years of operation. Furthermore, most of the risk for the FPSO study system comes from spills between 100,000 and 500,000 bbl, which are only expected once every 4,500 years of operation. Table 3.3 and Fig. 3.12 show how the contributions to the risks for the Spar and TLP versus those for the FPSO are different even though the resulting risks are comparable (Fig. 3.11).

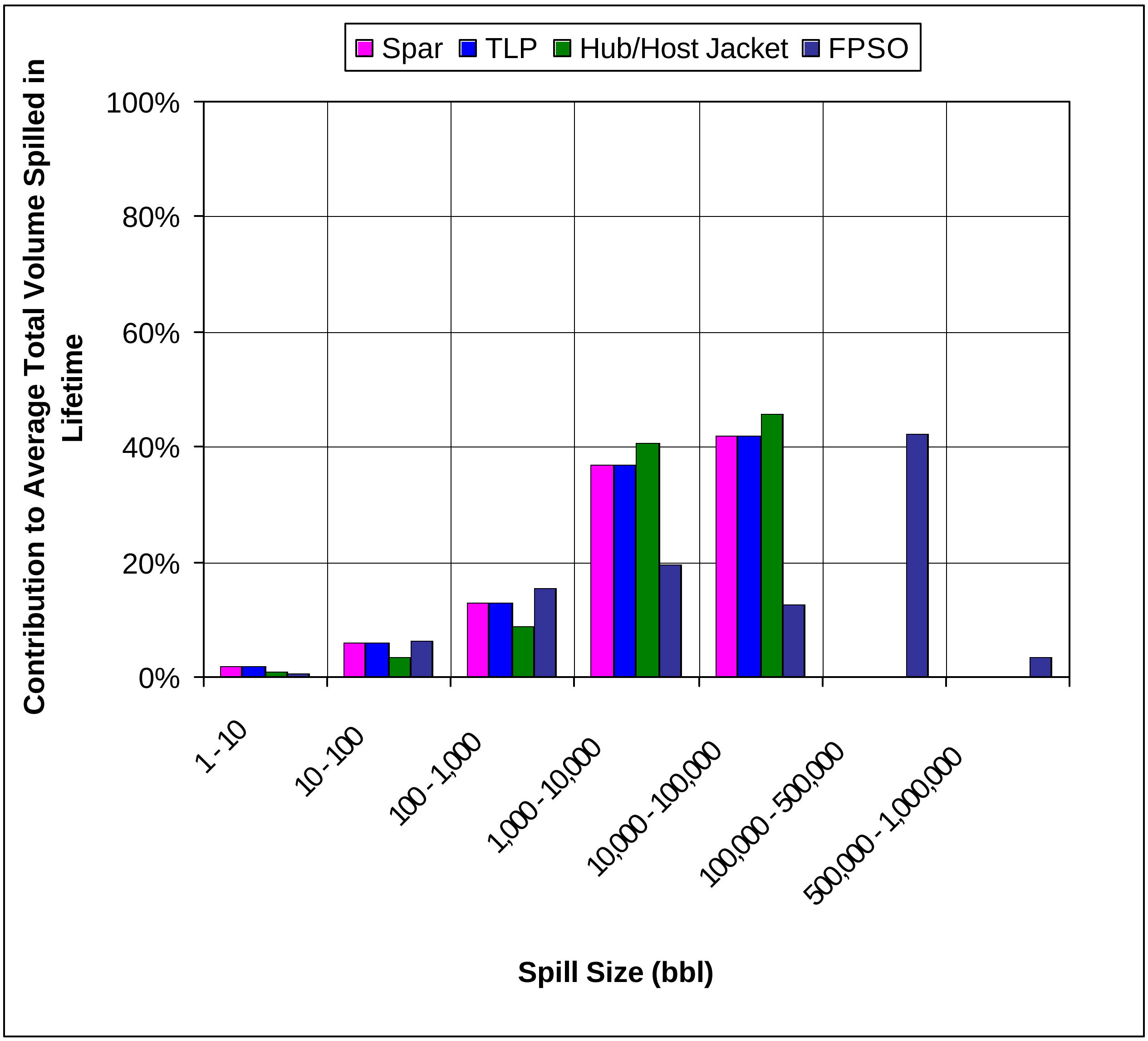


Fig. 3.12 Contribution to Average Total Spill Volume versus Spill Size

Table 3.3 Expected Return Periods for Spills

| | Expected Return Period between Spills (years) | | | | | | |
|---|---|---|---|---|---|---|---|
| System | 1 – 10 bbl | 10 – 100 bbl | 100 - 1,000 bbl | 1,000 - 10,000 bbl | 10,000 - 100,000 bbl | 100,000 - 500,000 bbl | 500,000 - 1,000,000 bbl |
| Spar | 0.8 | 3 | 15 | 60 | 580 | Not Credible | Not Credible |
| TLP | 0.8 | 3 | 15 | 60 | 580 | Not Credible | Not Credible |
| Hub/Host Jacket | 3 | 8 | 35 | 91 | 920 | Not Credible | Not Credible |
| FPSO | 3 | 3 | 12 | 110 | 2,500 | 4,700 | 300,000 |

One effect of the spill risk being dominated by rare, high consequence events is that the confidence intervals in the predicted average oil spill volumes range over nearly an order of magnitude (Fig. 3.11). This uncertainty reflects the typically limited quantity and quality of historical data available to estimate frequencies for rare events. Note that the confidence interval for the FPSO is wider than those for the other systems (Fig. 3.11) because there are relatively fewer data available for FPSO's in the Gulf of Mexico and because the FPSO risk is dominated by very rare events with expected return periods of approximately 4,500 years.

The contributions to the total oil spill risk from different sub-systems are shown on Figs. 3.13 through 3.15. Production, which dominates the smaller spill sizes (Fig. 3.3), does not contribute substantially to the total risk (Fig. 3.13). The main contributor to oil spills from production are related to the processing facilities (topsides on Fig. 3.15). Transportation, which dominates the larger spill sizes (Fig. 3.5), is the main contributor to the total oil spill risk (Fig. 3.14). The main contributors to oil spills from transportation are pipelines and shuttle tankers (Fig. 3.15).

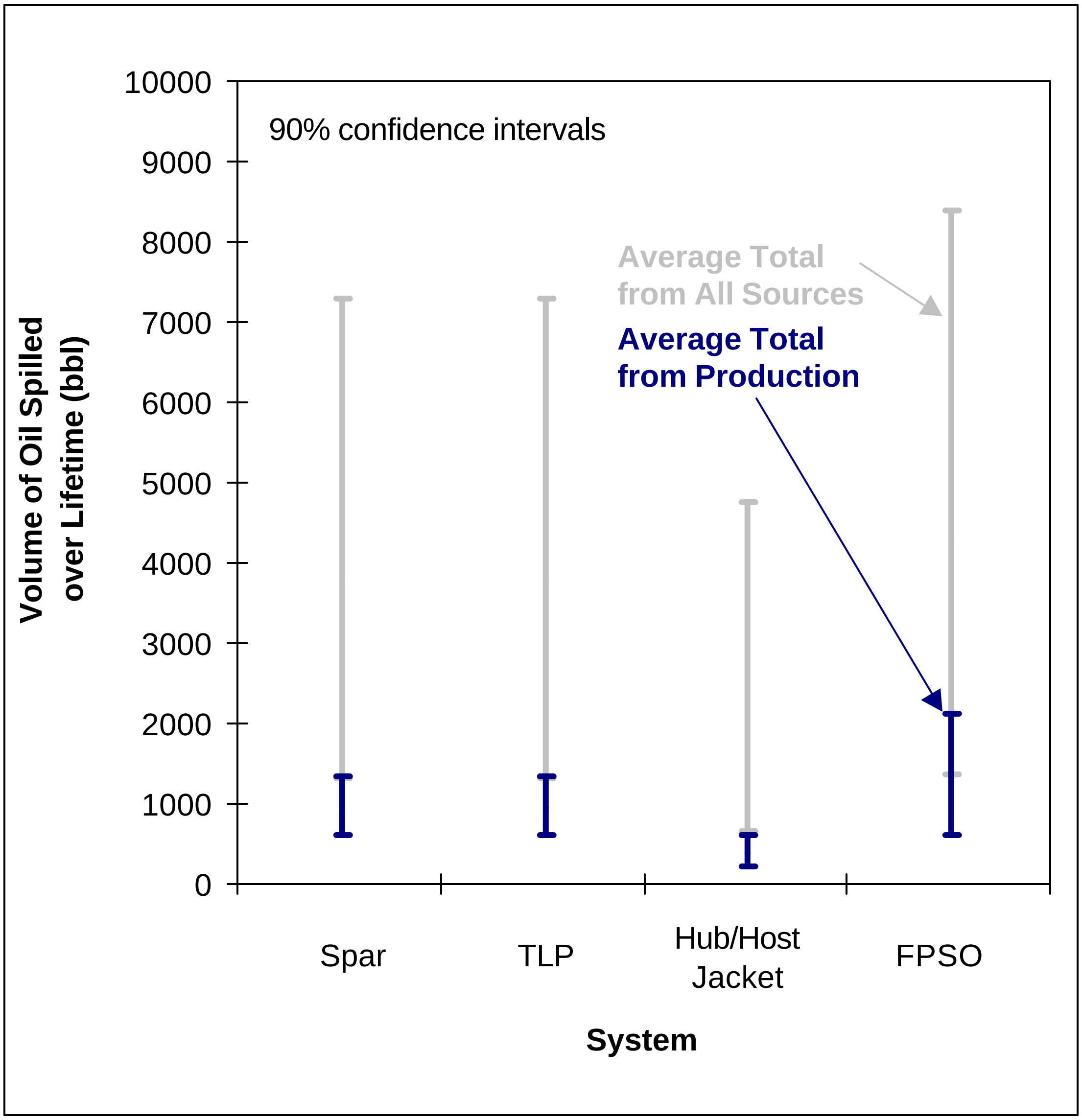


Fig. 3.13 Average Total Volume of Oil Spilled over Lifetime – Production Sources

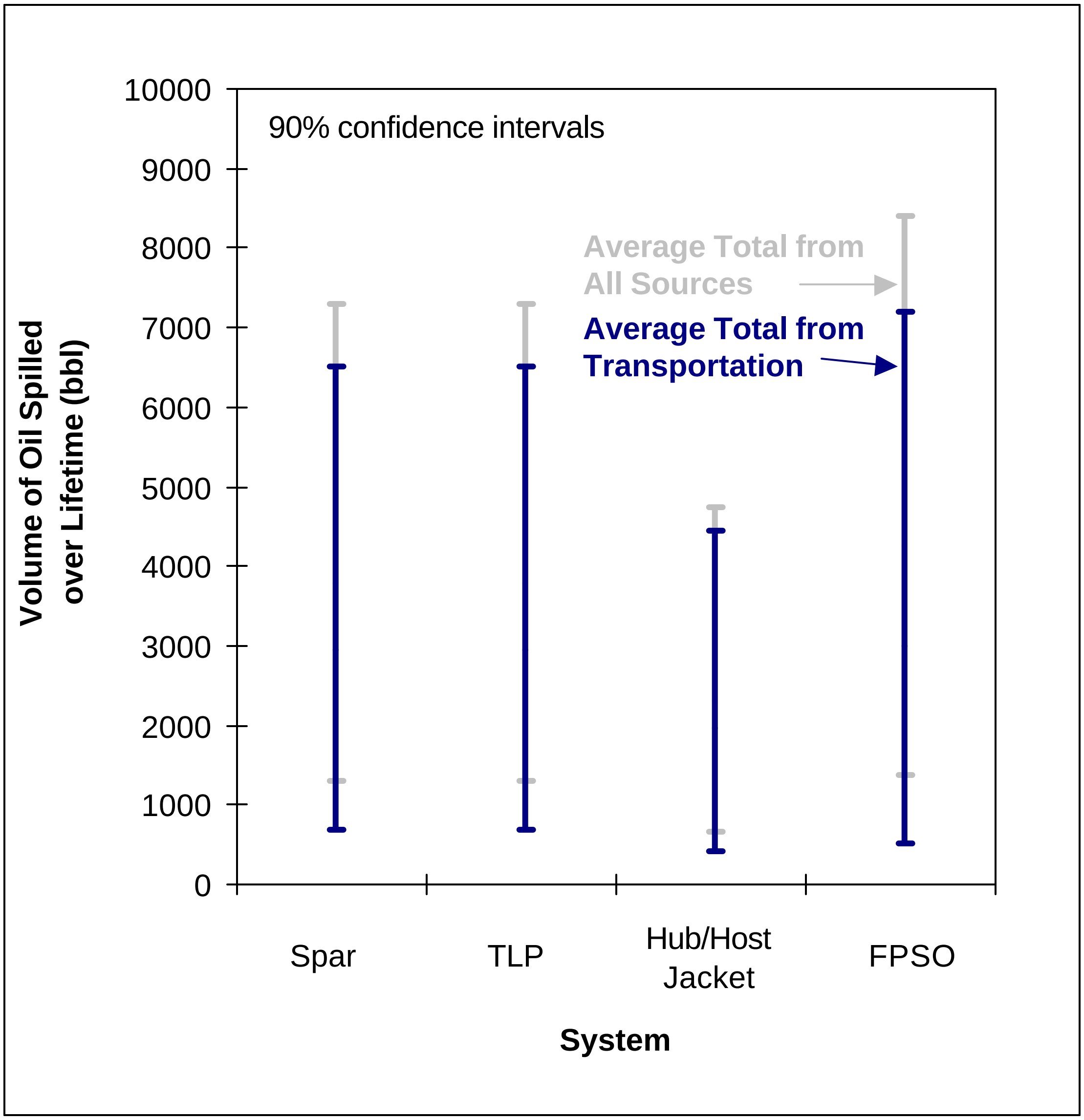


Fig. 3.14 Average Total Volume of Oil Spilled over Lifetime – Transportation Sources

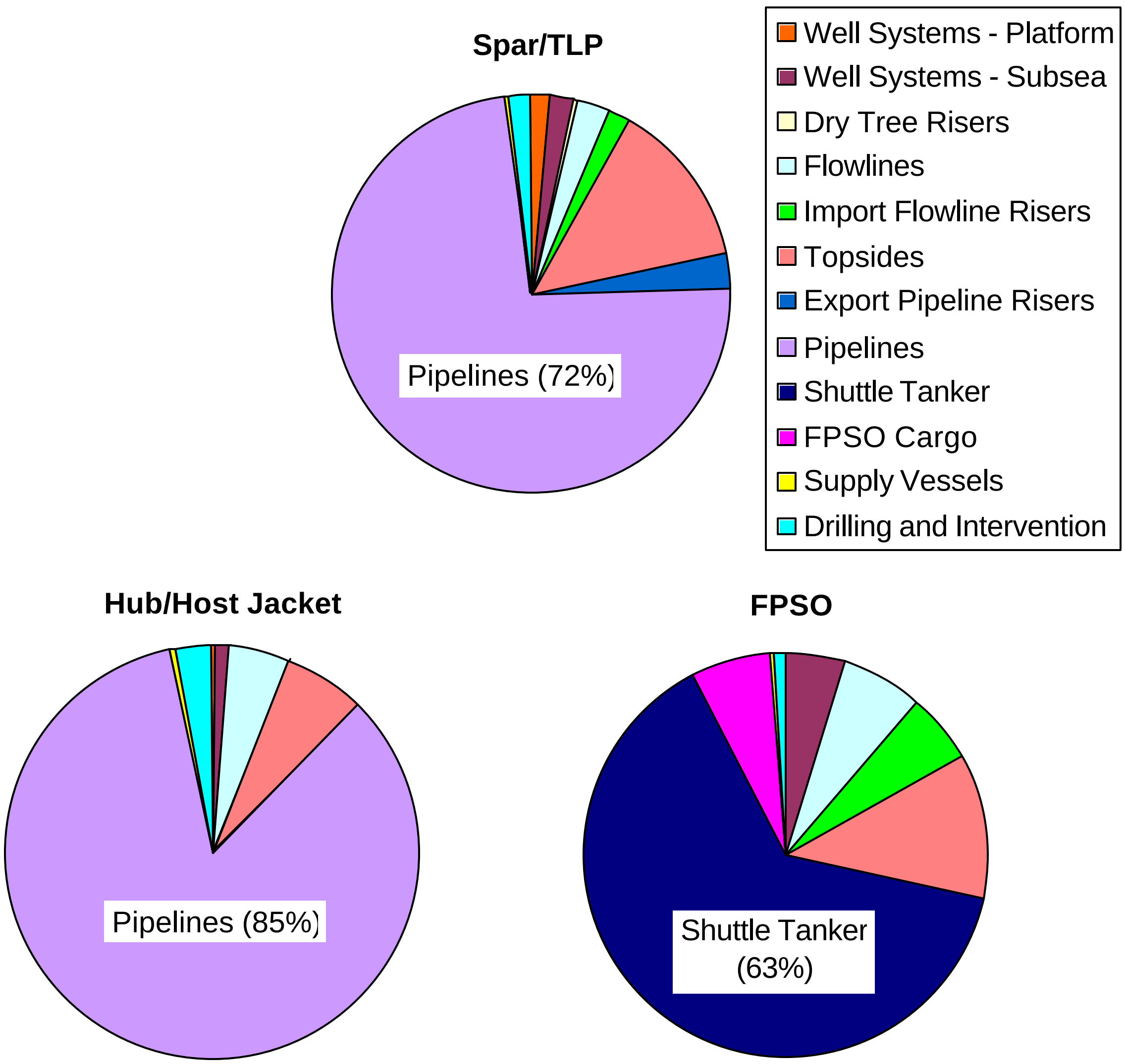


Fig. 3.15 Contribution to Average Total Spill Volume versus Spill Source

### 3.2.3 Maximum Single Oil Spill in Lifetime

Results for the average single maximum spill are shown on Fig. 3.16 for each study system. The results indicate that the risks for the different study systems are comparable. Furthermore, these results emphasize that the maximum spill volume from a single incident dominates the average total spill volume. The relative contribution of the maximum spill to the total spill volume is shown on Fig. 3.17, indicating that more than 70 percent of the total is expected to come from a single incident. Finally, the confidence intervals on Fig. 3.16 reflect the uncertainty inherent in estimating frequencies for rare events.

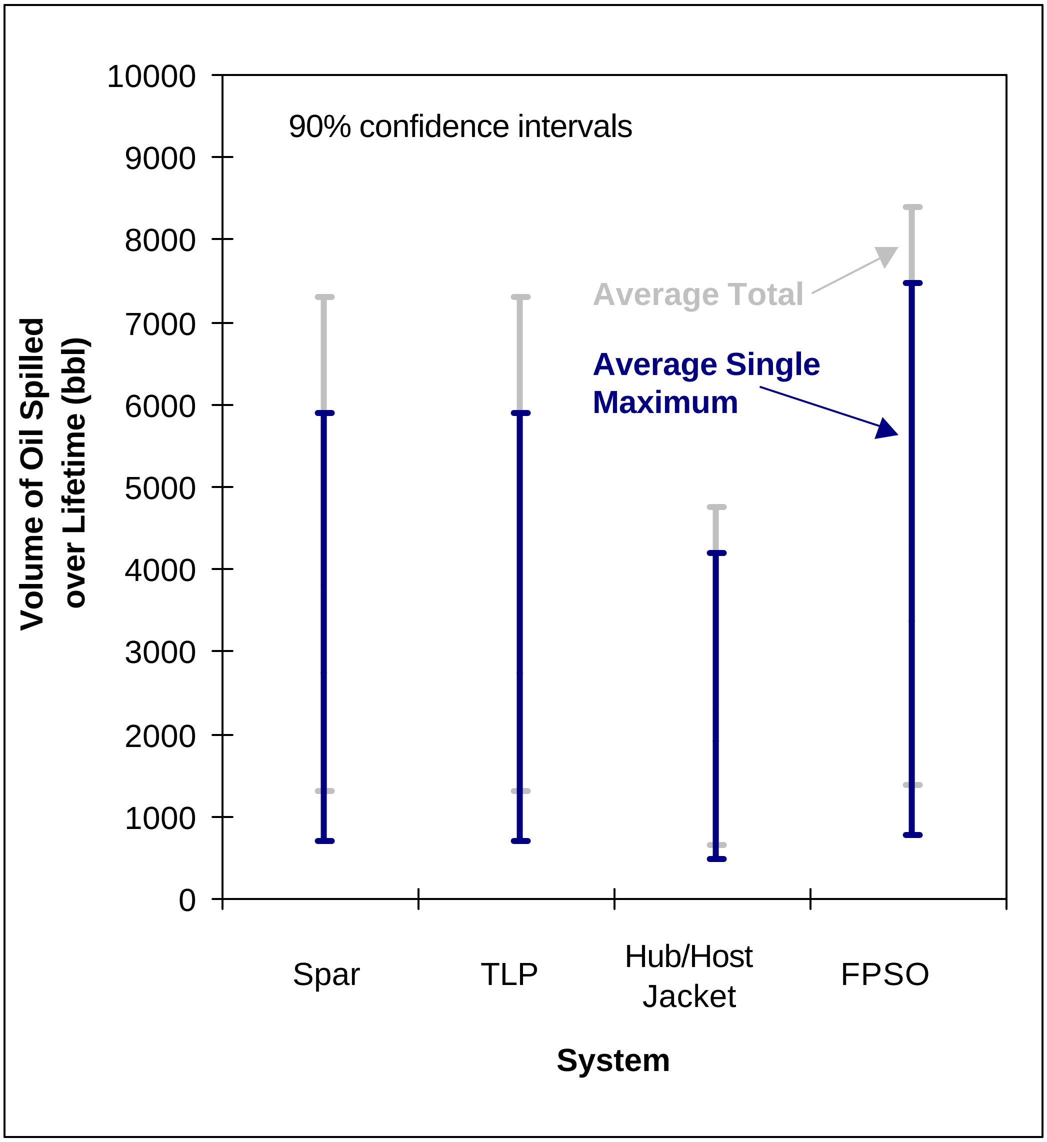


Fig. 3.16 Average Maximum Volume Spilled from a Single Incident in the Lifetime

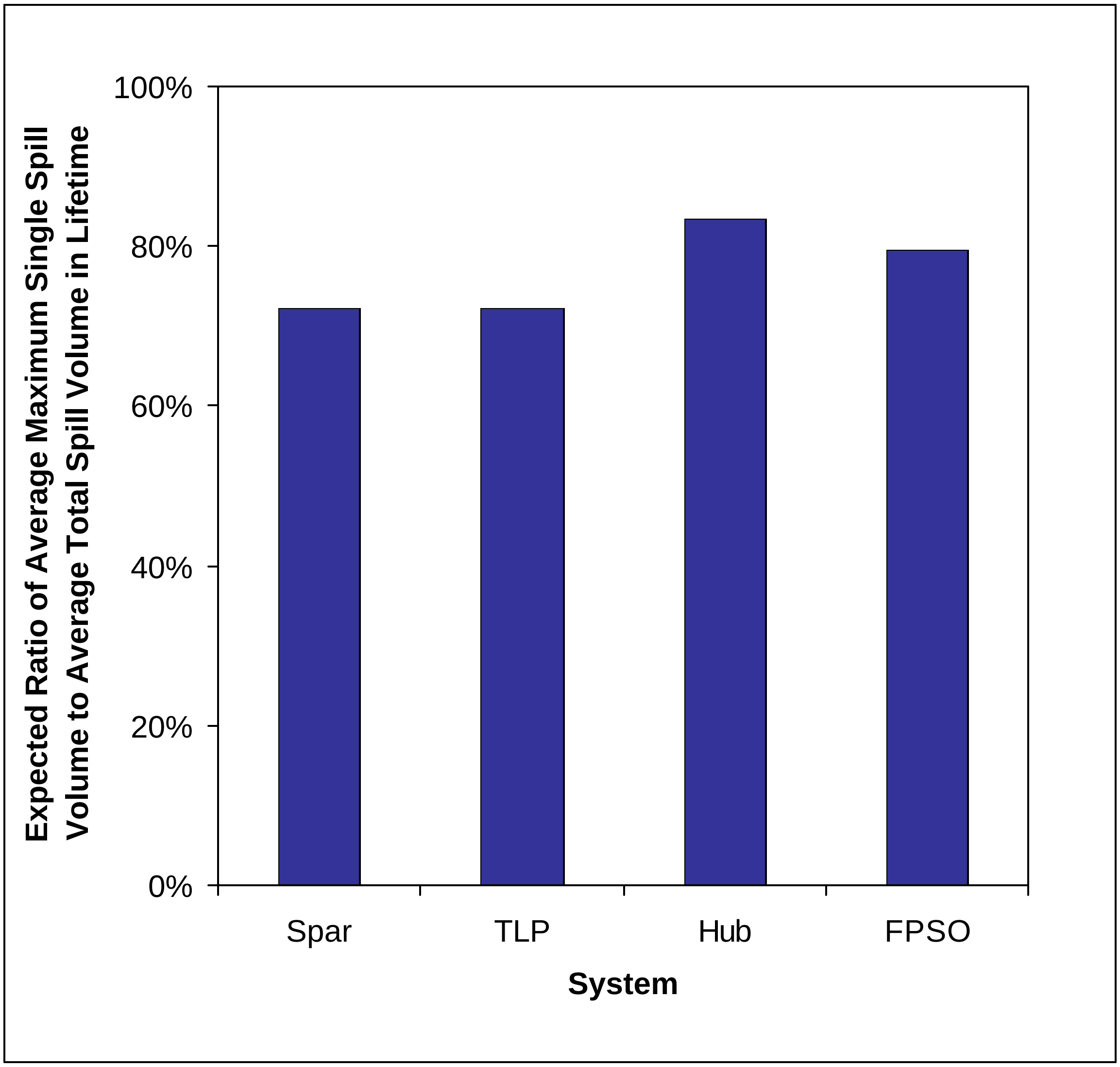


Fig. 3.17 Contribution of Maximum Spill Volume to Total Spill Volume

### 3.3 Summary

The quantitative risk results for oil spill and fatalities that were presented in this section lead to the following major conclusions:

1. There are no significant differences in the fatality risks among the four study systems.
2. There are no significant differences in the oil-spill risks among the four study systems.
3. The average total volume of oil spilled during the facility lifetime will be dominated by rare, large spills rather than frequent, small spills.
4. The major contribution to the oil spill risks for all systems is the transportation of oil

from the production facility to the shore terminal by either pipelines or shuttle tankers. Spill risks for pipelines and shuttle tankers are comparable, although the frequencies and sizes of possible spills are different for pipelines versus shuttle tankers. The spill risks for pipelines are dominated by the possibility of spills between 10,000 and 100,000 bbl in size that are expected to occur once every 600 years on average. The spill risks for shuttle tankers are dominated by the possibility of spills between 100,000 and 500,000 bbl in size that are expected to occur on average once every 4,500 years.

5. The confidence intervals in predicted oil spill volumes range over about an order of magnitude, reflecting the limited quantity and quality of historical data available to estimate frequencies for rare events.

## 4. CONCLUSIONS AND RECOMMENDATIONS

A quantitative risk analysis was performed to assess and compare oil spill and fatality risks for four representative deepwater production systems in the Gulf of Mexico. Three of the study system types have already been operated successfully in the Gulf of Mexico: two floating production systems in deepwater with oil pipelines, a Spar and a Tension Leg Platform (TLP); and a shallow-water jacket serving as a hub and host to deepwater production. One of the study system types has not been used in the Gulf of Mexico: a tanker-based Floating Production Storage and Offloading (FPSO) system with oil transportation to shore via shuttle tankers. The objective of this analysis was to understand and compare the risks of the FPSO with those for currently acceptable alternatives for deepwater production.

Conceptual system descriptions that are representative of existing and typical technology in the Gulf of Mexico were developed for the four systems. The scope of these descriptions included the entire production systems and operations from the wells through the transport of product to the shore.

Three risk measures were assessed and analyzed for each system: the total number of fatalities in a 20-year production life as a measure of the human safety risk, the total volume of oil spilled in a 20-year production life as a measure of the chronic environmental risk, and the maximum volume spilled in a single incident in a 20-year production life as a measure of the acute environmental risk. The process of developing the conceptual descriptions for the systems and then evaluating the risks has drawn on expertise from all facets of oil and gas production, including operators, contractors, manufacturers, class societies and regulators.

### 4.1 Conclusions

The following major conclusions have been drawn from the results of this analysis:

1. There are no significant differences in the fatality risks among the four study systems.
2. There are no significant differences in the oil-spill risks among the four study systems.

3. The average total volume of oil spilled during the facility lifetime will be dominated by rare, large spills rather than frequent, small spills.

4. The major contribution to the oil spill risks for all systems is the transportation of oil from the production facility to the shore terminal by either pipelines or shuttle tankers. Spill risks for pipelines and shuttle tankers are comparable, although the frequencies and sizes of possible spills are different for pipelines versus shuttle tankers. The spill risks for pipelines are dominated by the possibility of spills between 10,000 and 100,000 bbl in size that are expected to occur once every 600 years on average. The spill risks for shuttle tankers are dominated by the possibility of spills between 100,000 and 500,000 bbl in size that are expected to occur on average once every 4,500 years.

5. The confidence intervals in predicted oil spill volumes range over about an order of magnitude, reflecting the limited quantity and quality of historical data available to estimate frequencies for rare events.

Therefore, the expected risks associated with the FPSO are comparable to those for already accepted alternatives for deepwater production, including a Spar, a TLP and a shallow-water jacket serving as a hub and a host to deepwater production.

### 4.2 Recommendations

The following recommendations have been developed from this work:

1. The results from this study should be periodically updated because they provide a valuable baseline for future analyses of risk in the Gulf of Mexico. The three measures of risk used in this study can all be readily measured and tracked for new and existing deepwater production facilities in the Gulf of Mexico.

2. The quality of existing data sets for the Gulf of Mexico should be improved so that they are of greater value in future risk analyses. First, the type and quality of data that are currently collected should be evaluated, and any changes recommended from this evaluation should be implemented in a timely manner. Second, single agencies should be responsible for tracking and compiling similar types of data. Third, all data records should be reviewed annually by the industry and regulators to improve the clarity, quality

and usefulness of the information in these records. Finally, the data should be published annually in a clear and an easily accessible format.

3. Additional information about the populations of offshore facilities and operations in the Gulf of Mexico should be collected on an annual basis. Specifically, the following information from federal and state waters in the Gulf of Mexico would be valuable: the length of active pipelines operating per year, the number of tanker on-loading and off-loading events in ports and lightering zones per year, and the number of man-hours in production-related activities, supply vessel operations and tanker operations per year.

4. Uncertainty in the predicted performance for these four study systems should be considered carefully in drawing conclusions from and applying the results from this study.

5. The process used on this project to assess risks has been effective in obtaining valuable technical information from industry and regulators, and should be considered in supporting other analyses of new technology in the Gulf of Mexico.

## 5. ACKNOWLEDGMENTS

The authors wish to acknowledge the Minerals Management Service for funding this project. Specific individuals at MMS who have been instrumental in this study are Paul Martin, Charles Smith, James Regg and Cheryl Anderson. In addition, the following individuals have played key roles in the project: Professor Larry Lake and Research Assistant Jihad Jaber, The University of Texas at Austin; Joe Gebara, EQE International; Lieutenant Commander Bill Daughdrill and Joe Myers, United States Coast Guard; and Allen Verret, Private Consultant. Finally, the Deepstar Consortium has been instrumental in coordinating and facilitating the involvement of industry experts on workshop teams.

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Appendix A

Glossary of Major Technical Terms Used in System Descriptions

Table A.1 Glossary of Major Terms Used in System Descriptions

| Word | Definition |
|---|---|
| Docking Call | A call by a tanker or a supply vessel at a port or a production facility to transfer cargo either to or from the vessel. |
| Flowline | Piping transporting oil and gas from a subsea tree to a host platform. |
| Host | A facility that processes production from a subsea well system. |
| Hub | A facility that passes, lifts and/or processes throughput from other platforms to the shore terminal. |
| Import/Export Riser | Riser taking import flow from a flowline at the mudline to the floating production system at the surface or export flow from the floating production system to a pipeline at the mudline. |
| Jumper | Flexible or fixed piping used to connect subsea well system components (manifolds, trees, flowlines). |
| Pipeline | Piping transporting oil or gas from platform to the shore terminal. |
| Platform Well System | Well casings and perforations connected to surface trees, manifold and control system. |
| Process Equipment | The equipment used to separate oil and gas, de-water oil and gas, treat water, and meter oil and gas, pump oil and compress gas. |
| Product Swivel | A coupling between a geo-stationary flowline and rotating flowline on the FPSO that allows fluids to be transferred to or from the subsea wells. A number of these fluid couplings may be vertically stacked to accommodate multiple flowlines. |
| Dry Tree Riser | Riser surrounding and protecting production tubing from mudline to surface tree on a floating production system. Production tubing is exposed to reservoir pressure. |
| Shuttle Tanker | A tanker used to offload oil from an offshore production facility, transport the oil to the shore terminal, and discharge the oil to the shore terminal. |
| Subsea Manifold | Arrangement of valves, pipes and fittings to gather production fluids from multiple subsea trees and direct it into a fewer number of flowlines. |
| Subsea Tree | Arrangement of valves, pipes, sensors, fittings and connections to monitor and control production flow and pressure on top of a well at the mudline. Tree is exposed to reservoir pressure. |
| Subsea Well System | Well casings and perforations connected to subsea trees, and subsea manifold and control system. |
| Surface Tree | Arrangement of valves, pipes, sensors, fittings and connections to monitor and control production flow and pressure at the top of the production tubing on the platform deck. Tree is exposed to reservoir pressure. |
| Turret | A two-part, generally circular structure that allows the vessel to weathervane in response to winds, waves and currents. The earth-fixed part is connected to the mooring lines, and the vessel-fixed part is attached to the hull of the FPSO. The two parts are then allowed to rotate with respect to each other by means of one or more sets of lubricated bearings. |
| Umbilical | Bundled arrangement of tubing, piping and electrical conductors to transmit control fluid and electrical signals to a subsea well system. |

Appendix B

List of Workshop and Interview Participants

**Table B.1.1 Participants in Workshop #1 - Hub, November 11, 1999**

| Participant | Affiliation |
|---|---|
| Malcolm Sharples | ABS |
| Dirceu Botelho | Chevron |
| Allen Verrett | Deepstar |
| Andy Wolford | EQE |
| Joe Gebara | EQE |
| Tracy Johnson | EQE |
| Marty Krafft | FMC/SOFEC |
| Cyril Arney | Marathon Oil |
| Charles Smith | MMS |
| Jim Regg | MMS |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Jim Seery | Oxy USA |
| Ken Arnold | Paragon |
| Sandeep Khurana | Paragon |
| Bob Andring | SIEP/Shell |
| Chuck White | Statoil |
| Dave Wisch | Texaco |

**Table B.1.2 Participants in Workshop #1 - FPSO, November 15, 1999**

| Participant | Affiliation |
|---|---|
| Kent Dangtran | ABS |
| Malcolm Sharples | ABS |
| Dick Ingels | Chevron |
| Chuck Steube | Conoco |
| Allen Verrett | Deepstar |
| Chris Harper | DNV |
| Andy Wolford | EQE |
| Joe Gebara | EQE |
| Tracy Johnson | EQE |
| Brett Wilson | Exxon |
| David Jones | FMC/SOFEC |
| Marty Krafft | FMC/SOFEC |
| Andrew Johnstone | Lloyd's Register |
| Charles Smith | MMS |
| Paul Martin | MMS |
| Tor Tangvald | NAVION |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Jim Seery | Oxy USA |
| Richard Hill | Paragon |
| Sandeep Khurana | Paragon |
| Jerry Young | SOFEC |
| Chuck White | Statoil |
| Alan Clarke | Texaco |
| Larry Lake | UT |

**Table B.1.3 Participants in Workshop #1 - TLP, November 16, 1999**

| Participant | Affiliation |
|---|---|
| Craig Lee | ABS |
| Kent Dangtran | ABS |
| Steve Leverette | Atlantia |
| Oriol Rijken | Atlantia |
| Allen Verrett | Deepstar |
| Chris Harper | DNV |
| Andy Wolford | EQE |
| Joe Gebara | EQE |
| Tracy Johnson | EQE |
| Brett Wilson | Exxon |
| Jack Mercier | Global Maritime |
| Andrew Johnstone | Lloyd’s Register |
| Charles Smith | MMS |
| Paul Martin | MMS |
| Tommy Laurendine | MMS |
| Kay Choate | OTRC/TAMU |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Jim Seery | Oxy USA |
| Demir Karsan | Paragon |
| Sandeep Khurana | Paragon |
| Mike Curole | Shell/SIEP |
| Chuck White | Statoil |
| Jihad Jaber | UT |

**Table B.1.4 Participants in Workshop #1 - Spar, November 17, 1999**

| Participant | Affiliation |
|---|---|
| Bob Bowie | ABS |
| Kent Dangtran | ABS |
| Steve Perryman | BPAmoco |
| Irv Brooks | Chevron |
| Allen Verrett | Deepstar |
| Remi Eriksen | DNV |
| Andy Wolford | EQE |
| Joe Gebara | EQE |
| Tracy Johnson | EQE |
| Brett Wilson | Exxon |
| Ben Poblete | Lloyd’s Register |
| Felix Dyhrkopp | MMS |
| Paul Martin | MMS |
| Kay Choate | OTRC/TAMU |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Jim Seery | Oxy USA |
| Sandeep Khurana | Paragon |
| Phil Bohlmann | Shell |
| Chuck White | Statoil |
| Jihad Jaber | UT |

**Table B.2.1 Participants in Workshop #2 - TLP, March 27, 2000**

| Participant | Affiliation |
|---|---|
| Steve Leverette | Atlantia |
| Hugh Banon | BP |
| A. J. Verret | Deepstar |
| Andy Wolford | EQE |
| Tracy Johnson | EQE |
| Andrew Johnstone | Lloyd's Register |
| Tommy Laurendine | MMS |
| Charles Smith | MMS/TMR |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Mike Curole | Shell |
| Chuck White | Statoil |
| Joe Myers | USCG - HQ |
| Bill Daughdrill | USCG D8 |
| Larry Lake | UT |

**Table B.2.2 Participants in Workshop #2 - FPSO, March 28, 2000**

| Participant | Affiliation |
|---|---|
| Malcolm Sharples | ABS |
| Dick Ingels | Chevron |
| Chuck Steube | Conoco |
| Harry Sharkis | Conoco |
| A. J. Verret | Deepstar |
| Andy Wolford | EQE |
| Tracy Johnson | EQE |
| Brian Grundmeier | Exxon/Mobil |
| W. Brett Wilson | Exxon/Mobil |
| Eric Ringle | FMC |
| David A. Jones | FMC/SOFEC |
| Andrew Johnstone | Lloyd’s Register |
| David Eggers | Mentor Subsea |
| Jim Regg | MMS |
| Tommy Laurendine | MMS |
| Charles Smith | MMS/TMR |
| Tor B. Tangrald | Navion ASA |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Jim Seery | Oxy |
| Rick Meyer | Shell |
| Chuck White | Statoil |
| Joe Myers | USCG – HQ |
| Bill Daughdrill | USCG D8 |
| Jihad Jaber | UT |
| Larry Lake | UT |

**Table B.2.3 Participants in Workshop #2 – Spar, March 29, 2000**

| Participant | Affiliation |
|---|---|
| Matt Tremblay | ABS |
| Steve Perryman | BP Amoco |
| Irv Brooks | Chevron |
| A. J. Verret | Deepstar |
| Andy Wolford | EQE |
| Tracy Johnson | EQE |
| W. Brett Wilson | Exxon/Mobil |
| Benjamin Poblete | Lloyd's Register |
| Felix Dyhrkopp | MMS |
| Charles Smith | MMS/TMR |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Phil Bohlmann | Shell |
| Francisco Noyola | SparTEC, Inc. |
| Chuck White | Statoil |
| Joe Myers | USCG - HQ |
| Bill Daughdrill | USCG D8 |

**Table B.2.4 Participants in Workshop #2 – Hub/Host Jacket, March 30, 2000**

| Participant | Affiliation |
|---|---|
| Matt Tremblay | ABS |
| Andy Wolford | EQE |
| Tracy Johnson | EQE |
| Felix Dyhrkopp | MMS |
| Charles Smith | MMS/TMR |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Bob Andring | Shell |
| Chuck White | Statoil |
| Joe Myers | USCG - HQ |
| Bill Daughdrill | USCG D8 |

**Table B.3.1 Participants in Workshop #3 – Spar, May 15, 2000**

| Participant | Affiliation |
|---|---|
| Yong Bai | ABS |
| Irv Brooks | Chevron |
| Allen Verret | Deepstar |
| Andy Wolford | EQE |
| Brett Wilson | Exxon |
| Ben Poblete | Lloyd's Register |
| Tommy Laurendine | MMS |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| James Seery | Oxy USA |
| Phil Bohlmann | Shell |

**Table B.3.2 Participants in Workshop #3 – Hub/Host Jacket, May 16, 2000**

| Participant | Affiliation |
|---|---|
| Jack Chen | ABS |
| Allen Verret | Deepstar |
| Andy Wolford | EQE |
| Tommy Laurendine | MMS |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Bob Andring | Shell |
| Dave Wisch | Texaco |
| Bill Daughdrill | USCG D8 |
| Joe Myers | USCG HQ |

**Table B.3.3 Participants in Workshop #3 – FPSO, May 17, 2000**

| Participant | Affiliation |
|---|---|
| Craig Lee | ABS |
| Mark Wang | ABS |
| Dick Ingels | Chevron |
| Tony Fantauzzi | Chevron |
| Harry Sharkis | Conoco |
| Allen Verret | Deepstar |
| Jerry Spires | DNV |
| Andy Wolford | EQE |
| Brett Wilson | Exxon |
| Brian Grundmeier | Exxon |
| David Jones | FMC/SOFEC |
| Andrew Johnstone | Lloyd's Register |
| David Eggers | McDermott |
| Charles Smith | MMS |
| Felix Dyhrkopp | MMS |
| Jim Regg | MMS |
| Tor Tangvald | Navion |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Rick Meyer | Shell |
| Chuck White | Statoil |
| Alan Clarke | Texaco |
| Bill Daughdrill | USCG D8 |
| Joe Myers | USCG HQ |
| Jihad Jaber | UT |

**Table B.3.4 Participants in Workshop #3 – TLP, May 18, 2000**

| Participant | Affiliation |
|---|---|
| Yong Bai | ABS |
| Steve Leverette | Atlantia |
| Allen Verret | Deepstar |
| Jerry Spires | DNV |
| Andy Wolford | EQE |
| Jack Mercier | Global Maritime |
| Charles Smith | MMS |
| Felix Dyhrkopp | MMS |
| Jim Regg | MMS |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Mike Curole | Shell |
| Chuck White | Statoil |
| Jihad Jaber | UT |

**Table B.4.1 Participants in Workshop #4 – FPSO, September 26, 2000**

| Participant | Affiliation |
|---|---|
| Mark Wang | ABS |
| Bill Scaife | BP |
| Dick Ingels | Chevron |
| Harry Sharkis | Conoco |
| Chuck Steube | Conoco Shipping |
| Chuck White | Consultant |
| Allen Verret | Deepstar |
| Andy Wolford | EQE |
| Brett Wilson | Exxon |
| David Jones | FMC/SOFEC |
| Marty Krafft | FMC/SOFEC |
| Andrew Johnstone | Lloyd's Register |
| Chris Desmnd | LOOP LLC |
| David Eggers | Mentor Subsea |
| D. Martin | MMS |
| Felix Dyrkopy | MMS |
| Jim Regg | MMS |
| Tommy Laurendine | MMS |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Jim Seery | OXY |
| Rick Meyer | Shell |
| Bill Daughdrill | USCG |
| Joe Meyers | USCG |
| John Cushing | USCG |
| Jihad Jaber | UT |
| Larry Lake | UT |

**Table B.4.2 Participants in Workshop #4 – All Systems, September 27, 2000**

| Participant | Affiliation |
|---|---|
| Steve Leverette | Atlantia |
| Bill Scaik | BP |
| Chuck White | Consultant |
| Allen Verret | Deepstar |
| J.P. Hurel | Elf Exploration |
| Brett Wilson | Exxon |
| Ben Poblete | Lloyd's Register |
| Charles Smith | MMS |
| Felix Dyhrkopy | MMS |
| Jim Regg | MMS |
| TT Laurendine | MMS |
| Skip Ward | OTRC/TAMU |
| Bob Gilbert | OTRC/UT |
| Jim Seery | OXY |
| Bob Andring | Shell |
| Phill Bohlmann | Shell |
| Rick Meyer | Shell |
| Dave Wisch | Texaco |
| Bill Daughdrill | USCG D8 |
| Joe Myers | USCG HQ |

**Table B.5 Participants in Technical Interview Sessions**

| Subject | Participant | Affiliation |
|---|---|---|
| Diving and Remotely Operated Vehicles | Ross Saxon | Association of Diving Contractors |
| | Skipper Strong | Cal Dive |
| | Charles Royce | Oceaneering |
| | Jerry Gauthier | Oceaneering |
| Subsea Production | Grayum Davis | Aker Engineering |
| | Kerry Kirkland | Aker Engineering |
| | Tom Kelly | Cameron |
| | Eric Ringle | FMC |
| Supply Vessels | Jim Gray | Aker Marine Contractors |
| | Roger White | Edison Chouest Offshore |
| | Alan Clarke | Texaco |
| | Peter Fortier | Tidewater Marine |
| Helicopters | Carl Brown | Air Logistics |
| | Ted Winslow | BP Amoco |
| | Frank Draves | ERA Aviation |
| | Jacob Hansen | ERA Aviation |
| | Dick Landrum | Marathon |
| | Tom Carter | Marathon |
| | Ken Townsen | PHI |
| | Virgil Russell | PHI |
| | Chuck White | Statoil |
| | Ken Develle | Texaco |
| Construction | Wayne French | Bay Ltd. |
| | Jerry Methvin | BP Amoco |
| | Pat Campbell | McDermott Engineering |
| | Michael Hessel | Oceaneering International |
| | Demir Karsan | Paragon Engineering |
| | Robert Gamble | Spirit Energy |
| Mobile Offshore Drilling Unit Operations | Lee Nirider | Marathon Oil Co. |
| | David Eggers | Mentor Subsea Technology Services |
| | Klaus Backstrom | R&B Falcon |
| | Earl Shanks | Transocean SedcoForex |
| Pipelines | Jack Vernon | EQE |
| | Mariano Hinojosa | LDEQ |
| | Alex Alvarado | MMS |
| | Frans Kopp | Shell |
| Platform Drilling Rig Operations | Moss Bannerman | Chevron |
| | Burt Simon | Shell |

| Subject | Participant | Affiliation |
|---|---|---|
| Well Intervention | John Allen | ABB |
| | Brian Taylor | Horizon Engineering |
| | Dennis McDaniel | Kerr McGee |
| | Doug Devoy | Matthews Daniels |
| Shuttle Tanker Operations | John Stiff | ABS |
| | Capt. Ramos | Chevron |
| | Dick Inglis | Chevron |
| | Chuck Steube | Conoco |
| | Bob Wolfram | ExxonMobil |
| | Chris Jenman | Global Maritime |
| | John Mercier | Global Maritime |
| | Peter Lunde | SBM-IMODCO |
| | Tricia Clark | Skaugen Petrotrans |
| | Chuck White | Statoil |
| | Richard Kaser | USCG |
| | Jeff Ramos | USCG |
| Structures | Malcolm Sharples | ABS |
| | Ron De Jong | Aker Maritime |
| | Yves Delepine | Aker Maritime |
| | Steve Leverette | Atlantia |
| | Steve Perryman | BP Amoco |
| | Frank Puskar | EQE |
| | Andrew Johnstone | Lloyd's Register |
| | David Wisch | Texaco |
| Surface Production | Grayum Davis | Aker Engineering |
| | Tom Kelly | Cameron |
| | Jack Vernon | EQE |
| | Eric Ringle | FMC |
| | Barry Brasher | Mentor |
| | Brian Taylor | Texaco |

Appendix C

Conceptual Descriptions for Study Systems

**Table C.1**
**Location**

| Number | Variable | FPSO | SPAR | TLP | HUB |
|---|---|---|---|---|---|
| **1.1** | *Water Depth* | 5,000 feet | 4,000 feet | 4,000 feet | 600 feet |
| **1.2** | *Distance to Shore Terminals* | 125 miles | 125 miles | 125 miles | 80 miles |

## Table C.2
## Well Systems

| Number | Component | FPSO | SPAR | TLP | HUB |
|---|---|---|---|---|---|
| **2.1** | *Well Count and Drill Center* | 9 Production wells (3 sets of 3 subsea tie-back wells with a single manifold each) | 9 Production wells (6 platform wells and 3 subsea tie-back wells with a single manifold) | 9 Production wells (6 platform wells and 3 subsea tie-back wells with a single manifold) | 9 Production wells (6 platform wells and 3 subsea tie-back wells with a single manifold) |
| **2.2** | *Trees* | Wet | Combination (3 wet trees and 6 dry trees) | Combination (3 wet trees and 6 dry trees) | Combination (3 wet trees and 15 dry trees) |
| **2.3** | *Gas Lift* | No | No | No | No |
| **2.4** | *Subsea Trees* | Horizontal | Horizontal | Horizontal | Horizontal |
| **2.5** | *Jumpers from Subsea Wells to Manifold* | Insulated Steel | Insulated Steel | Insulated Steel | Insulated Steel |
| **2.6** | *Subsea Manifold* | Active | Active | Active | Active |
| **2.7** | *Distance between Subsea Field and Production Facility* | 5-15 miles | 5-15 miles | 5-15 miles | 5-15 miles |
| **2.8** | *Umbilicals to Subsea Trees (hydraulic, chemical, power)* | Single multiplex (with annulus vent) for each manifold | Single multiplex (with annulus vent) for each manifold | Single multiplex (with annulus vent) for each manifold | Single multiplex (with annulus vent) for each manifold |

**Table C.3**
**Risers**

| **Number** | **Component** | **FPSO** | **SPAR** | **TLP** | **HUB** |
|---|---|---|---|---|---|
| **3.1** | *Dry Tree Risers* | Not applicable | 6 Top-tension risers (buoyancy cans), dual casing, Vortex Induced Vibration (VIV) suppression as needed | 6 Top-tension risers (tensioners), dual casing, VIV suppression as needed | Steel pipe conductors |
| **3.2** | *Export Pipeline Risers* | Steel catenary risers, piggable, VIV suppression as needed | Steel catenary risers, piggable, VIV suppression as needed | Steel catenary risers, piggable, VIV suppression as needed | Steel pipe risers, installed inside framing |
| **3.3** | *Import Flowline Risers* | 6 Insulated steel catenary risers, piggable loop, VIV suppression as needed | 2 Insulated steel catenary risers, piggable loop, VIV suppression as needed | 2 Insulated steel catenary risers, piggable loop, VIV suppression as needed | 2 Steel pipe risers, installed inside framing, piggable loop |
| **3.4** | *Platform Drilling Risers* | Not applicable | Top tension risers (buoyancy tanks) | Top tension risers (tensioners) | Steel pipe conductors |
| **3.5** | *Import Risers from DeepwaterProduction Facilities* | Not applicable | Not applicable | Not applicable | Steel pipe risers, installed inside framing |

**Table C.4**
**Station Keeping (Off-Vessel Mooring)**

| **Number** | **Component** | **FPSO** | **SPAR** | **TLP** | **HUB** |
|---|---|---|---|---|---|
| **4.1** | *Number of Legs/Lines* | 9 mooring lines in 3 groups of 3 each | 16 clustered mooring lines in 4 groups of 4 each | 12 tendons with 3 located on each column | 4 legs, 8 piles |
| **4.2** | *Configuration* | Catenary | Taut | Vertical Tendons | Leg and skirt piles |
| **4.3** | *Material* | Wire rope/chain | Wire rope/chain | Tubular steel | Steel |
| **4.4** | *Foundation Type* | Suction piles | Suction piles | Driven piles | Driven piles |
| **4.5** | *Replacement of Mooring Lines* | None planned in 20-year life | None planned in 20-year life | None planned in 20-year life | Not Applicable |

**Table C.5**
**On-Vessel Mooring**

| **Number** | **Component** | **FPSO** | **SPAR** | **TLP** | **HUB** |
|---|---|---|---|---|---|
| **5.1** | *Positioning for drilling* | Not Applicable | Active | None (drill rig skid) | Not Applicable |
| **5.2** | *Type* | Permanent | Permanent | Permanent | Not Applicable |
| **5.3** | *Location* | Internal turret | External | External (tendon porches) | Not Applicable |
| **5.4** | *Weather-vaning* | Passive | Not Applicable | Not Applicable | Not Applicable |
| **5.5** | *Bearing System* | Roller | Not Applicable | Not Applicable | Not Applicable |
| **5.6** | *Chain jacks* | Removed after installation | Fixed, one per mooring line | Not Applicable | Not Applicable |

## Table C.6
## Fluid Transfer System (Riser to Process Manifold)

| **Number** | **Component** | **FPSO** | **SPAR** | **TLP** | **HUB** |
|---|---|---|---|---|---|
| **6.1** | *Production Fluid Transfer System* | Multipass swivel | Flexible jumpers | Flexible jumpers | Steel piping |
| **6.2** | *Turret to Process System on Hull* | Hardened jumper hose from turret | Not Applicable | Not Applicable | Not Applicable |
| **6.3** | *Export Fluid Transfer System* | High pressure, multipass swivel | Rigid piping with flex joint | Rigid piping with flex joint | Steel piping |

**Table C.7**
**Hull**

| Number | Component | FPSO | SPAR | TLP | HUB |
|---|---|---|---|---|---|
| **7.1** | *Cargo Storage* | 1,000,000 barrels | No cargo storage | Not Applicable | Not Applicable |
| **7.2** | *Ballast capacity* | Segregated | Combination (solid ballast in soft tanks and water ballast in hard tanks) | Water ballast | Not Applicable |
| **7.3** | *Ballast control* | Active | Active | Active | Not Applicable |
| **7.4** | *Type* | Ship-shape | Classic (full cylinder hull) | 4 columns with pontoons | Jacket |
| **7.5** | *Configuration* | Double hull | Multiple vertical bulkheads, multiple horizontal decks, cofferdam bulkheads in ship impact zone | Pontoons and columns subdivided into separate water-tight compartments | Space frame |
| **7.6** | *Marine systems* | Marine systems included inside hull | Marine systems included inside hull | Marine systems included inside hull | Not Applicable |
| **7.7** | *Bilge system* | Included | Included | Included | Not Applicable |
| **7.8** | *Propulsion* | No propulsion | Not Applicable | Not Applicable | Not Applicable |
| **7.9** | *FPSO Thruster Assist* | No thrusters | Not Applicable | Not Applicable | Not Applicable |
| **7.10** | *Tank Inspection Access* | Designed to provide safe inspection access to all compartments | Designed to provide safe inspection access to all hard tanks | Designed to provide safe inspection access to all compartments | Not Applicable |
| **7.11** | *Green water protection* | Adequate freeboard and bulwarks as required | Freeboard | Air gap designed to prevent wave in deck | Air gap designed to prevent wave in deck |
| **7.12** | *Moonpool configuration* | Circular turret | Square, central moonpool | Not Applicable | Not Applicable |

**Table C.8**
**Production**

| **Number** | **Component** | **FPSO** | **SPAR** | **TLP** | **HUB** |
|---|---|---|---|---|---|
| **8.1** | *Peak Oil Production/ Transshipment* | 150,000 bopd | 150,000 bopd | 150,000 bopd | 50,000 bopd/ 200,000 bopd transshipment |
| **8.2** | *Peak Gas Production/ Transshipment* | 200 MMscfd | 200 MMscfd | 200 MMscfd | 50 MMscfd/ 500 MMscfd transshipment |
| **8.3** | *Peak Water Production* | 150,000 bwpd | 150,000 bwpd | 150,000 bwpd | 50,000 bwpd |
| **8.4** | *Pig launcher/ receivers* | Each import/export line | Each import/export line | Each import/export line | Each import/export line |
| **8.5** | *Trains* | Dual train | Dual train | Dual train | Single train |
| **8.6** | *Separation* | 3-stage | 3-stage | 3-stage | 3-stage |
| **8.7** | *Gas Export* | Pipeline export | Pipeline export | Pipeline export | Pipeline export |
| **8.8** | *Oil Export* | Shuttle tanker | Pipeline export | Pipeline export | Pipeline export |
| **8.9** | *Flare* | Emergency and maintenance flare | Emergency and maintenance flare | Emergency and maintenance flare | Emergency and maintenance flare |
| **8.10** | *Water Injection* | Not Included | Not Included | Not Included | Not Included |
| **8.11** | *Gas Lift* | Not Included | Not Included | Not Included | Not Included |
| **8.12** | *Produced Water Disposal* | Discharged (EPA NPDES Permit) | Discharged (EPA NPDES Permit) | Discharged (EPA NPDES Permit) | Discharged (EPA NPDES Permit) |
| **8.13** | *Slug Catcher* | Not Applicable | Not Applicable | Not Applicable | Each gas import line |
| **8.14** | *Metering* | Export lines | Export lines | Export lines | Export and import lines |
| **8.15** | *Compression* | 3-stage compression | 3-stage compression | 3-stage compression | 3-stage compression |

**Table C.9**
**Oil Offloading System**

| Number | Component | FPSO | SPAR | TLP | HUB |
|---|---|---|---|---|---|
| **9.1** | *Offloading configuration.* | Tandem | Not Applicable | Not Applicable | Not Applicable |
| **9.2** | *Cargo Pumps* | Conventional pump room | Not Applicable | Not Applicable | Not Applicable |
| **9.3** | *Offloading Rate* | 50,000 bph | Not Applicable | Not Applicable | Not Applicable |
| **9.4** | *Inert gas system* | Individual tank isolation capability | Not Applicable | Not Applicable | Not Applicable |
| **9.5** | *Offloading Hoses* | Floating hose | Not Applicable | Not Applicable | Not Applicable |

**Table C.10**
**Shuttle Tanker**

| **Number** | **Component** | **FPSO** | **SPAR** | **TLP** | **HUB** |
|---|---|---|---|---|---|
| **10.1** | *Hull Configuration* | Double hull | Not Applicable | Not Applicable | Not Applicable |
| **10.2** | *Capacity* | 500,000 bbls | Not Applicable | Not Applicable | Not Applicable |
| **10.3** | *Berthing* | Hawser with thruster assist and/or tug | Not Applicable | Not Applicable | Not Applicable |
| **10.4** | *Shuttle Tanker Destination* | St. James-like terminal | Not Applicable | Not Applicable | Not Applicable |

**Table C.11**
**Pipelines**

| **Number** | **Component** | **FPSO** | **SPAR** | **TLP** | **Jacket** |
|---|---|---|---|---|---|
| **11.1** | *Gas Export Pipeline* | New pipeline to Hub and existing pipeline to shore | New pipeline to Hub and existing pipeline to shore | New pipeline to Hub and existing pipeline to shore | Existing pipeline to shore |
| **11.2** | *Gas Pipeline Destination* | Empire-like gas terminal | Empire-like gas terminal | Empire-like gas terminal | Empire-like gas terminal |
| **11.3** | *Oil Export Pipeline* | Not Applicable | New pipeline to Hub and existing pipeline to shore | New pipeline to Hub and existing pipeline to shore | Existing pipeline to shore |
| **11.4** | *Oil Pipeline Destination* | Not Applicable | St. James-like terminal | St. James-like terminal | St. James-like terminal |

## Table C.12
## General Layout

| Number | Component | FPSO | SPAR | TLP | HUB |
|---|---|---|---|---|---|
| **12.1** | *Quarters/Flare Location* | Quarters stern/flare bow | Quarters upwind/flare downwind | Quarters upwind/flare downwind | Quarters upwind/flare downwind |
| **12.2** | *Manning Level* | 30 – 45 process<br>10 marine | 30 – 45 process<br>6 marine<br>65 drilling | 30 – 45 process<br>6 marine<br>65 drilling | 30 – 45 process<br>50 drilling |
| **12.3** | *Life Boat Arrangement* | As per MMS/USCG requirements | Permanent safety craft with 100% of capacity on each of two corners | Permanent safety craft with 100% of capacity on each of two corners | As per MMS/USCG requirements |
| **12.4** | *Collision Avoidance Warning System* | Monitor/Alarm | Non-continuously manned radar | Non-continuously manned radar | Beacon system |
| **12.5** | *Helicopter Pad* | Two helicopters and refueling capability | Two helicopters and refueling capability | Two helicopters and refueling capability | Two helicopters and refueling capability |
| **12.6** | *Marine Crew* | Dedicated Marine Crew | Trained marine crew part of production and operations crew | Trained marine crew part of production and operations crew. | Not Applicable |

**Table C.13**
**System Operations**

| **Number** | **Component** | **FPSO** | **SPAR** | **TLP** | **HUB** |
|---|---|---|---|---|---|
| **13.1** | *Hurricane Abandonment* | Yes, except for skeleton marine crew | Yes | Yes | Yes |
| **13.2** | *Non-Hurricane Evacuation* | Primary TEMPSC | Primary TEMPSC | Primary TEMPSC | Primary TEMPSC |
| **13.3** | *Drilling during Production* | Yes from MODU | Yes for both platform rig and MODU | Yes for both platform rig and MODU | Yes for both platform rig and MODU |
| **13.4** | *Ballast Movement* | Yes | Yes | Yes | Not Applicable |
| **13.5** | *Supply Boat and Service Boat Anchoring Operations* | Dynamically positioned supply vessels | Dynamically positioned supply vessels | Dynamically positioned supply vessels | Boat landing/barge bumpers |
| **13.6** | *Workover Rig* | Workover via MODU for all wells | Drill rig replaced by workover rig after drilling program completion; Workover via MODU for subsea wells | Drill rig replaced by workover rig after drilling program completion; Workover via MODU for subsea wells | Drill rig replaced by workover rig after drilling program completion; Workover via MODU for subsea wells |
| **13.7** | *FPS Relocation for MODU Drilling* | Not required | Not required | Not required | Not Applicable |
| **13.8** | *Diving Operations* | Hull inspections | Hull inspections down to 200 feet below water line | Hull inspections | Jacket inspections down to 200 feet below water line |
| **13.9** | *ROV Operations* | Inspections | Inspections and drilling operations | Inspections and drilling operations | Inspections |

Appendix C.1

Spar General Arrangement Drawings and Operation Schedule

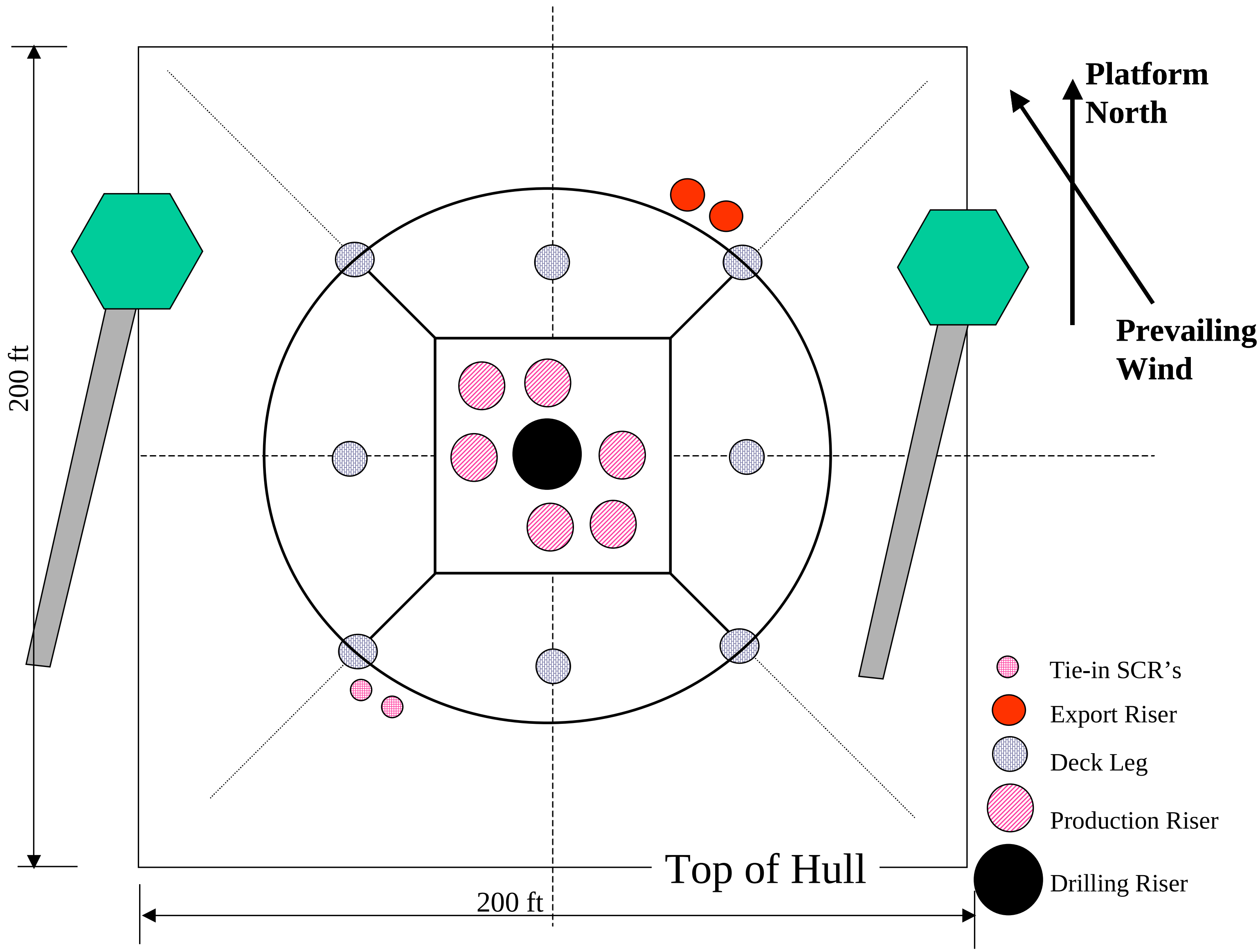



Figure C.1.1 General Arrangement for Top of Hull of Spar

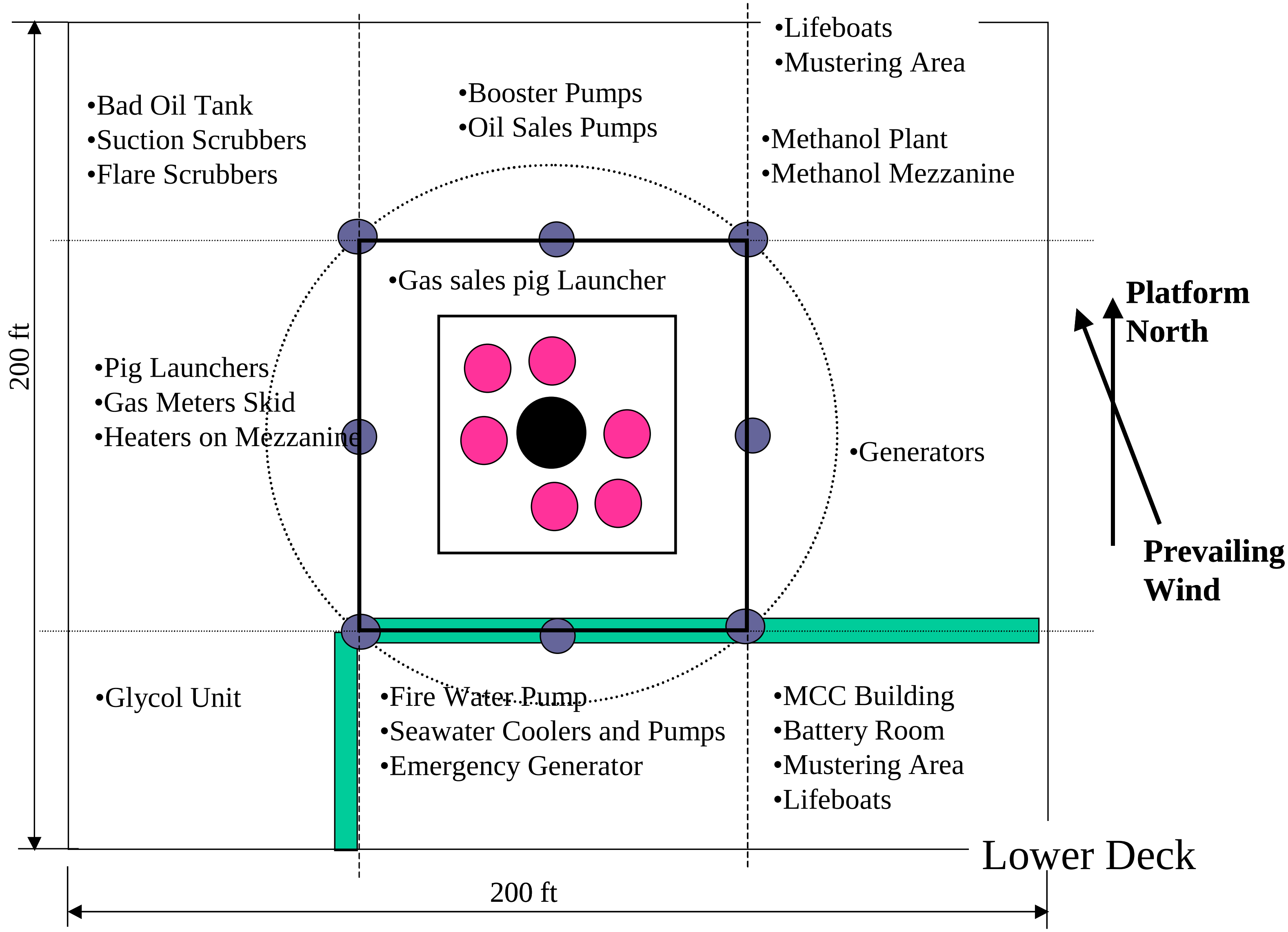



Figure C.1.2 General Arrangement for Lower Deck of Spar

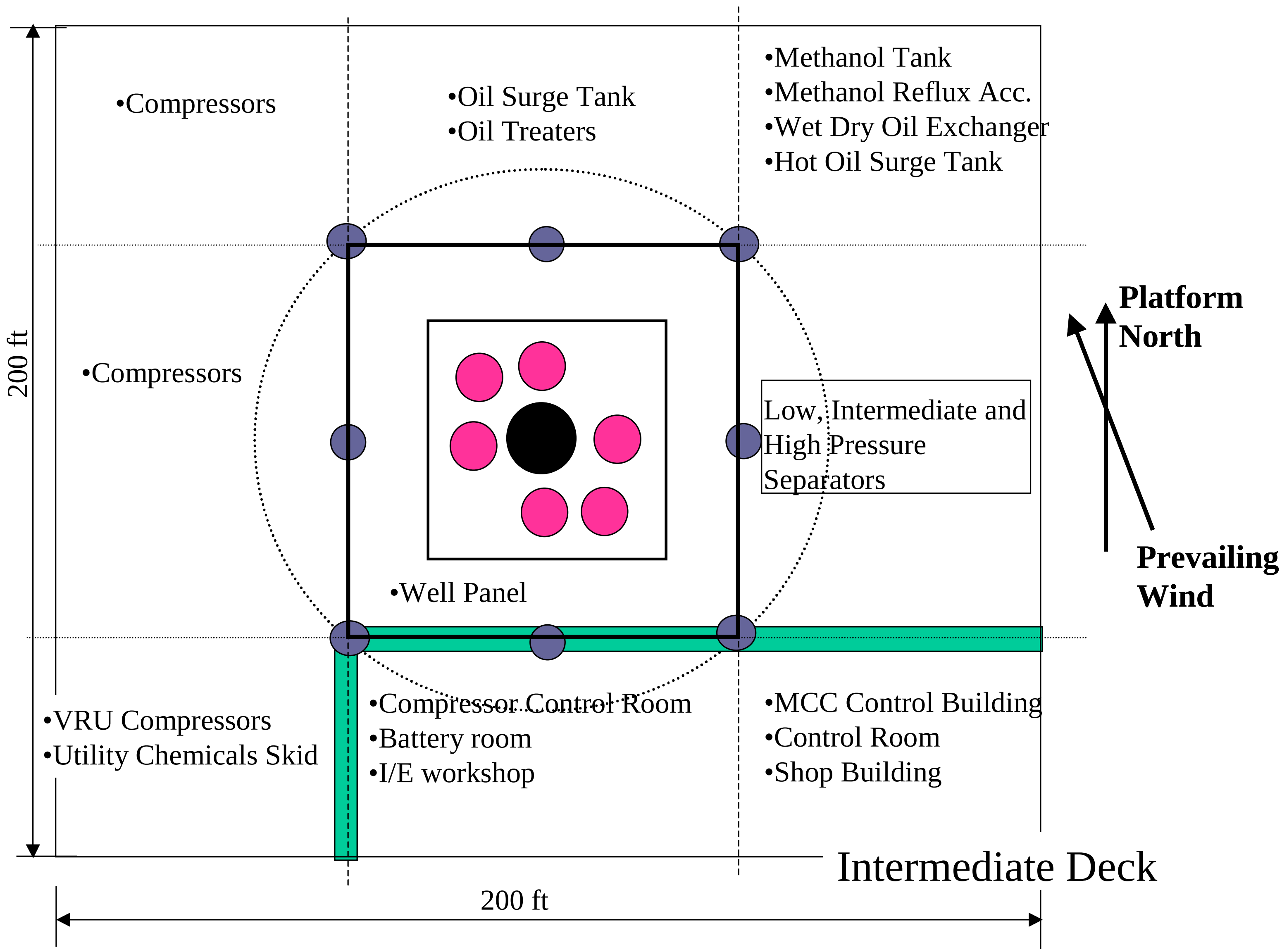



Figure C.1.3 General Arrangement for Intermediate Deck of Spar

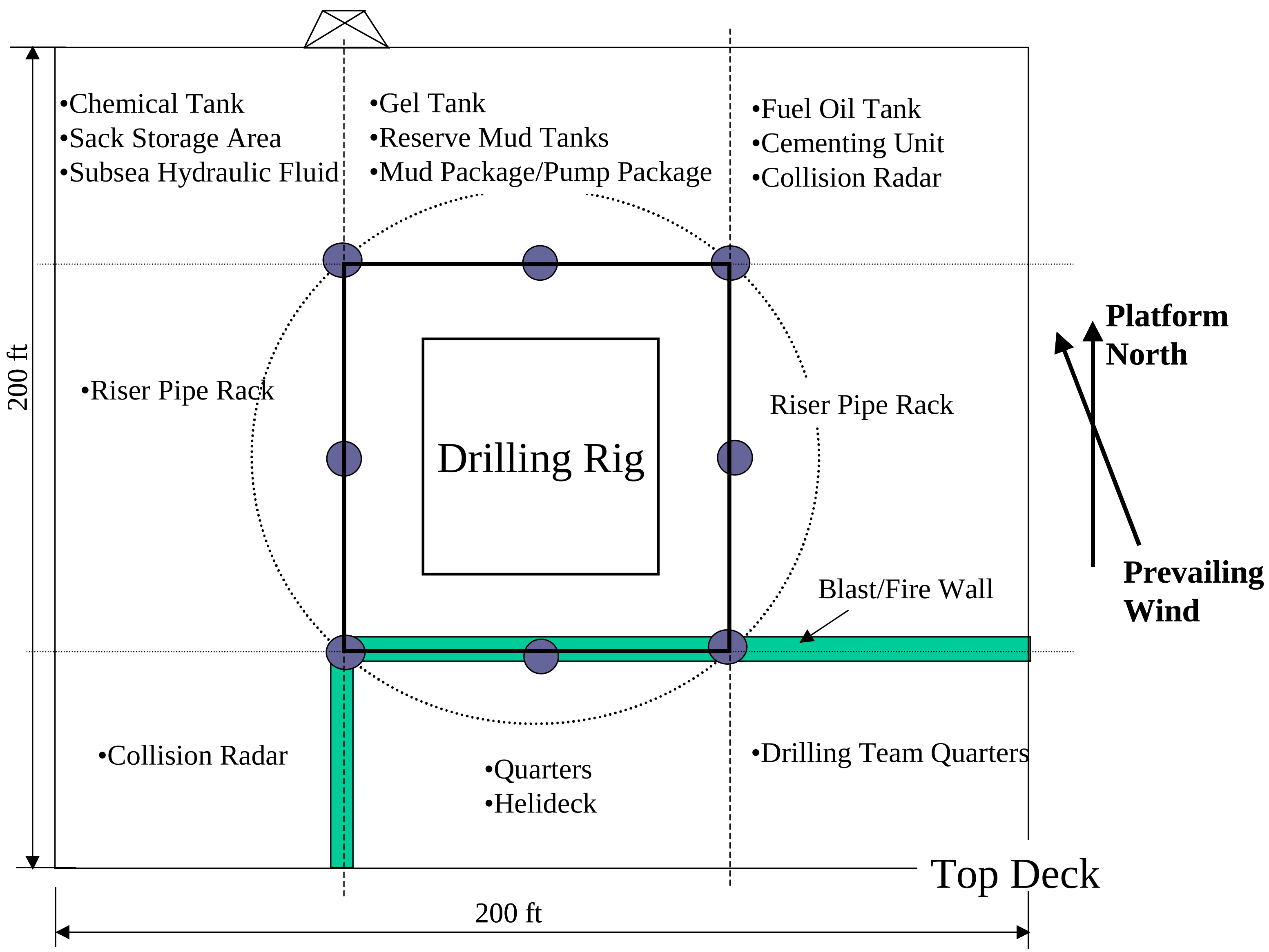



Figure C.1.4 General Arrangement for Top Deck of Spar

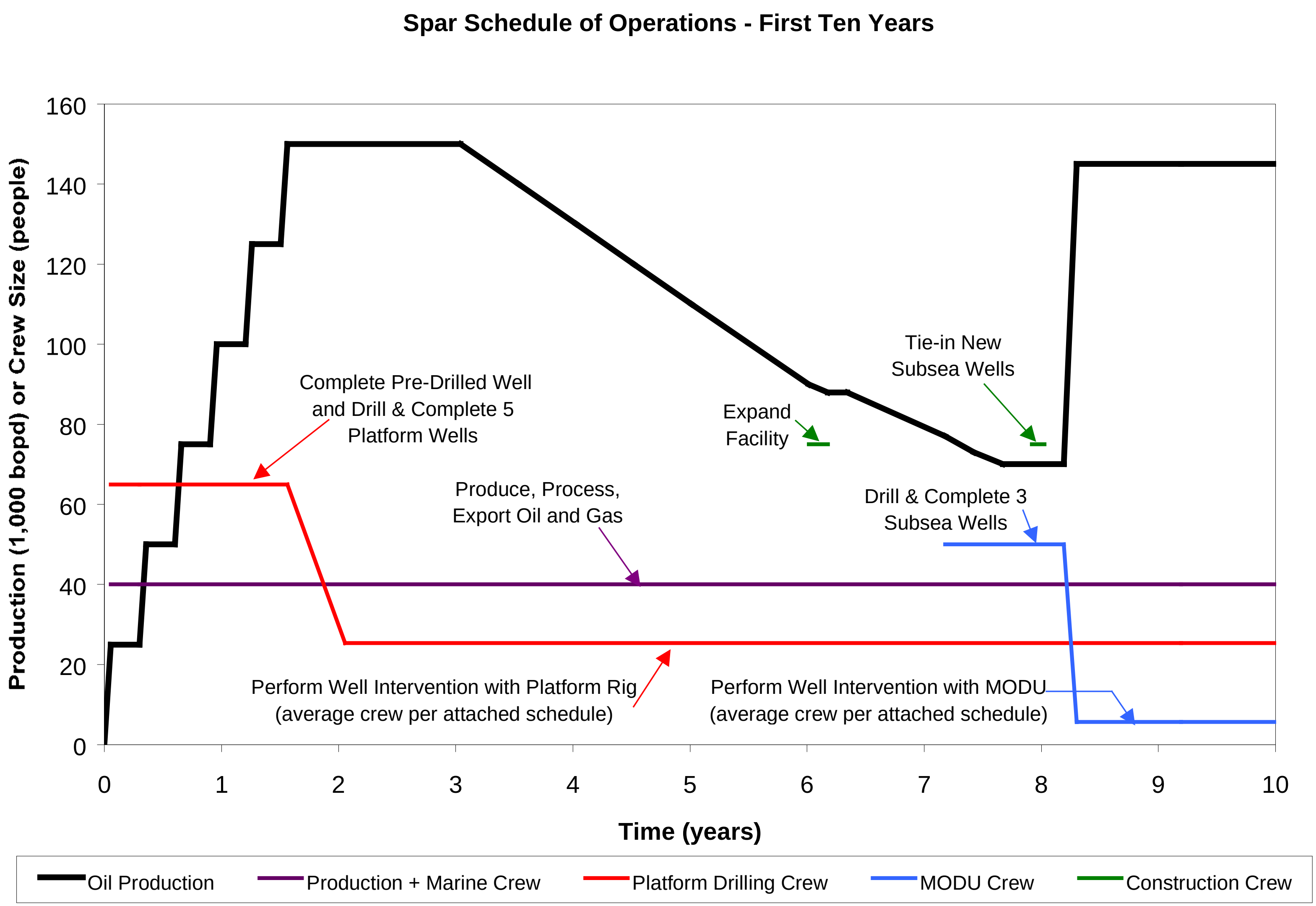



Figure C.1.5 Schedule of Operations for Spar (First Ten Years)

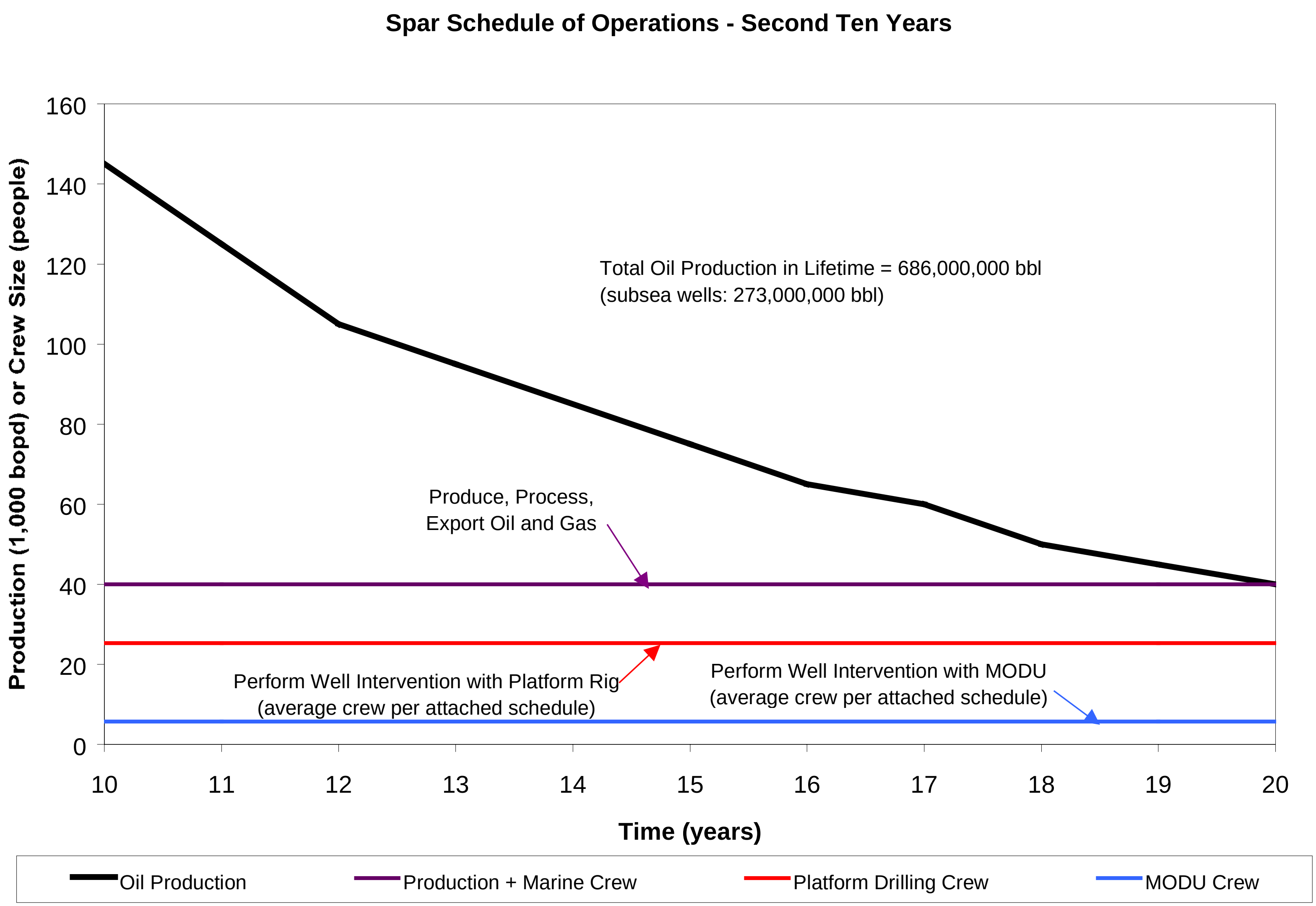



Figure C.1.6 Schedule of Operations for Spar (Second Ten Years)

Table C.1.1 Well Intervention Schedule for Spar

| | days | crew | man-days |
|---|---|---|---|
| 6 Platform Wells (20 years) | | | |
| Slickline (3 per well-year @ 5 days) | 1800 | 4 | 7200 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Change out (1/3 per well-yr @ 50 days) | 2000 | 40 | 80000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 | 40 | 48000 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 | 40 | 20800 |
| Average Platform Crew Size (20 years) | | | **25** |
| | | | |
| 3 Subsea Wells (12 years) | | | |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 | 4 | 720 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 | 8 | 1152 |
| Change out (1/8 per well-yr @ 50 days) | 225 | 8 | 1800 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 | 40 | 7200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 | 40 | 6240 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 | 40 | 7800 |
| Average MODU Crew Size (12 years) | | | **6** |

Appendix C.2

TLP General Arrangement Drawings and Operation Schedule

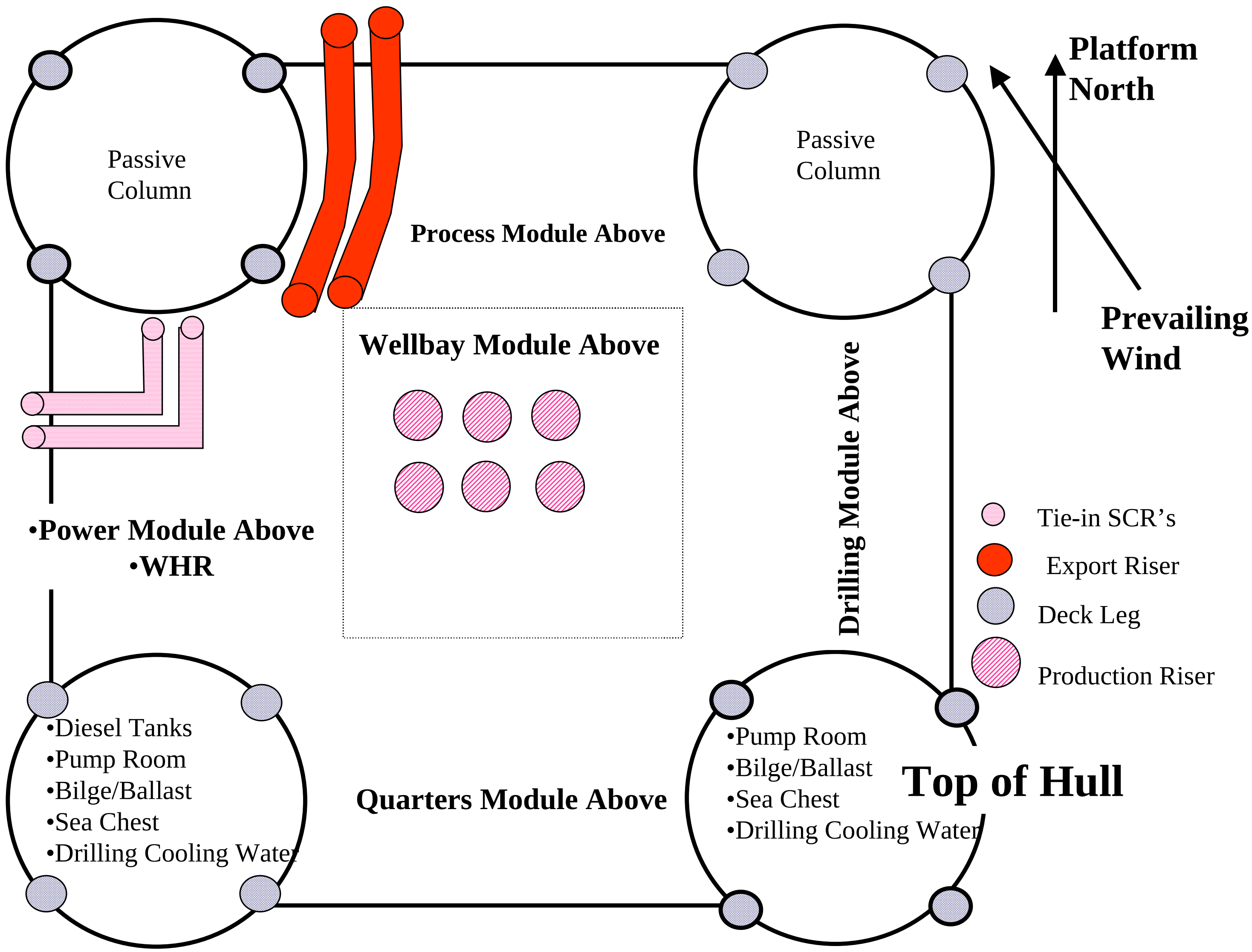



Figure C.2.1 General Arrangement for Top of Hull of TLP

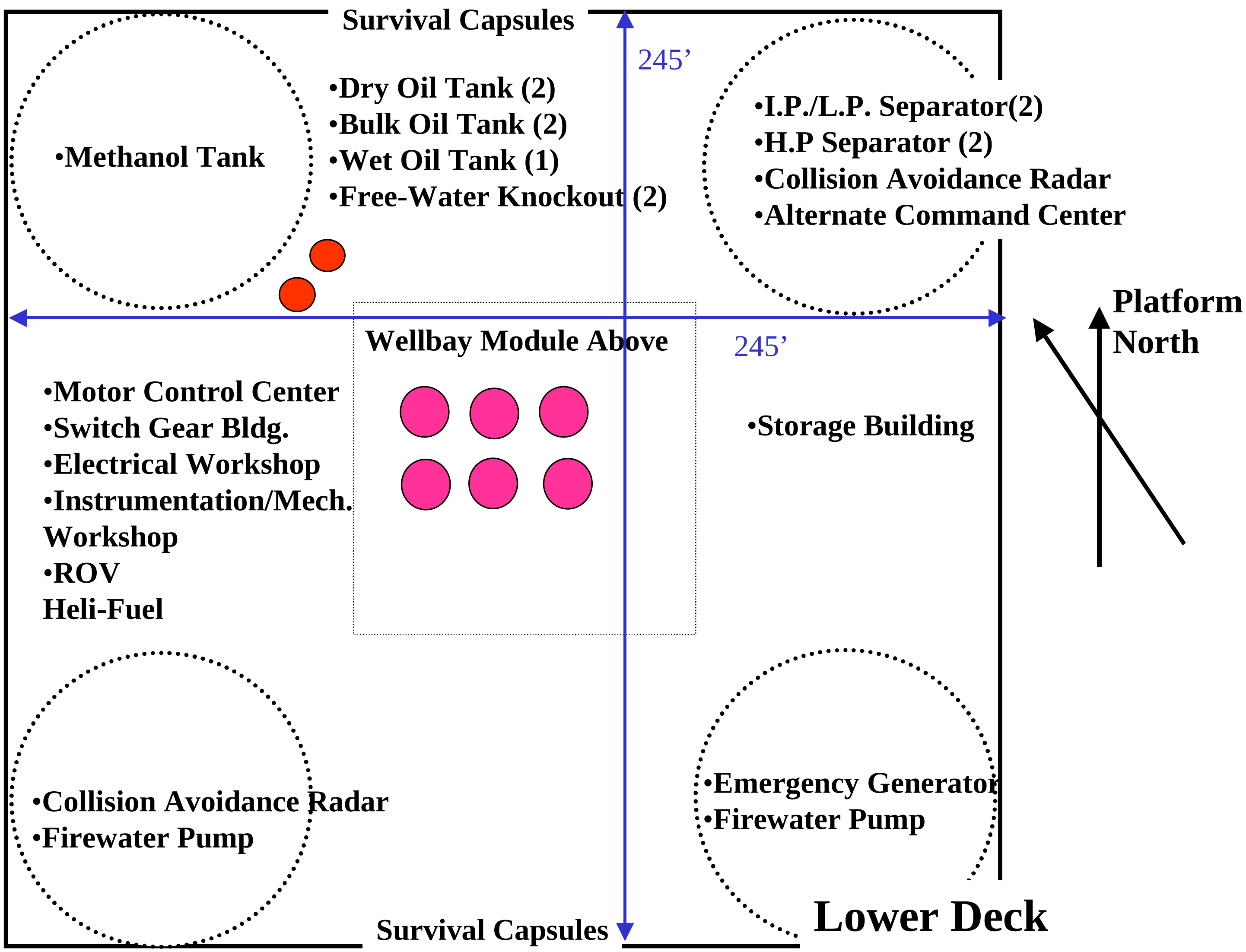



Figure C.2.2 General Arrangement for Lower Deck of TLP

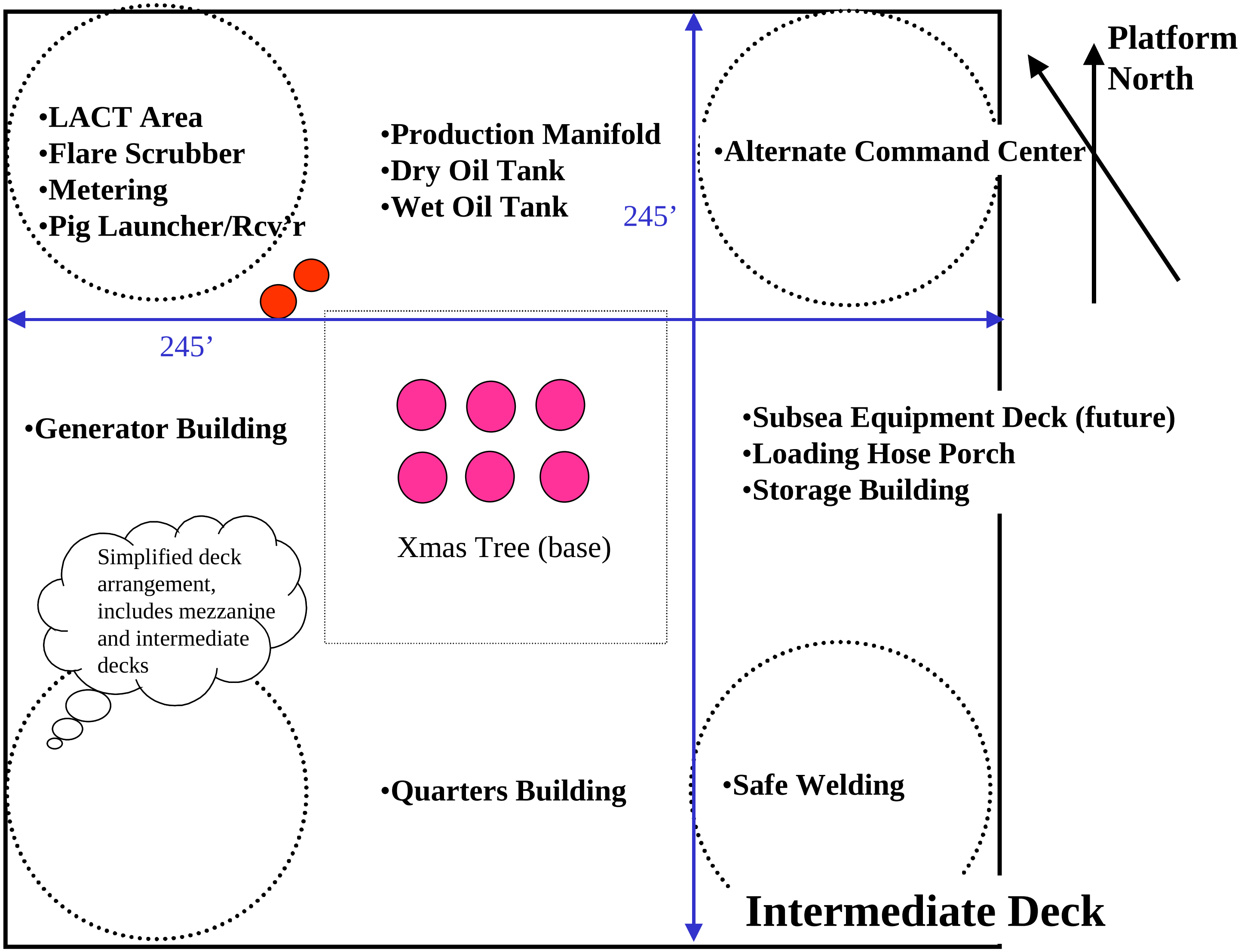



Figure C.2.3 General Arrangement for Intermediate Deck of TLP

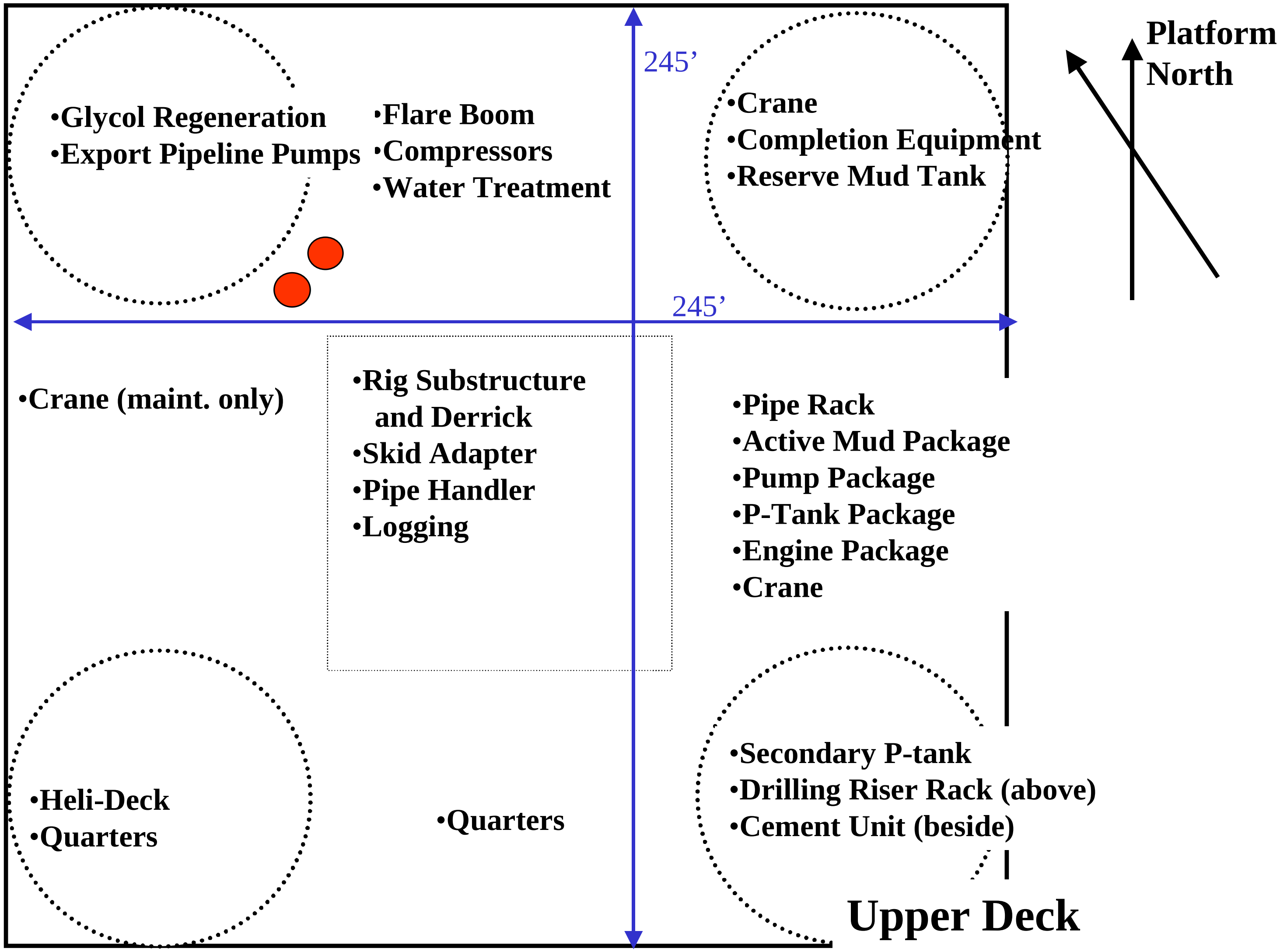



Figure C.2.4 General Arrangement for Upper Deck of TLP

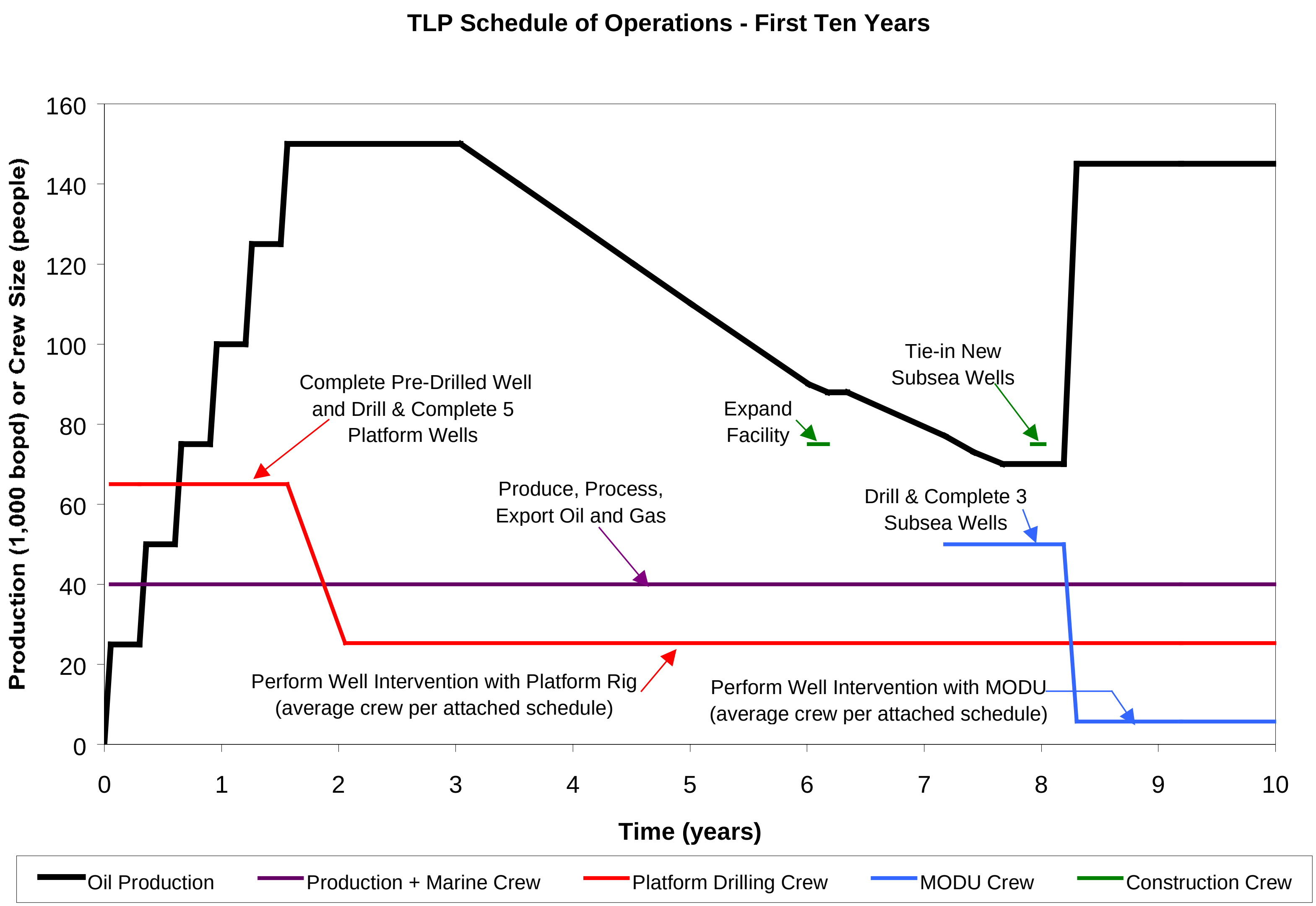



Figure C.2.5 Schedule of Operations for TLP (First Ten Years)

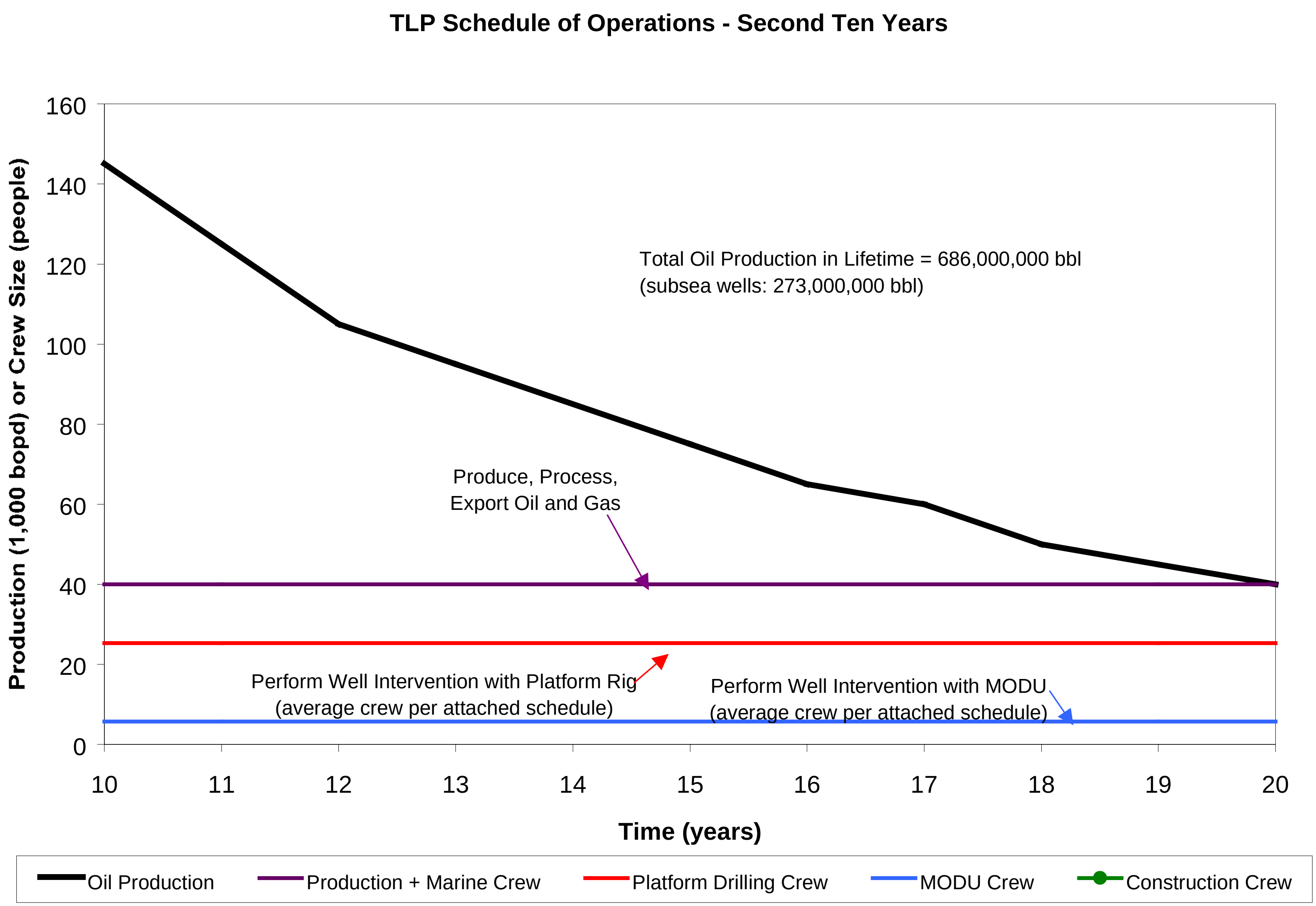



Figure C.2.6 Schedule of Operations for TLP (Second Ten Years)

Table C.2.1 Well Intervention Schedule for TLP

| | days | crew | man-days |
|---|---|---|---|
| 6 Platform Wells (20 years) | | | |
| Slickline (3 per well-year @ 5 days) | 1800 | 4 | 7200 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Change out (1/3 per well-yr @ 50 days) | 2000 | 40 | 80000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 | 40 | 48000 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 | 40 | 20800 |
| Average Platform Crew Size (20 years) | | | **25** |
| | | | |
| 3 Subsea Wells (12 years) | | | |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 | 4 | 720 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 | 8 | 1152 |
| Change out (1/8 per well-yr @ 50 days) | 225 | 8 | 1800 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 | 40 | 7200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 | 40 | 6240 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 | 40 | 7800 |
| Average MODU Crew Size (12 years) | | | **6** |

## Appendix C.3

## Hub/Host Jacket General Arrangement Drawings and Operation Schedule

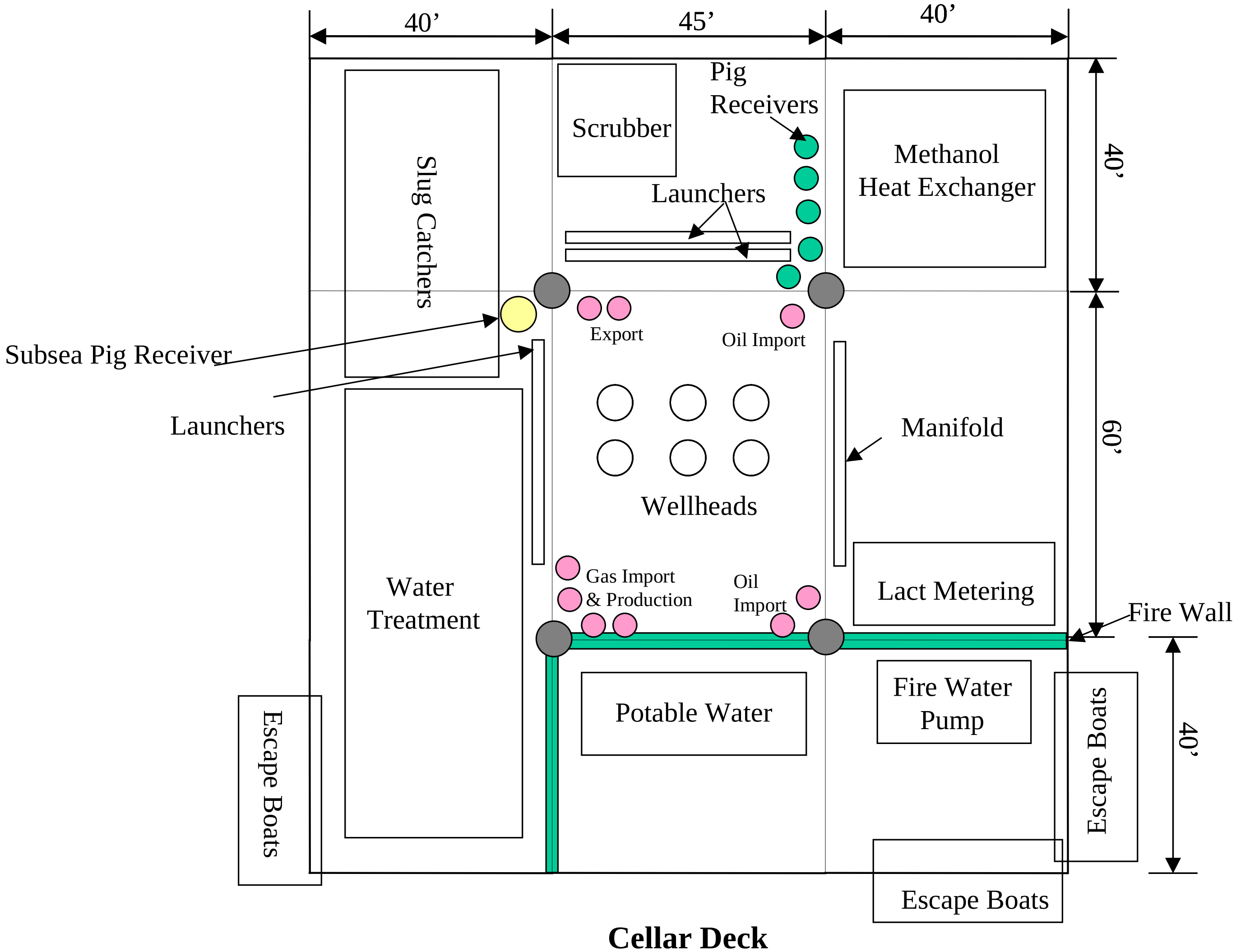



Figure C.3.1 General Arrangement for Cellar Deck of Hub/Host Jacket

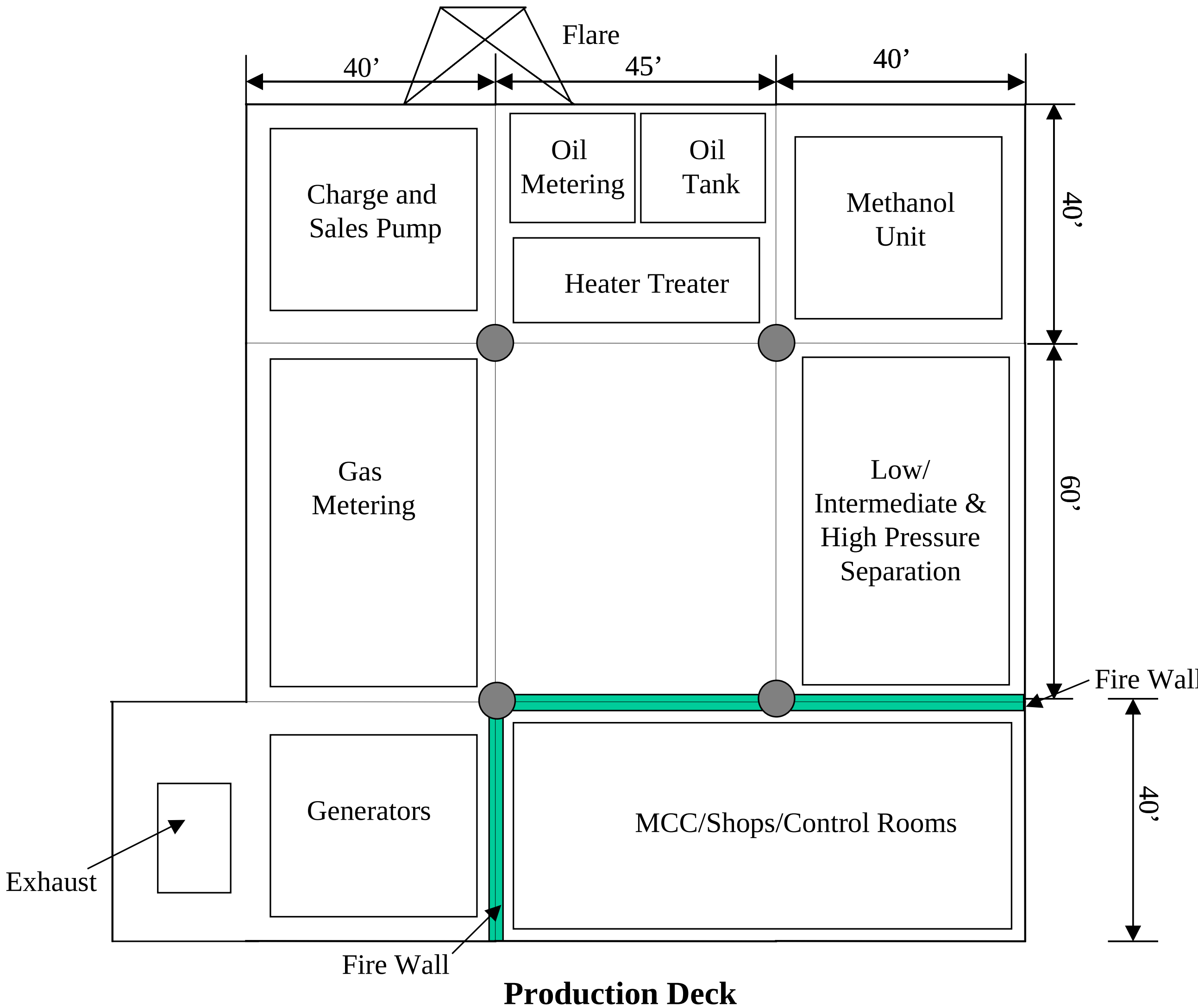



Figure C.3.2 General Arrangement for Production Deck of Hub/Host Jacket

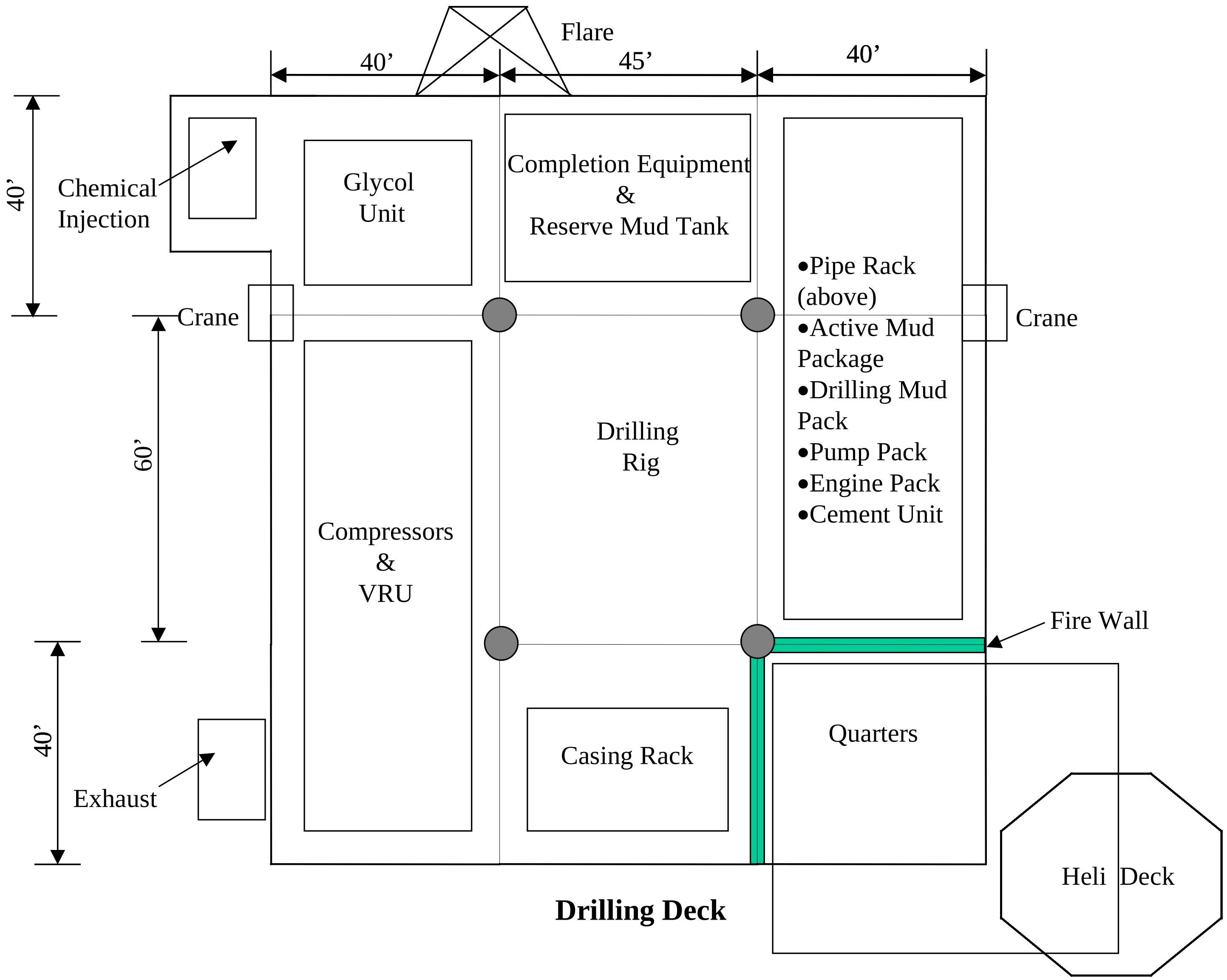



Figure C.3.3 General Arrangement for Drilling Deck of Hub/Host Jacket

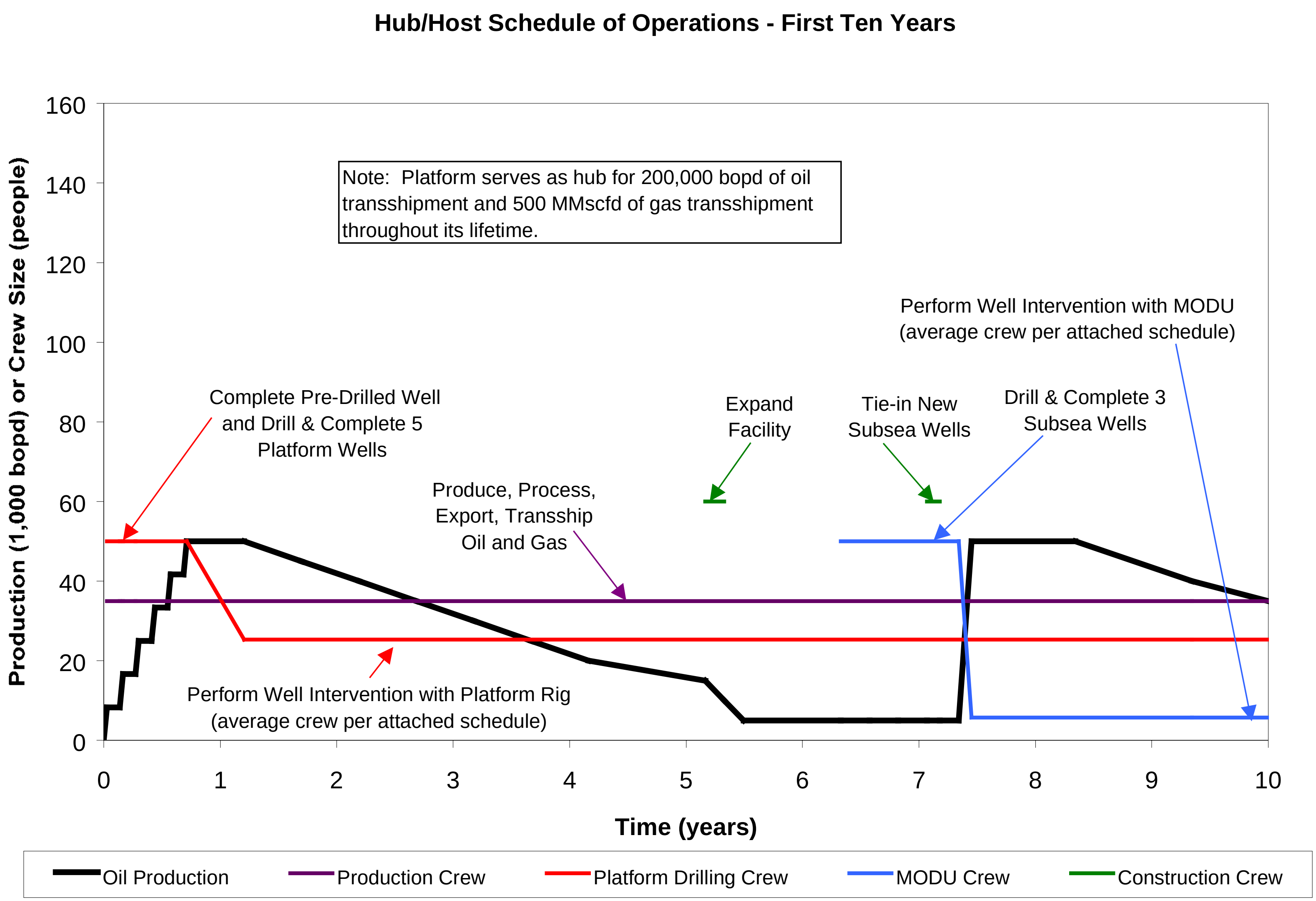



Figure C.3.4 Schedule of Operations for Hub/Host Jacket (First Ten Years)

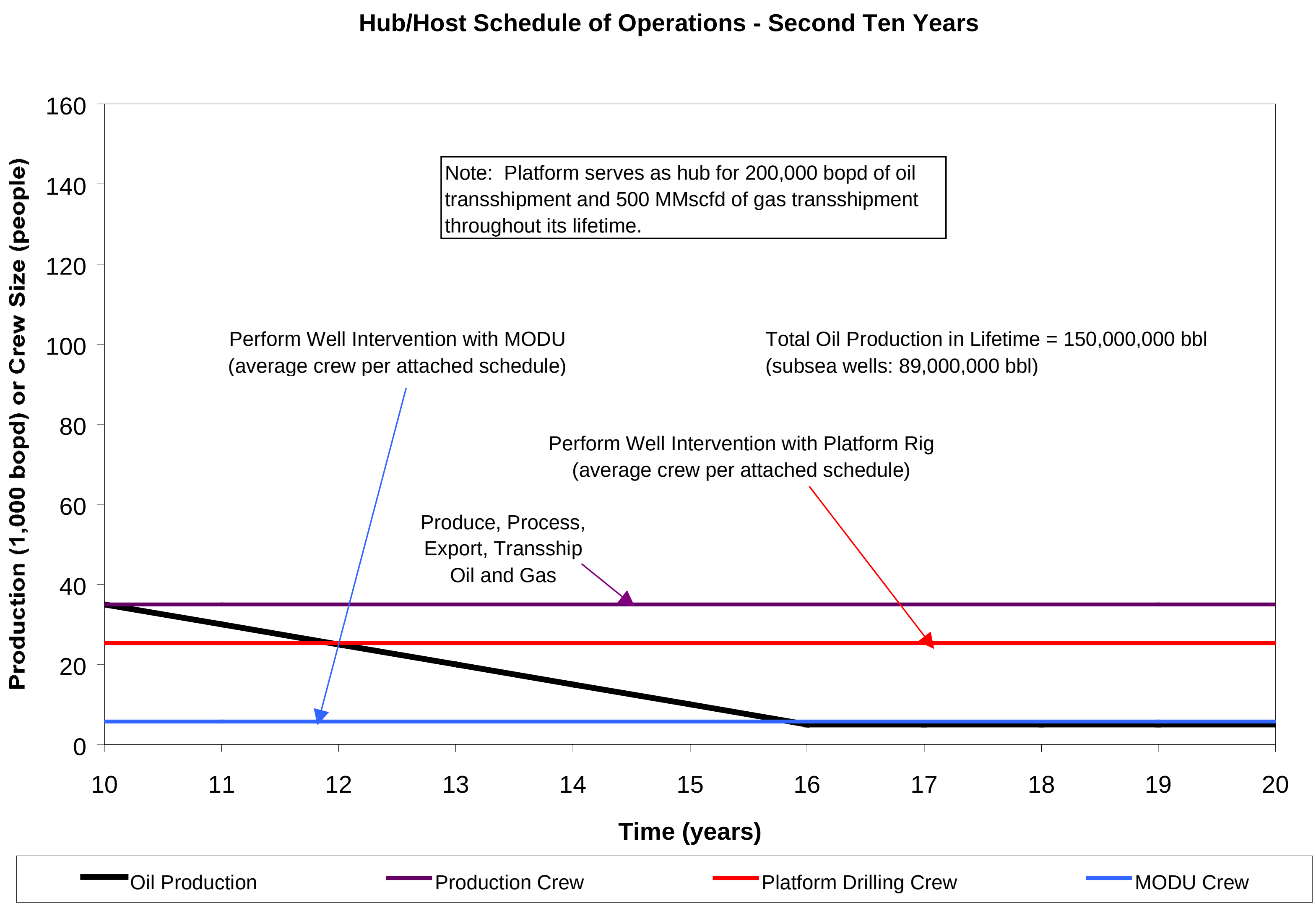



Figure C.3.5 Schedule of Operations for Hub/Host Jacket (Second Ten Years)

Table C.3.1 Well Intervention Schedule for Hub/Host Jacket

| | days | crew | man-days |
|---|---|---|---|
| 6 Platform Wells (20 years) | | | |
| Slickline (3 per well-year @ 5 days) | 1800 | 4 | 7200 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Change out (1/3 per well-yr @ 50 days) | 2000 | 40 | 80000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 | 40 | 48000 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 | 40 | 20800 |
| Average Platform Crew Size (20 years) | | | **25** |
| | | | |
| 3 Subsea Wells (12 years) | | | |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 | 4 | 720 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 | 8 | 1152 |
| Change out (1/8 per well-yr @ 50 days) | 225 | 8 | 1800 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 | 40 | 7200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 | 40 | 6240 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 | 40 | 7800 |
| Average MODU Crew Size (12 years) | | | **6** |

Appendix C.4

FPSO General Arrangement Drawings and Operation Schedule

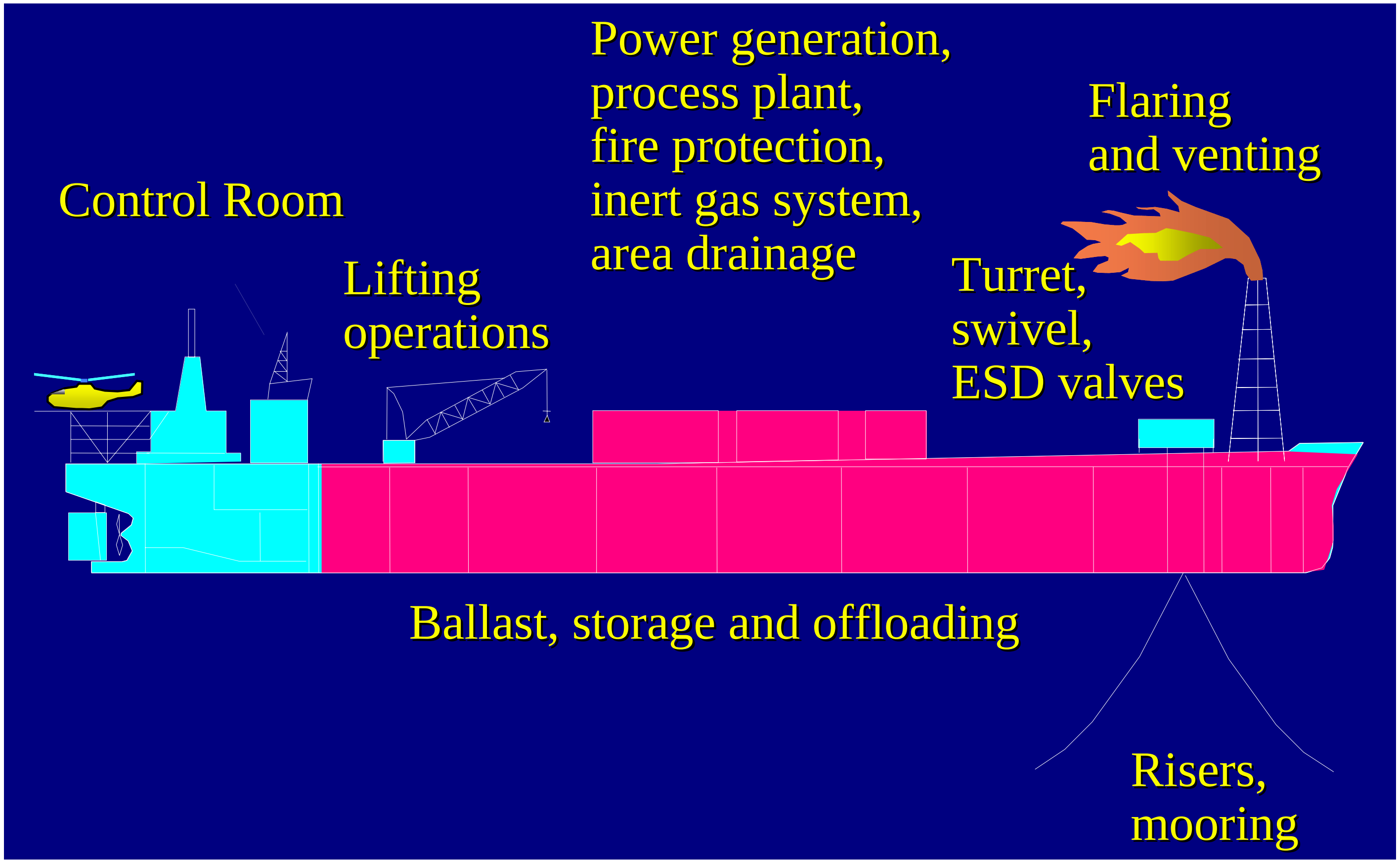



Figure C.4.1 General Arrangement for FPSO – Cross Section

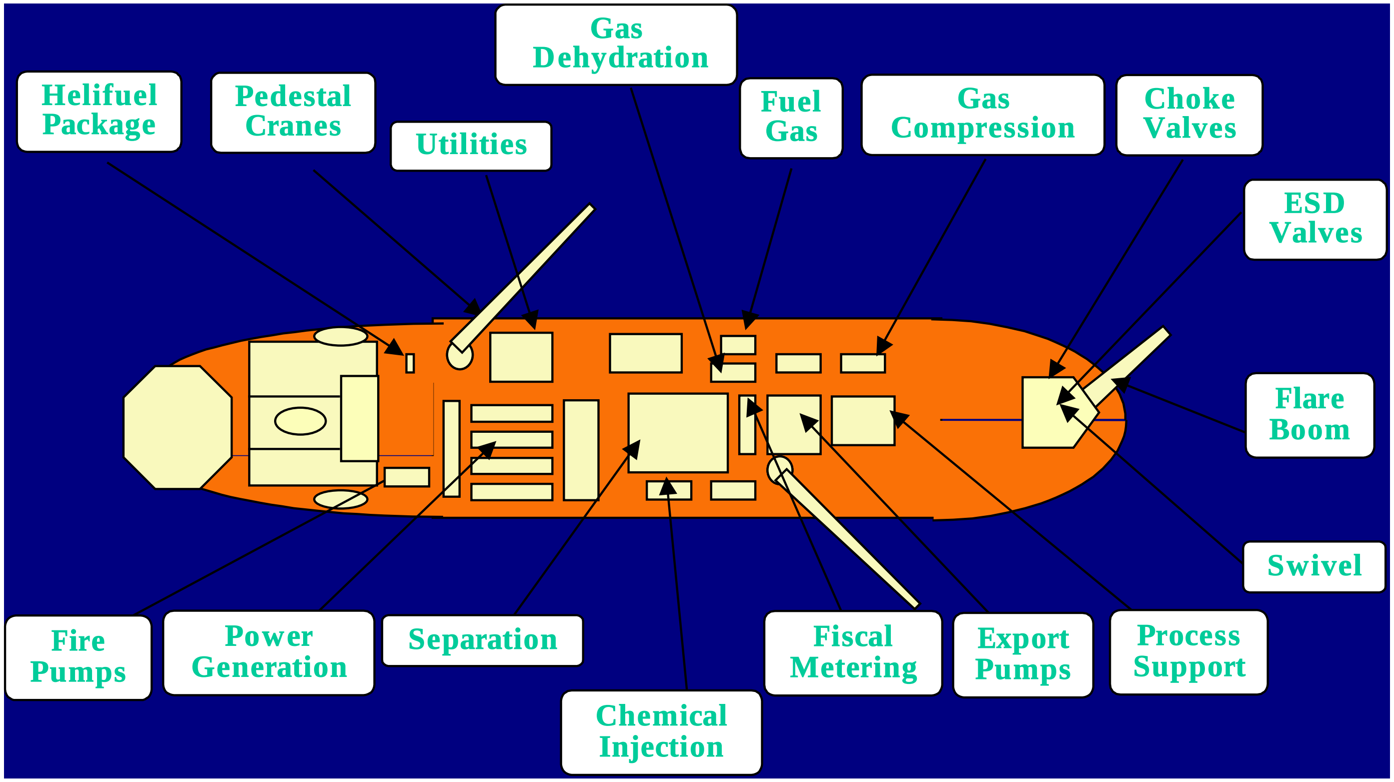



Figure C.4.2 General Arrangement for FPSO – Plan View

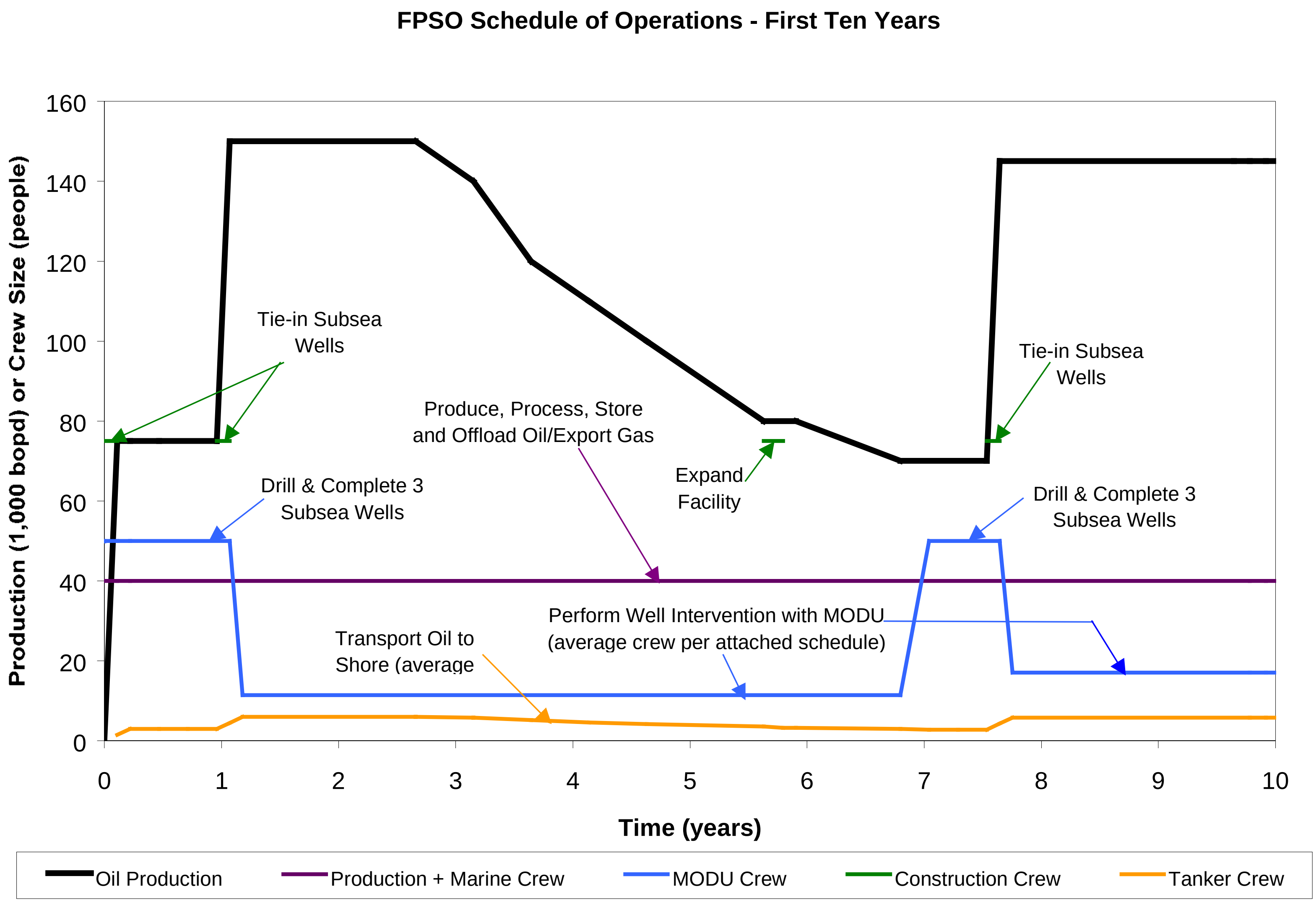



Figure C.4.3 Schedule of Operations for FPSO (First Ten Years)

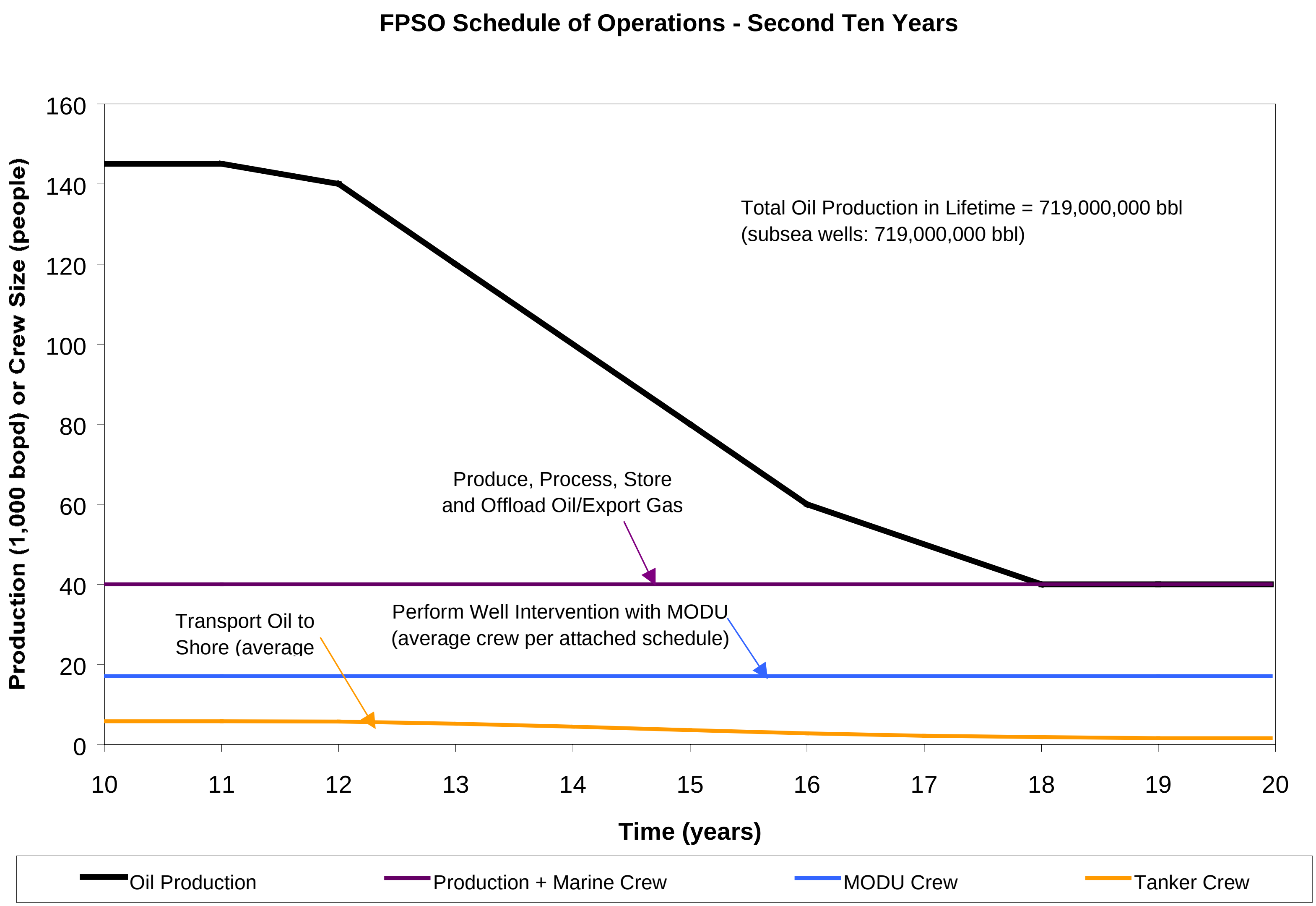



Figure C.4.4 Schedule of Operations for FPSO (Second Ten Years)

Table C.4.1 Well Intervention Schedule for FPSO

| | days | crew | man-days |
|---|---|---|---|
| 6 Subsea Wells (20 years) | | | |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 600 | 4 | 2400 |
| Hydraulic (1/5 per well-yr @ 20 days) | 480 | 8 | 3840 |
| Change out (1/8 per well-yr @ 50 days) | 750 | 8 | 6000 |
| Recompletion (1/10 per well-yr @ 50 days) | 600 | 40 | 24000 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 | 40 | 20800 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 650 | 40 | 26000 |
| Average MODU Crew Size (20 years) | | | **11** |
| | | | |
| 3 Subsea Wells (12 years) | | | |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 | 4 | 720 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 | 8 | 1152 |
| Change out (1/8 per well-yr @ 50 days) | 225 | 8 | 1800 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 | 40 | 7200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 | 40 | 6240 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 | 40 | 7800 |
| Average MODU Crew Size (20 years) | | | **6** |

# Appendix D

## Methodology for Risk Calculations



List of Tables



List of Figures

## D.1. BASIC MODELS DESCRIBING RISK MEASURES

The models used to assess the risk measures are described in this section. The measures of risk are the total number of fatalities in the lifetime, the total volume of oil spilled in the lifetime, and the maximum volume of oil spilled in a single incident.

The total number of fatalities and the total volume of oil spilled are expressed mathematically by the following equation

$$\mathrm{TOTAL}_C = \sum_{i=0}^{X_{occur}} \mathrm{Consequence}_i \qquad \text{(D-1)}$$

where $\mathrm{TOTAL}_C$ is the total consequence over the lifetime (that is, the the total number of fatalities or the total volume of oil spilled), $X_{occur}$ is the number of occurrences or incidents with a consequence in the lifetime (that is, the number of incidents with a fatality or the number of incidents with an oil spill), and $\mathrm{Consequence}_i$ is the individual consequence in each occurrence (that is, the number of fatalities in an incident or the volume of oil spilled in an incident). Table D.1 shows an example of oil spills over the lifetime of a production system to illustrate how Eq. (D-1) is used. Both the number of incidents and the consequence in each incident are random variables because they will not be known for a given production system until it is operated for its lifetime and they will vary from system to system. The risk for a future system is quantified by the expected value (or average) of $\mathrm{TOTAL}_c$, which is obtained by evaluating all of the possible values for $X_{occur}$ and $\mathrm{Consequence}_i$ and weighting them by their respective probabilities

$$\mu_{\mathrm{TOTAL}_C} = \sum_{x=0}^{\infty}\left[\sum_{i=0}^{x}\left(\int_0^{\infty} c_i f_C(c)\,dc\right)\right] p_X(x) = \mu_{X_{occur}}\mu_{\mathrm{Consequence}_i} \qquad \text{(D-2)}$$

where $f_c(c)$ is the probability density function for the consequence in an individual incident, $p_x(x)$ is the probability mass function for the number of occurrences, and $\mu$ dentoes the mean or expected value. The average total represents the average value that would be obtained if the totals were averaged for a fleet of systems with the same attributes as the study system (e.g., the sum of all the oil spilled from each Spar in its 20 year lifetime divided by the total number of Spars in the fleet).

The maximum volume of oil spilled in a single incident is expressed mathematically by the following equation

$$MAX_C = \max\left(Consequence_1, Consequence_2, ..., Consequence_{X_{occur}}\right) \qquad \text{(D-3)}$$

Table D.1 shows an example of oil spills over the lifetime of a production facility to illustrate Eq. (D-3). As with the total consequence, the risk for a future system is quantified by the expected value (or average) of $MAX_C$, which is obtained as follows

$$\mu_{MAX_C} = \sum_{x=0}^{\infty}\left[\int_0^{\infty} c_{max,x} f_{C_{max}|x}\left(c_{max}|x\right) dc_{max}\right] p_X\left(x\right) = \sum_{x=0}^{\infty}\left(\mu_{C_{max}|x}\right) p_X\left(x\right) \qquad \text{(D-4)}$$

where $c_{max,x}$ is the maximum consequence in a single incident from a total of x incidents in the lifetime, $f_{C_{max}|x}\left(c_{max}|x\right)$ is the probability density function for the maximum consequence in x incidents, and $\mu_{C_{max}|x}$ is the mean or expected value for the maximum consequence if there are x incidents. The average maximum represents the average value that would be obtained if the maximum spill volumes were averaged for a fleet of systems with the same attributes as the study system (e.g., the sum of the maximum spill volumes for each Spar in its 20 year lifetime divided by the total number of Spars in the fleet).

The next two sections describe how the risk measures for the average total consequence and the average maximum consequence in a single incident are estimated using historical data and input from technical experts. These estimates include the expected value for the average, the standard deviation in the average (because there is a finite amount of data available to estimate the average value), confidence intervals for the average.

Table D.1  Example Record for Production System Showing Risk Measures for Oil Spills

| Date<br>(facility operated from 2005 to 2025) | Volume Spilled<br>(bbl) |
|---|---|
| 2/2/2005 | 1 |
| 7/31/2006 | 2 |
| 1/4/2010 | 1 |
| 3/16/2017 | 10 |
| 4/23/2019 | 1 |
| 6/1/2019 | 1 |
| 11/19/2024 | 5 |
| | **TOTAL = 21 bbl** |
| | **MAX = 10 bbl** |

## D.2. CALIBRATION OF RISK MODELS WITH HISTORICAL DATA

This section describes the steps used to calibrate the risk models with historical data. The historical data are divided into the various sub-system categories listed in Table D.2. These sub-system categories were chosen to facilitate understanding, comparing and analyzing the historical data.

Table D.2 Sub-System Categories and Exposure Factors Used in Risk Assessment

| Risk Measure | Sub-System Category | | Exposure Factor |
|---|---|---|---|
| Fatalities | Production | | man-hours |
| | Drilling | | man-hours |
| | Supply Vessels | | docking calls |
| | Helicopter Transport | | passengers |
| | Tanker Operations | | docking calls |
| | Major Accident | | platform-years |
| Oil Spills | Production System | Well Systems – Platform (or Surface) | bbl produced |
| | | Well Systems – Subsea | bbl produced |
| | | Dry Tree (or Production) Risers | riser-years |
| | | Flowlines | mile-years |
| | | Import Flowline Risers | riser-years |
| | | Topsides | bbl processed |
| | | Supply Vessels | docking calls |
| | | Drilling and Intervention | man-hours |
| | Transportation System | Pipelines | mile-years |
| | | Export Pipeline Risers | riser-years |
| | | Shuttle Tanker (Offloading in Field and at Port) | docking calls |
| | | FPSO Cargo Tank | platform-years |

### D.2.1 Step One – Summarize Data for Sub-Systems

The first step is to summarize the data for each sub-system category. A detailed description of the data sets used is provided in Jaber (2000).

Since individual fatalities are generally isolated events, each fatality is treated as an individual incident with an expected consequence equal to one (that is, $\mu_{Consequence_i} = 1.0$ in Eq. D-2). Therefore, the fatality records are summarized as the total number of fatalities over the data period, as shown in Table D.3 for production crews. The one exception to this approach is for the sub-system category of a "Major Accident," which by definition involves multiple fatalities. In this case, the expected consequence was estimated to be 30 fatalities.

Table D.3 Summary of Fatality Data for Gulf of Mexico Production Crews

| Total Number of Fatalities from 1992-1999 |
|---|
| 27 |

Unlike fatalities, the range of possible spill volumes per incident spans orders of magnitude, and the frequency distribution for oil spills is highly skewed in that small oil spills are substantially more likely than large oil spills. This highly skewed distribution of spills causes difficulty in estimating the mean spill volume per incident, $\mu_{Consequence_i}$ in Eq. (D-2), and the mean value for the maximum spill volume if there are x incidents, $\mu_{C_{max}|x}$ in Eq. (D-4). In order to overcome this difficulty, a technique known as stratified sampling is used. The range of possible oil spill volumes in an incident is sub-divided into a set of categories, and then the data are binned by category as shown in Table D.4 for oil spills from shuttle tankers. There are two advantages to this approach. First, different causes are generally associated with small spills versus large spills. By sub-dividing the spill sizes, these different causes are treated separately. Second, more precise estimates for $\mu_{Consequence_i}$ and $\mu_{C_{max}|x}$ are possible using stratified sampling (e.g., Rice 1995). The categories of sub-division adopted for this study are the same categories used in the Environmental Impact Statement for FPSOs in the Gulf of Mexico (MMS 2000): 1 – 10 bbl; 10 – 100 bbl; 100 – 1,000 bbl; 1,000 – 10,000 bbl; 10,000 – 100,000 bbl; 100,000 – 500,000 bbl and 500,000 – 1,000,000 bbl.

Table D.4 Summary of Oil Spill Data for Gulf of Mexico Tankers

| Spill Size Range (bbl) | Number of Incidents from 1992-1999 |
|---|---|
| 1 – 10 | 15 |
| 10 – 100 | 5 |
| 100 - 1,000 | 3 |
| 1,000 – 10,000 | 0 |
| 10,000 – 100,000 | 0 |
| 100,000 – 500,000 | 0 |
| 500,000 - 1,000,000 | 0 |

### D.2.2 Step Two – Select Exposure Factors for Sub-Systems

The second step is to select exposure factors for fatalities and oil spills for each sub-system so that the historical data can be applied or extrapolated to the study systems. The *exposure* for a risk is an indicator of the factors that influence the risk. In this way, the data can be extrapolated to each study system based on the exposure to the risk for that study system. The factors used to express the exposure for each sub-system category are summarized above in Table D.2. These factors were selected based on precedence and on input from the technical experts.

As an example, the exposure adopted for production crew fatalities is the number of man-hours worked. Based on available information (Appendix E), there were estimated to be 391,000,000 man-hours worked in the Gulf of Mexico between 1992 and 1999 for the data summarized in Table D.3. This estimate is an approximation because it is based on an extrapolation of two-years worth of data and because the available data required an adjustment due to under-reporting (see Appendix E). In order to account for this uncertainty in the exposure associated with the historical data, a coefficient of uncertainty (the standard deviation divided by the mean) is assigned to each estimated exposure factor. Three categories of uncertainty are defined and the coefficient of uncertainty is assigned in accordance with Table D.5. For the case of production man-hours with moderate uncertainty in the estimated exposure, a coefficient of uncertainty of 0.33 is used.

As another example, the exposure adopted for oil spills from shuttle tankers is the number of docking calls in the field and at the shore terminal. Based on available information (Appendix F), there were estimated to be 32,800 docking calls for tankers in lightering zones and at ports between 1992 and 1999 in the Gulf of Mexico. A coefficient of uncertainty of 0.33 is also assigned to this estimate to reflect moderate uncertainty.

Table D.5 Coefficient of Uncertainty Values to Reflect Uncertainty in Estimates

| Magnitude of Uncertainty | Assigned Coefficient of Uncertainty |
|---|---|
| None | 0.0 |
| Moderate (tens of percent) | 0.33 |
| Severe (orders of magnitude) | 1.0 |

### D.2.3 Step Three – Estimate Frequencies of Occurrence for Sub-Systems from Data

The third step is to estimate the frequencies of occurrence for different types of incidents relative to the exposure factors. Occurrences are assumed to follow a Poisson process, which means that occurrences can happen at any point in time and that occurrences are independent of one another. Both of these features are reasonable in modeling fatalities and oil spills over long time periods, and Poisson models are very commonly used for these purposes (e.g., Anderson and LaBelle 1994). There is one parameter that describes a Poisson process: the mean frequency or rate of occurrence, $\nu$. This section describes how the mean occurrence rate is estimated from data sets in the following situations: (1) a single data set with a given number of incidents over a known exposure; (2) a single data set with a given number of incidents over an unknown and estimated exposure; and (3) multiple data sets with different exposures.

#### D.2.3.1 Known Exposure in Data Set

In the case where the exposure in the data set is known with certainty, analytical solutions are available to estimate the mean occurrence rate from the number of incidents (e.g., Ang and Tang 1975). A statistically unbiased estimate (the expected value) for the mean occurrence rate is obtained with the following equation

$$\text{Expected Value for Mean Occurrence Rate} = E(\nu) = k/n \qquad \text{(D-5)}$$

where k is the effective number of occurrences which is the number of occurrences plus one (k = x + 1 where x is the number of occurrences in the data record) and n is the exposure for the data set. Note that the expected value for the mean occurrence rate is non-zero even if no incidents have occurred in the data record since the effective number of occurrences is the number of occurrences in the data record plus one.  Therefore, input from the technical experts is used to evaluate whether a specific event is possible if it has not occurred in the data record.

There is uncertainty in the estimated mean occurrence rate due to having a limited amount of data (that is, a limited length of exposure in the data set used to estimate the rate).  The uncertainty in the estimated rate is expressed as a standard deviation as follows

$$\text{Standard Deviation in Mean Occurrence Rate} = \text{StdDev}(\nu) = \sqrt{\frac{k}{n^2}} \qquad \text{(D-6)}$$

The coefficient of uncertainty for the mean occurrence rate is the standard deviation divided by the expected value.  The standard deviation increases as the length of exposure, n, decreases (fewer data are available).

Finally, the distribution for the mean occurrence rate has a gamma distribution described by the mean value from Eq. (D-5) and the standard deviation from Eq. (D-6).  This gamma distribution can be used to establish confidence bounds in the estimated value for the mean occurrence rate.

**D.2.3.2  Estimated Exposure in Data Set**

In the case where the exposure in the data set is uncertain and estimated, approximate solutions have been developed to estimate the mean occurrence rate from the number of incidents (Gilbert et al. 2001).  The expected value is approximated as follows

$$\text{Expected Value for Mean Occurrence Rate} = E(\nu) \simeq (k/\mu_n)(1+\Omega_n^2) \qquad \text{(D-7)}$$

where k is the effective number of occurrences (k = x + 1 where x is the number of occurrences in the data record), $\mu_n$ is the estimated exposure for the data set and $\Omega_n$ is the coefficient of uncertainty in the estimated exposure.  The expected mean occurrence rate reduces to the effective number of occurrences divided by the mean exposure (Eq. D-5) when the exposure is known with certainty ($\Omega_n = 0$).  Increasing uncertainty in the exposure increases the expected value for the mean occurrence rate. This result occurs because the estimated rate is more sensitive to a potential decrease in the exposure below the mean exposure than it is to a potential increase in the exposure above the mean exposure.

There is additional uncertainty in the estimated mean occurrence rate due to uncertainty in the exposure. The uncertainty in the estimated rate, expressed as a standard deviation, is obtained from the following approximation

$$\text{Standard Deviation in Mean Occurrence Rate} = \text{StdDev}(\nu) \simeq \sqrt{\frac{k}{\mu_n^2} + \left(\frac{k^2}{\mu_n^2} + 3\frac{k}{\mu_n^2}\right)\Omega_n^2} \qquad \text{(D-8)}$$

The standard deviation increases as (1) the length of exposure, $\mu_n$, decreases (fewer data are available) and (2) the uncertainty in the exposure, $\Omega_n$, increases.

Example calculations to estimate the mean occurrence rates for fatalities from production and for oil spills from shuttle tankers are presented in Tables D.6 and D.7, respectively. Notice that the magnitude of uncertainty in the estimated mean rate (the coefficient of uncertainty) increases as the number of incidents in the data set available to estimate the rate decreases. Example probability distributions for the mean occurrence rates for two oil spill categories are shown on Fig. D.1. These distributions, which are gamma distributions with the respective means and standard deviations from Table D.7, can be used to calculate 90-percent confidence bounds for the estimated rates (the $5^{th}$ and $95^{th}$ percentiles in Fig. D.1).

Table D.6 Calculations to Estimate Mean Occurrence Rate for Production Fatalities

| | |
|---|---|
| **Input Information:** | |
| Mean Exposure for 1992-1999, $\mu_n$ (man-hr) | 3.91E+08 |
| Coefficient of Uncertainty in Exposure, $\Omega_n$ | 0.33 |
| Number of Fatalities from 1992-1999, x | 27 |
| Effective Number of Occurrences, k | 28 |
| | |
| **Statistical Analysis:** | |
| Expected Rate (per man-hr) | **7.93E-08** |
| Std. Dev. in Rate (per man-hr) | **2.83E-08** |
| Coefficient of Uncertainty in Rate | **0.36** |

Table D.7 Calculations to Estimate Mean Occurrence Rates for Oil Spills from Shuttle Tankers – Data from the Gulf of Mexico

Total Exposure (docking calls) in Gulf of Mexico:

| | |
|---|---|
| Expected Total Docking Calls | 32,800 |
| Coefficient of Uncertainty | 0.33 |

**Statistical Analysis:**

| Spill Size Range (bbl) | Number of Spills | Statistically-Based Estimates for Frequencies Based on Raw Data | | | | |
|---|---|---|---|---|---|---|
| | | $k_{GOM}$ | Expected $n_{GOM}$ (calls) | Expected Rate (per call) | Std. Dev. in Rate (per call) | Coefficient of Uncertainty in Rate |
| 1 - 10 | 15 | 16 | 32,800 | **5.4E-04** | 2.1E-04 | **0.39** |
| 10 - 100 | 5 | 6 | 32,800 | **2.0E-04** | 1.1E-04 | **0.52** |
| 100 – 1,000 | 3 | 4 | 32,800 | **1.4E-04** | 8.1E-05 | **0.60** |
| 1,000 - 10,000 | 0 | 1 | 32,800 | **3.4E-05** | 3.7E-05 | **1.08** |
| 10,000 - 100,000 | 0 | GOM Data Combined with World Data to Develop Estimate | | | | |
| 100,000 - 500,000 | 0 | GOM Data Combined with World Data to Develop Estimate | | | | |
| 500,000 – 1,000,000 | | Not Credible | | | | |

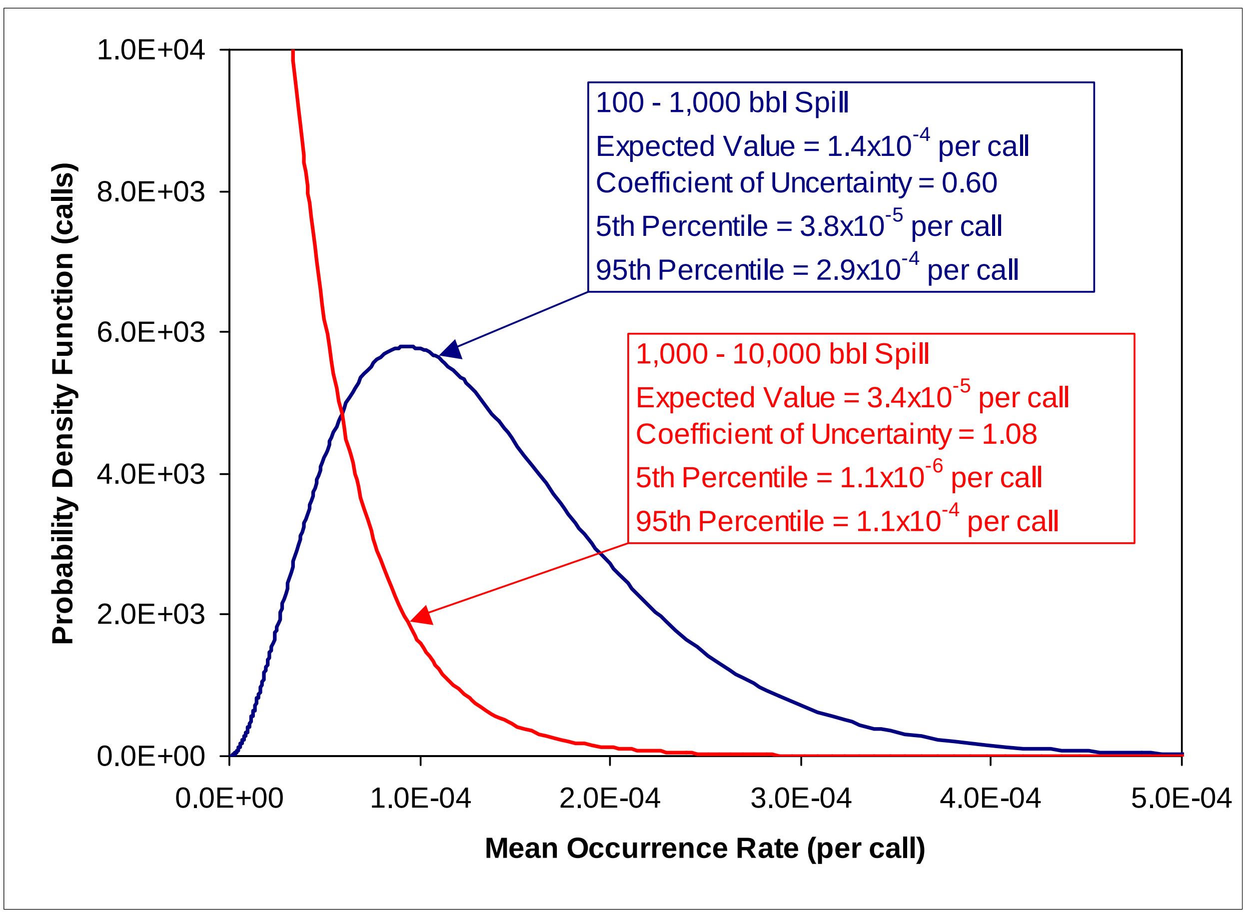



Fig. D.1 Example Probability Distributions for Estimated Mean Occurrence Rates

#### D.2.3.3 Multiple Data Sets

In the case of oil spills from shuttle tankers, there are no occurrences of spills greater than 1,000 bbl in the Gulf of Mexico between 1992 and 1999 (Table D.7), yet spills greater than 10,000 bbl and 100,000 bbl are possible. In order to estimate mean occurrence rates for spill sizes greater than 10,000 bbl, the data from the Gulf of Mexico are combined with tanker data from the rest of the world over the period from 1992 to 1999. First, the expected value and coefficient of uncertainty are estimated from the raw world data using Eqs. (D-5) and (D-6), as shown in Table D.8. Note that uncertainties in the estimated exposures for each data set are accounted for when the data sets are combined.

The advantage to including the world-wide data is the longer data record (720,000 docking calls versus 32,800 docking calls), which allows for more precise estimates of the mean occurrence rates for large spills (n is larger in Eq. D-6). The disadvantage to including these data is that the conditions in the rest of the world are not necessarily representative of those in the Gulf of Mexico. Specifically, tanker spills are considered to be more likely on average in the rest of the world than in the Gulf of Mexico for the following reasons, in order of importance:

1) the regulatory environment in the Gulf of Mexico is more restrictive than that world wide on average;
2) the environmental conditions in the Gulf of Mexico are less severe than those world wide on average;
3) the consequences of grounding are significantly less in the Gulf of Mexico compared to those world wide on average due to the lack of rocky coasts in the Gulf of Mexico;
4) the shuttle tankers to be used in the Gulf of Mexico will have a smaller parcel size than those used world wide on average;
5) the Gulf of Mexico has less congested waterways than those in other ports world wide on average; and
6) newer vessels will be used in the Gulf of Mexico (due to requirements for double hulls and other regulations) compared to those used world wide on average.

Before combining the data sets, the data from the rest of the world are adjusted so that they are statistically representative of conditions in the Gulf of Mexico. In order to account for the differences in tanker operations between the Gulf of Mexico and the world, the statistically-estimated frequencies for the rest-of-world are reduced by a factor of 1/3 based on input from technical experts. The primary basis for this factor of 1/3 is that the frequencies of spills in the Gulf of Mexico in smaller spill-size categories (50-5,000 bbls and >5,000 bbls) are both approximately 40 percent of the world-wide frequencies between 1992 and 1999. A coefficient of uncertainty of 1.0 is applied to this reduction factor to account for the considerable uncertainty in estimating this reduction factor from data for smaller spill sizes and expert judgement (values as small as 1/10 and even smaller are considered possible for this factor). The adjusted statistics for the data from the rest of the world are presented in Table D.9. The adjusted value for the expected rate is obtained by multiplying the expected values for the adjustment factor and the rate from the raw data. The adjusted value for the coefficient of uncertainty is obtained by taking the square root of the sum of the squared coefficient of uncertainty values for the adjustment factor and for the rate from the raw data.

Finally, the data sets for the Gulf of Mexico and for the rest of the world are combined now that they have the same basis (that is, both are representative of the conditions in the Gulf of Mexico). An equivalent exposure and an equivalent effective number of occurrences for the world data are calculated from the expected value and the coefficient of uncertainty as follows

$$\mu_{n^*} = \frac{\text{Expected Rate}}{\left(\text{Coefficient of Uncertainty x Expected Rate}\right)^2} \qquad \text{(D-9)}$$

and

$$k^* = \left(\text{Expected Rate}\right)\mu_{n^*} \qquad \text{(D-10)}$$

where the asterik indicates an equivalent value. These equations follow from the gamma distribution for the mean occurrence rate. The information from the Gulf of Mexico (no occurrences in the data record) is then combined with the world data as follows using a technique known as Bayesian updating (e.g., Ang and Tang 1975)

$$k_{total} = k^*_{world} + x_{GOM} \tag{D-11}$$

and

$$\mu_{n_{total}} = \mu_{n^*_{world}} + \mu_{n_{GOM}} \tag{D-12}$$

where $x_{GOM}$ is the number of occurrences in the data record for the Gulf of Mexico. The coefficient of variation for the total exposure is calculated as follows by assuming that the uncertainties in the exposures for the world and for the Gulf of Mexico are statistically independent

$$\Omega_{n_{total}} = \frac{\sqrt{\left(\mu_{n^*_{world}} \Omega_{n_{world}}\right)^2 + \left(\mu_{n_{GOM}} \Omega_{n_{GOM}}\right)^2}}{\mu_{n_{total}}} \tag{D-13}$$

Finally, the combined estimate for the expected value and coefficient of uncertainty in the mean occurrence rate are obtained by plugging $k_{total}$, $\mu_{n_{total}}$ and $\Omega_{n_{total}}$ into Eqs. (D-7) and (D-8). These calculations are shown in Table D.10.

Table D.8 Calculations to Estimate Mean Occurrence Rates for Oil Spills from Shuttle Tankers – Data from Rest of the World (Outside the Gulf of Mexico)

Total Exposure (docking calls) in Rest of World:

| | |
|---|---|
| Expected Total Docking Calls | 720,000 |

**Statistical Analysis:**

| Spill Size Range (bbl) | Number of Spills | Statistically-Based Estimates for Frequencies based on Raw Data | | | | |
|---|---|---|---|---|---|---|
| | | $k_{world}$ | Expected $n_{world}$ (calls) | Expected Rate (per call) | Std. Dev. in Rate (per call) | Coefficient of Uncertainty in Rate |
| 10,000 - 100,000 | 10 | 11 | 720,000 | 1.5E-05 | 4.6E-06 | 0.30 |
| 100,000 - 500,000 | 6 | 7 | 720,000 | 9.7E-06 | 3.7E-06 | 0.38 |

Table D.9 Calculations to Adjust World-Based Estimates for Mean Occurrence Rates for Oil Spills from Shuttle Tankers

| Spill Size Range (bbl) | Estimates from Raw Data | | Expert-Based Adjustment Factor | | Adjusted Estimates from Data | |
|---|---|---|---|---|---|---|
| | Expected Rate (per call) | Coefficient of Uncertainty in Rate | Expected Value for Factor | Coefficient of Uncertainty in Factor | Expected Rate (per call) | Coefficient of Uncertainty in Rate |
| 10,000 - 100,000 | 1.5E-05 | 0.30 | 0.33 | 1.0 | 5.1E-06 | 1.04 |
| 100,000 - 500,000 | 9.7E-06 | 0.38 | 0.33 | 1.0 | 3.2E-06 | 1.07 |

Table D.10 Calculations to Combine Data Sets for World and Gulf of Mexico to Estimate Mean Occurrence Rates for Oil Spills from Shuttle Tankers

| Spill Size Range (bbl) | World Data | | | Gulf of Mexico Data | | | Combined Data | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $k^*_{world}$ | $\mu_{n^*_{world}}$ (calls) | $\Omega_{n_{world}}$ | $x_{GOM}$ | $\mu_{n_{GOM}}$ | $\Omega_{n_{GOM}}$ | $k_{total}$ | $\mu_{n_{total}}$ (calls) | $\Omega_{n_{total}}$ | Expected Rate (per call) | Coefficient of Uncertainty in Rate |
| 10,000 - 100,000 | 0.93 | 1.8E+05 | 0.33 | 0 | 3.3E+04 | 0.33 | 0.93 | 2.1E+05 | 0.28 | **4.7E-06** | **1.11** |
| 100,000 - 500,000 | 0.87 | 2.7E+05 | 0.33 | 0 | 3.3E+04 | 0.33 | 0.87 | 3.0E+05 | 0.30 | **3.1E-06** | **1.15** |

## D.3. APPLICATION OF CALIBRATED RISK MODELS TO ASSESS STUDY SYSTEM RISKS

This section describes the steps used to apply the calibrated risk models in order to assess the risk measures for each study system. First the sub-system risks are assessed, and then these sub-system risks are combined to assess the system risks.

### D.3.1 Step Four – Determine Sub-System Exposures for Study Systems

The fourth step is to determine the exposure for each sub-system category in each study system. As an example for the production crew fatality risk, there is an average crew of 40 workers (including production and construction activities) on the FPSO working 24 hours per day and 365 days per year over the 20 year operational life, giving 70,080,000 man-hours of exposure. For the shuttle tanker spill risk, there are 3,196 docking calls that will be required over the 20-year life to offload the FPSO and shuttle the oil to the shore.

### D.3.2 Step Five – Assess Sub-System Risks for Study Systems

The fifth step is to assess the sub-system risk for each study system based on the frequency of incidents from the data set and the exposure for the study system. The estimated mean occurrence rates are applied to the study systems in accordance with their exposures to assess risks. However, the estimated mean occurrence rates are not necessarily equal to the mean occurrence rates estimated from the historical data (Step Three above) because the production systems that constitute the historical data are not necessarily representative of the study systems. The effect of extrapolating from historical occurrence rates to predict future performance is accounted for by applying an adjustment (or bias) factor to the data-based estimates as follows (Gilbert et al. 2001)

$$E(\nu^*) = \mu_B E(\nu) \quad \text{(D-14)}$$

where $E(\nu^*)$ is the expected value for the adjusted mean occurrence rate, $E(\nu)$ is the expected value for the mean occurrence rate estimated from the historical data (the result of Step Three above), and $\mu_B$ is the estimated (or expected value) for the adjustment. The estimated value for the adjustment is based on input from the technical experts. This adjustment may introduce additional uncertainty into the estimated mean occurrence rate, which is reflected as follows (Gilbert et al. 2001)

$$\text{StdDev}(\nu^*) = \sqrt{\text{StdDev}(\nu)^2 \mu_B^2 + (\Omega_B \mu_B)^2 E(\nu)^2} \quad \text{(D-15)}$$

where $\Omega_B$ is the coefficient of uncertainty in the adjustment factor, which is assigned using Table D.5. The expected value and the standard deviation for the adjusted mean occurrence are then used to assess the sub-system risks for fatalities and oil spills.

Example calculations for the mean occurrence rate of production crew fatailities are summarized in Table D.11. The expected value estimated from the data set is not adjusted ($\mu_B$ = 1.0); however, there was uncertainty in extrapolating directly from the historical data which is more representative of smaller, fixed jacket production systems versus larger, floating production systems. Therefore, a coefficient of uncertainty representing a moderate amount of uncertainty (Table D.5) is used, $\Omega_B$ = 0.33.

Table D.11 Adjusted Mean Occurrence Rate for Production Crew Fatalities

| | |
|---|---|
| Estimated Mean Occurrence Rate from Data | |
| E(ν) (per man-hr) | 7.9E-08 |
| StdDev(ν) (per man-hr) | 2.8E-08 |
| Coefficient of Uncertainty in Mean Rate | 0.36 |
| | |
| Expert-Based Extrapolation Factor | |
| Expected Value for Bias Factor, $\mu_B$ | 1.0 |
| Coefficient of Uncertainty in Bias Factor, $\Omega_B$ | 0.33 |
| | |
| Combined Estimate for Mean Occurrence Rate | |
| E(ν*) (per man-hr) | 7.9E-08 |
| StdDev(ν*) (per man-hr) | 3.9E-08 |
| Coefficient of Uncertainty in Mean Rate | 0.49 |

Example calculations for the mean occurrence rates of shuttle tanker spills are summarized in Table D.12. A bias is not imposed on the mean occurrence rates ($\mu_B$ = 1.0), but uncertainties in the extrapolations are considered to be moderate ($\Omega_B$ = 0.33).

Table D.12 Adjusted Mean Occurrence Rates for Shuttle Tanker Spills

| | **Data-Based Estimate** | | **Expert-Based Extrapolation Bias** | | **Combined (Expert+Data) Estimate** | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Expected Value for Mean Rate (per call) | Coefficient of Uncertainty for Mean Rate | Expected Value for Bias Factor, $\mu_B$ | Coefficient of Uncertainty for Bias Factor | Expected Value for Mean Rate (per call) | Coefficient of Uncertainty for Mean Rate |
| 1 - 10 | 5.4E-04 | 0.39 | 1.0E+00 | 0.33 | 5.4E-04 | 0.51 |
| 10 - 100 | 2.0E-04 | 0.52 | 1.0E+00 | 0.33 | 2.0E-04 | 0.61 |
| 100 – 1,000 | 1.4E-04 | 0.60 | 1.0E+00 | 0.33 | 1.4E-04 | 0.68 |
| 1,000 - 10,000 | 3.4E-05 | 1.08 | 1.0E+00 | 0.33 | 3.4E-05 | 1.13 |
| 10,000 - 100,000 | 4.7E-06 | 1.11 | 1.0E+00 | 0.33 | 4.7E-06 | 1.16 |
| 100,000 - 500,000 | 3.1E-06 | 1.15 | 1.0E+00 | 0.33 | 3.1E-06 | 1.19 |
| 500,000 – 1,000,000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**D.3.2.1 Sub-System Risks for Fatalities**

The expected value for the average total number of fatalities per sub-system category is given by the following equation

$$E(\text{Average Total Number of Fatalities}) = E(\nu^*)\,t \qquad \text{(D-16)}$$

where t is exposure for the study system. Also, the coefficient of variation in the average total number of fatalities is equal to the coefficient of uncertainty in the mean occurrrence rate, $\text{StdDev}(\nu^*)/E(\nu^*)$. Example calculations for the production crew on the FPSO are summarized in Table D.13, giving an expected value of 0.56 fatalities in 20 years with a coefficient of uncertainty of 0.49.

Table D.13 Expected Value and Standard Deviation for FPSO Production Crew Fatalities

| | |
|---|---|
| Combined Estimate for Mean Occurrence Rate | |
| E(ν*) (per man-hr) | 7.9E-08 |
| StdDev(ν*) (per man-hr) | 3.9E-08 |
| Coefficient of Uncertainty in Mean Rate | 0.49 |
| | |
| Study System Exposure for FPSO (man-hr) | 7.0E+06 |
| | |
| Average Total Number of Fatalities | |
| Expected Value | **0.56** |
| Coefficient of Uncertainty | **0.49** |

### D.3.2.2 Sub-System Risks for Oil Spills

Evaluating the sub-system risks for oil spills is more complicated than for fatalities because (1) the oil spills are divided into multiple spill size categories and (2) the expected maximum spill size in a single incident needs to be calculated as well as the expected total spill volume.

The expected value for the average total oil spilled in the exposure is calculated from Eq. (D-2) by summing the product of the expected number of incidents multiplied by the expected size of a spill for all of the spill size categories as follows

$$E\left(\text{Average Total Oil Spill Volume}\right) = \sum_{i=1}^{m} E\left(N_i\right) E\left(\text{Spill Size i}\right) \qquad \text{(D-17)}$$

where E(Total Oil Spill Volume) is the expected value for the total oil spill volume, $E(N_i)$ is the the expected number of occurrences for incidents in spill size category i, and E(Spill Size i) is the expected spill volume in spill size category i.  The expected number of occurrences is calculated by multiplying the expected frequency of occurrence by the study system exposure

$$E\left(N_i\right) = E\left(\nu_i^*\right) t \qquad \text{(D-18)}$$

where $E(N_i)$ is the expected number of incidents in spill size category i and t is the exposure.

The expected or representative spill size in a category, E(Spill Size i) in Eq. (D-17), is calculated by assuming that the spill size is uniformly distributed over the range of spill sizes for that category, as shown on Fig. D.2. The expected value is then approximated by the antilog of the midpoint on a logarithmic scale. These representative spill sizes are summarized in Table D.14. In modeling the tail of the probability distribution for large spill sizes, a lower triangular distribution instead of a uniform distribution is used for some sub-systems (Fig. D.2), specifically pipelines and shuttle tankers, based on input from the technical experts. In these cases, the expected value is approximated by the antilog of the lower-third point on a logarithmic scale (Table D.14). Also, the expected spill size for a spill from the FPSO cargo tank in the 100,000 to 500,000 bbl range is chosen to reflect the most typical operating condition, which is a cargo of 350,000 bbl.

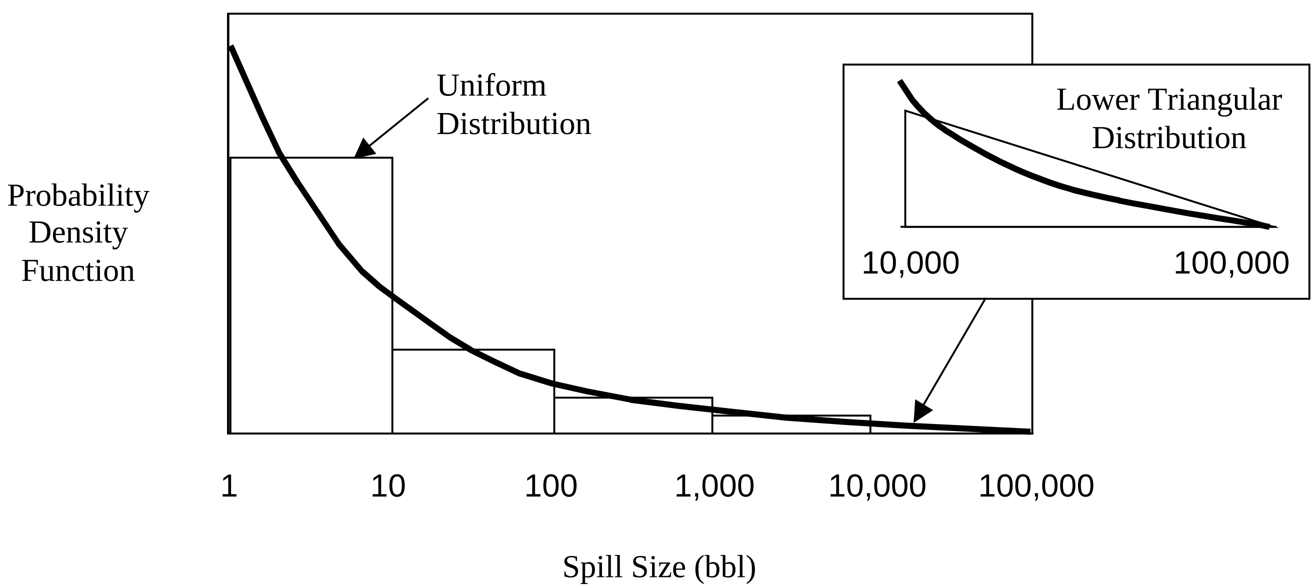



Fig. D.2 Representative Spill Sizes for Spill Size Categories

The expected value for the average maximum volume spilled in a single incident is obtained from Eq. (D-4) by summing the product of the probability that the maximum spill size is in category i multiplied by the expected spill size in that category as follows

$$E\left(\text{Average Maximum Spill Volume in an Incident}\right) \simeq \sum_{i=1}^{m} P\left(\text{spill size i is maximum}\right) E\left(\text{Spill Size i}\right) \quad \text{(D-19)}$$

where E(Average Maximum Spill Volume in an Incident) is the expected value for the average maximum oil spill volume in a single incident and P(spill size i is maximum in t) is the probability that a particular spill size is the maximum spill size in the exposure and calculated as follows

$$\begin{aligned} P(\text{spill size i is maximum in t}) &= P(\text{at least one incident in i})\,P(\text{no spills in larger categories}) \\ &= \left(1-e^{-E(\nu_i^*)t}\right)\left[\prod_{j=m}^{i+1} e^{-E(\nu_j^*)t}\right] \end{aligned} \tag{D-20}$$

where m is the total number of spill size categories. Equation (D-19) is an approximation because the expected spill size for category i, E(Spill Size i) from Table D.14, is being used to approximate the expected maximum spill size in category i, which would be greater than the expected spill size if multiple incidents occur. However, this approximation is reasonable because the expected maximum spill size is governed by the largest spill size categories where the possibility of multiple spills is remote.

Table D.14 Expected Spill Sizes for Spill Size Categories

| Spill Size Range (bbl) | Expected Spill Size for Uniform Distribution (bbl) | Expected Spill Size for Lower Triangular Distribution (bbl) |
|---|---|---|
| 1 – 10 | 3 | Not Used |
| 10 – 100 | 32 | Not Used |
| 100 – 1,000 | 320 | Not Used |
| 1,000 – 10,000 | 3,200 | Not Used |
| 10,000 – 100,000 | 32,000 | 21,000 |
| 100,000 – 500,000 | 225,000 | 171,000 |
| 500,000 – 1,000,000 | 707,000 | Not Used |

Example calculations are summarized in Tables D.15 and D.16 for the FPSO shuttle tanker, giving 2,700 bbl for the expected total volume of oil spilled from the shuttle tanker and 2,600 bbl for the expected maximum volume spilled in a single incident. Note that the expected maximum volume in a single incident is nearly equal to the expected total volume, meaning that the total is dominated by the worst single incident.

Table D.15 Occurrence Information for Oil Spills from FPSO Shuttle Tanker

| Spill Size Range (bbl) | Expected Frequency, E(ν*) (per call) | Exposure in Life, t (calls) | Expected Number of Occurrences | Probability of Zero Spill Size i's in Life | Probability Spill Size i is Maximum Spill in Life |
|---|---|---|---|---|---|
| 1 – 10 | 5.4E-04 | 3196 | 1.7E+00 | 1.8E-01 | 2.4E-01 |
| 10 – 100 | 2.0E-04 | 3196 | 6.5E-01 | 5.2E-01 | 2.7E-01 |
| 100 – 1,000 | 1.4E-04 | 3196 | 4.3E-01 | 6.5E-01 | 3.1E-01 |
| 1,000 – 10,000 | 3.4E-05 | 3196 | 1.1E-01 | 9.0E-01 | 1.0E-01 |
| 10,000 – 100,000 | 4.7E-06 | 3196 | 1.5E-02 | 9.9E-01 | 1.5E-02 |
| 100,000 – 500,000 | 3.1E-06 | 3196 | 1.0E-02 | 9.9E-01 | 9.9E-03 |
| 500,000 – 1,000,000 | 0.0E+00 | 3196 | 0.0E+00 | 1.0E+00 | 0.0E+00 |

Table D.16 Expected Values of Oil Spill Volumes for Oil Spills from FPSO Shuttle Tanker

| Spill Size Range (bbl) | Expected Spill Size (bbl) | Expected Number of Occurrences | Expected Total Spill Volume (bbl) | Probability Spill Size i is Maximum Spill in Life | Expected Average Maximum Spill Volume (bbl) |
|---|---|---|---|---|---|
| 1 – 10 | 3 | 1.7E+00 | 5.2E+00 | 2.4E-01 | 7.3E-01 |
| 10 – 100 | 32 | 6.5E-01 | 2.1E+01 | 2.7E-01 | 8.7E+00 |
| 100 – 1,000 | 320 | 4.3E-01 | 1.4E+02 | 3.1E-01 | 9.8E+01 |
| 1,000 – 10,000 | 3,200 | 1.1E-01 | 3.5E+02 | 1.0E-01 | 3.2E+02 |
| 10,000 - 100,000 | 32,000 | 1.5E-02 | 4.8E+02 | 1.5E-02 | 4.7E+02 |
| 100,000 - 500,000 | 171,000 | 1.0E-02 | 1.7E+03 | 9.9E-03 | 1.7E+03 |
| 500,000 – 1,000,000 | 707,000 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |
| | | Σ | **2.7E+03** | | **2.6E+03** |

The standard deviations for the average total volume spilled and the average maximum volume spilled in a single incident are calculated as follows. The variance (or the square of the standard deviation) for the total volume spilled is obtained from the following equation

$$\mathrm{Var}\left(\text{Average Total Oil Spill Volume}\right) = \sum_{i=1}^{m} \mathrm{Var}\left(N_i\right) E\left(\text{Spill Size i}\right)^2 \qquad \text{(D-21)}$$

where Var(Total Oil Spill Volume) is the variance in the total oil spill volume due to uncertainty in the frequency of occurrence, and Var($N_i$) is the variance in the number of occurrences in spill size category i, which is given by the following

$$Var\left(N_i\right) = t^2 StdDev\left(\nu_i\right)^2 \qquad \text{(D-22)}$$

Therefore, the variance in the total oil spill volume increases as the uncertainty in the estimated value for the mean occurrence rate increases. Also, the variance for the maximum volume spilled in a single incident is obtained from the following first-order approximation

$$\mathrm{Var}\left(\text{Average Maximum Spill Volume in a Single Incident}\right) \simeq$$
$$\sum_{i=1}^{m} \mathrm{E}\left(\text{Spill Size i}\right)^2 \left(\prod_{j=i+1}^{m} e^{-\mathrm{E}(\nu_j)t}\right)^2 \left\{\left(e^{-\mathrm{E}(\nu_i)t}\right)^2 \mathrm{Var}\left(N_i\right) + \left(1-e^{-\mathrm{E}(\nu_i)t}\right)^2 \sum_{k=i+1}^{m} \mathrm{Var}\left(N_k\right)\right\} \quad \text{(D-23)}$$

Example calculations for the FPSO shuttle tanker are summarized in Table D.17, giving a standard deviation for the total volume spilled of $\sqrt{4.6\text{x}10^6\ \text{bbl}^2} = 2{,}100\ \text{bbl}$ and a standard deviation for the maximum volume spilled in a single incident of $\sqrt{4.5\text{x}10^6\ \text{bbl}^2} = 2{,}100\ \text{bbl}$.

Table D.17 Variances of Oil Spill Volumes for FPSO Shuttle Tanker

| Spill Size Range (bbl) | Expected Spill Size (bbl) | Exposure in Life, t (call) | StdDev(ν) (per call) | Variance for Number of Occurrences, Var(N) | Variance for Average Total Spill Volume ($bbl^2$) | Variance for Average Maximum Spill Volume ($bbl^2$) |
|---|---|---|---|---|---|---|
| 1 – 10 | 3 | 3,196 | 2.8E-04 | 7.9E-01 | 7.1E+00 | 1.6E-01 |
| 10 – 100 | 32 | 3,196 | 1.2E-04 | 1.6E-01 | 1.6E+02 | 2.2E+01 |
| 100 – 1,000 | 320 | 3,196 | 9.2E-05 | 8.7E-02 | 8.9E+03 | 3.0E+03 |
| 1,000 – 10,000 | 3,200 | 3,196 | 3.8E-05 | 1.5E-02 | 1.5E+05 | 1.2E+05 |
| 10,000 - 100,000 | 32,000 | 3,196 | 5.4E-06 | 3.0E-04 | 3.0E+05 | 2.9E+05 |
| 100,000 - 500,000 | 171,000 | 3,196 | 3.7E-06 | 1.4E-04 | 4.1E+06 | 4.1E+06 |
| 500,000 – 1,000,000 | 707,000 | 3,196 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |
| | | | | Σ | 4.6E+06 | 4.5E+06 |

**D.3.3 Step Six – Assess System Risks from Sub-System Risks**

The sixth and final step is to combine the information for the sub-system risks to obtain the total system risk.

#### D.3.3.1  System Risks for Fatalities

The expected value for the average total number of fatalities for the system is obtained by summing the expected values for each sub-system as follows

$$E\left(\text{Average Total Number of Fatalities}\right) = \sum_{j=1}^{p} E\left(\text{Average Total Number of Fatalities}\right)_j \quad \text{(D-24)}$$

where p is the total number of sub-systems.  Also, the standard deviation in the total number of fatalities for the system is obtained from the following equation

$$\begin{aligned} &\text{StdDev}\left(\text{Average Total Number of Fatalities}\right) \\ &= \sqrt{\sum_{j=1}^{p} \text{Var}\left(\text{Average Total Number of Fatalities}\right)_j} \end{aligned} \quad \text{(D-25)}$$

Finally, the distribution for the average total number of fatalities is assumed to be a gamma distribution.  This assumption is reasonable if the standard deviation for the average total number of fatalites is small, which is the case for fatalities, or if a single sub-system dominates the total.

#### D.3.3.2  System Risks for Oil Spills

For oil spills, the sub-system information is combined by first normalizing all of the sub-system frequencies by the same denominator – years.  Specifically, the number of occurrences is divided by the operational life of 20 years as follows

$$E\left(\nu_{20,i}\right)_j = \frac{E\left(N_i\right)_j}{20 \text{ years}} \quad \text{(D-26)}$$

and

$$\text{StdDev}\left(\nu_{20,i}\right)_j = \frac{\text{StdDev}\left(N_i\right)_j}{20 \text{ years}} \quad \text{(D-27)}$$

where $\nu_{20,i}$ is the normalized frequency of occurrence per year, i is the spill size category, and j is the sub-system (for example, shuttle tankers). The expected value and standard deviation for the total frequency for spill size category i is then obtained as follows

$$E\left(\nu_{20,i}\right) = \sum_{j=1}^{p} E\left(\nu_{20,i}\right)_j \tag{D-28}$$

and

$$\mathrm{StdDev}\left(\nu_{20,i}\right) = \sqrt{\sum_{j=1}^{p} \left[\mathrm{StdDev}\left(\nu_{20,i}\right)_j\right]^2} \tag{D-29}$$

where p is the total number of sub-systems. Given the expected value and the standard deviation of the total normalized frequency for each spill size category and an exposure period of 20 years, Equations (D-17) through (D-24) can be applied to find the expected values and standard deviations for the total volume of oil spilled and the maximum volume of oil spilled in a single incident for the system. Note that the average maximum volume of oil spilled is not simply the sum of the average maximum volumes for individual sub-systems (instead, Eqs. D-19 and D-23 must be applied using the expected value and standard deviation for $\nu_{20,i}$). The distributions for the average total volume of oil spilled and the average maximum volume spilled in a single incident are assumed to be gamma distributions. This assumption is reasonable if the standard deviation for the quantity is small or if a single sub-system dominates the total, which is the case for both oil spill measures.

Appendix E

Fatality Risk Assessments

Table E.1 Fatality Data: Summary of Raw Data and Refinements for this Study

| | | **Refinements to Raw Data** | | | |
|---|---|---|---|---|---|
| **Sub-system** | **Data Source** | **Spar** | **TLP** | **Hub/Host Jacket** | **FPSO** |
| **Production Crew** | Total number of fatalities for Gulf of Mexico taken from USCG Casualty Database for the years 1992-1999 and for the category "Platform," which includes fatalities from process and construction activities. Drilling-related fatalities on platforms excluded. Frequencies normalized by total man-hours worked in process and construction activities, which was estimated from MMS data for 1998 and 1999. | No Changes | No Changes | No Changes | No Changes |
| **Drilling Crews** | Total number of offshore Gulf of Mexico drilling fatalities taken from IADC database on driller safety for the years 1989-1998. Frequencies normalized by total man-hours worked, which was also taken from the same data source. Data not distinguished between exploratory versus production drilling, and platform versus MODU drilling. | No Changes | No Changes | No Changes | No Changes |
| **Supply Vessel Crews** | Total number of fatalities for Gulf of Mexico taken from USCG Casualty Database for the years 1985-1999 and for the category "Offshore Supply Vessel." Frequencies normalized by the number of port or docking calls. The total number of docking calls in the Gulf of Mexico for the years 1985-1999 roughly estimated from discussions with Edison Chouest. | No Changes | No Changes | No Changes | No Changes |

Table E.1 Fatality Data: Summary of Raw Data and Refinements for this Study

| | | Refinements to Raw Data | | | |
|---|---|---|---|---|---|
| **Sub-system** | **Data Source** | **Spar** | **TLP** | **Hub/Host Jacket** | **FPSO** |
| **Helicopter Transport** | Total number of fatalities for Gulf of Mexico taken from Oil and Gas Producers 1999 report on Worldwide Helicopter Safety. Data summarized for the years 1994 to 1998 in terms of number of fatalities and total number of occupants in the Gulf of Mexico. | No Changes | No Changes | No Changes | No Changes |
| **Tanker Operations** | Total number of fatalities for Gulf of Mexico taken from USCG Casualty Database for the years 1985-1999 and for the category "Tank Ship." Vessels not carrying crude oil and vessels less than 50,000 dead weight tons not included. Frequencies normalized by the number of port or docking calls for oil import operations in the Gulf of Mexico. The total number of tanker docking calls in the Gulf of Mexico for the years 1985-1999 estimated from oil import information in the NRC Marine Board lightering study and assuming average sizes for tankers. Estimates checked with Skaugen Petrotrans. | Not Applicable | Not Applicable | Not Applicable | No Changes |
| **Major Accident** | The frequency of a major (tens of fatalities) accident is estimated from the following information: no major accidents in the Gulf of Mexico between 1965 and 1999 with approximately 500 manned platforms in operation per year. The expected number of fatalities in a catastrophic accident is assumed to be 30. | No Changes (Note that estimate is considered to be conservative since no such accidents have occurred in the Gulf of Mexico.) | No Changes (Note that estimate is considered to be conservative since no such accidents have occurred in the Gulf of Mexico.) | No Changes (Note that estimate is considered to be conservative since no such accidents have occurred in the Gulf of Mexico.) | No Changes (Note that estimate is considered to be conservative since no such accidents have occurred in the Gulf of Mexico.) |

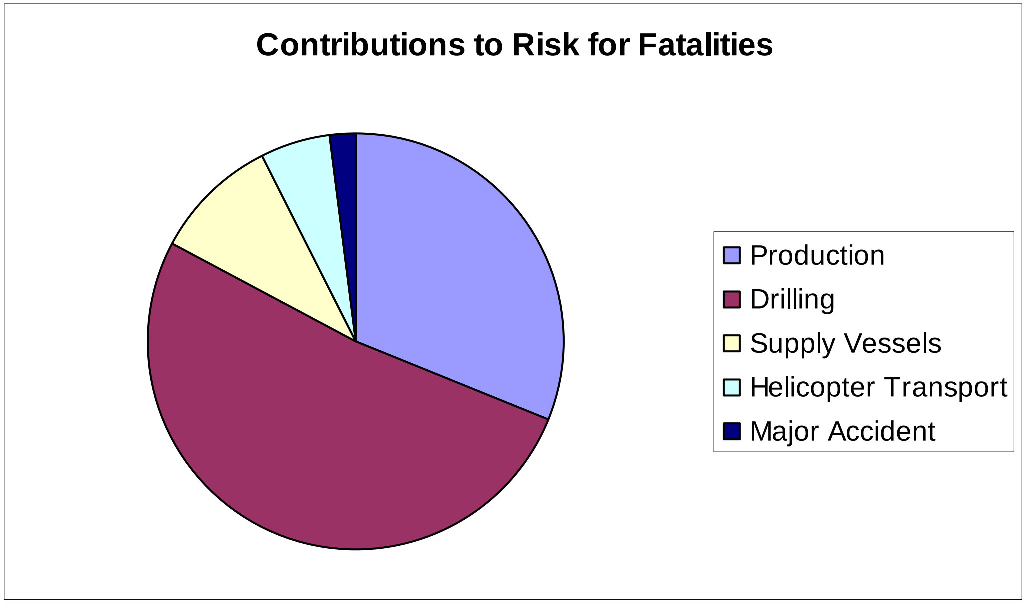
Appendix E.1

Fatality Risk Assessment for Spar

**Spar - Summary for Fatality Risk**

| | |
|---|---|
| **Expected Total Fatalities** | 1.8 |
| **Standard Deviation in Total Fatalities** | 0.3 |

| | | | Data-Based Estimate | | Expert-Based Extrapolation | | Combined (Expert+Data) | |
|---|---|---|---|---|---|---|---|---|
| **Activity** | **Exposure Units** | **Exposure (exposure units)** | **Expected Fatality Rate (per exposure unit)** | **Coefficient of Uncertainty in Fatality Rate** | **Expected Value for Bias** | **Coefficient of Uncertainty in Bias** | **Expected Value for Number of Fatalities** | **Coefficient of Uncertainty in Number of Fatalities** |
| Production | man-hours | 7.0E+06 | 7.9E-08 | 0.36 | 1.00 | 0.33 | 0.56 | 0.49 |
| Drilling | man-hours | 6.5E+06 | 1.4E-07 | 0.14 | 1.00 | 0.00 | 0.92 | 0.14 |
| Supply Vessels | docking calls | 1.2E+04 | 1.4E-05 | 0.34 | 1.00 | 0.33 | 0.17 | 0.47 |
| Helicopter Transport | passengers | 8.0E+04 | 1.2E-06 | 0.18 | 1.00 | 0.00 | 0.10 | 0.18 |
| Major Accident | platform years | 2.0E+01 | 1.7E-03 | 1.00 | 1.00 | 1.00 | 0.03 | 1.41 |




E.5 –Fatality Risk Assessment for Spar

**Spar - Production Crew**

| | |
|---|---|
| Exposure (man-hours) | 7.0E+06 |
| Expected Fatality Rate (per man-hour) | 7.9E-08 |
| Coefficient of Uncertainty in Fatality Rate | 0.36 |

Note: "Production Crew" includes product processing and construction activities.

**Basis:**

USCG Gulf of Mexico "Platform" Fatalities (Drilling-Related Fatalities Excluded)

| Year | Fatalities |
|---|---|
| 1992 | 4 |
| 1993 | 1 |
| 1994 | 4 |
| 1995 | 6 |
| 1996 | 2 |
| 1997 | 2 |
| 1998 | 8 |
| 1999 | 0 |

Total Exposure (man-hrs) for Gulf of Mexico (1992-1999):

| | |
|---|---|
| Annual 1998-1999 Avg. (MMS Production/Construction) | 4.16E+07 |
| Increase to account for 85% reporting | 4.89E+07 |
| Total 92-99 Man-hours (assume 98-99 avg. applies) | 3.91E+08 |
| Coefficient of Uncertainty in Exposure | 3.30E-01 |

Statistical Analysis:

| | |
|---|---|
| Exposure (man-hr) | 391,321,755 |
| Fatalities | 27 |
| k" | 28 |
| n" (man-hr) | 391,321,755 |
| Expected Rate (per man-hr) | 7.93E-08 |
| Std. Dev. in Rate (per man-hr) | 2.82865E-08 |
| Coefficient of Uncertainty in Rate | 3.57E-01 |

Production Crew Exposure for Study System

| | |
|---|---|
| Crew Size | 40 |
| Hours in 20 years | 175200 |

| | |
|---|---|
| **Total man-hours** | **7008000** |

**Spar - Drilling Crew**

| | |
|---|---|
| Exposure (man-hours) | 6.5E+06 |
| Expected Fatality Rate (per man-hour) | 1.4E-07 |
| Coefficient of Uncertainty in Fatality Rate | 0.14 |

**Basis:**

IADC Gulf of Mexico Statistics (1989-1999):

| IADC Gulf of Mexico Statistics | | | Fatalities Reported to USCG* |
|---|---|---|---|
| **Year** | **Hours Worked** | **Fatalities** | |
| 1989 | 33,211,815 | 11 | 15 |
| 1990 | 34,624,227 | 8 | 4 |
| 1991 | 28,210,398 | 2 | 0 |
| 1992 | 20,024,172 | 0 | 1 |
| 1993 | 23,603,277 | 3 | 3 |
| 1994 | 29,733,657 | 5 | 6 |
| 1995 | 32,386,695 | 3 | 3 |
| 1996 | 32,827,738 | 3 | 4 |
| 1997 | 41,222,488 | 8 | 6 |
| 1998 | 43,437,749 | 6 | 2 |
| 1999 | 33,011,864 | 0 | 3 |

*USCG Reported: Fatalities on MODUs and Drilling-Related Fatalities on Fixed Platforms

Statistical Analysis:

| | |
|---|---|
| Exposure (man-hr) | 352,294,080 |
| Coefficient of Uncertainty in Exposure | 0 |
| Fatalities | 49 |
| k" | 50 |
| n" (man-hr) | 352,294,080 |
| Expected Rate (per man-hr) | 1.42E-07 |
| Std. Dev. in Rate (per man-hr) | 2.00715E-08 |
| Coefficient of Uncertainty in Rate | 1.41E-01 |

Driller Exposure for Study System

| 6 Platform Wells (20 years) | **days** | **crew** | **man-days** |
|---|---|---|---|
| Drilling & Completion (5*90 + 6*20 days) | 570 | 65 | 37050 |
| Slickline (3 per well-year @ 5 days) | 1800 | 4 | 7200 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Change out (1/3 per well-yr @ 50 days) | 2000 | 40 | 80000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 | 40 | 48000 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 | 40 | 20800 |

| 3 Subsea Wells (12 years) | **days** | **crew** | **man-days** |
|---|---|---|---|
| Drilling & Completion (3*90 + 90 days) | 360 | 65 | 23400 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 | 4 | 720 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 | 8 | 1152 |
| Change out (1/8 per well-yr @ 50 days) | 225 | 8 | 1800 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 | 40 | 7200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 | 40 | 6240 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 | 40 | 7800 |

| | |
|---|---|
| Total (man-days): | 270162 |
| **Total man-hours** | **6483888** |

**Spar - Supply Vessel Crews**

| | |
|---|---|
| Exposure (docking calls) | 1.2E+04 |
| Expected Fatality Rate (per call) | 1.4E-05 |
| Coefficient of Uncertainty in Fatality Rate | 0.34 |

**Basis:**

USCG Gulf of Mexico "Offshore Supply Vessel" Fatalities

| Year | Fatalities |
|---|---|
| 1985 | 2 |
| 1986 | 1 |
| 1987 | 1 |
| 1988 | 0 |
| 1989 | 3 |
| 1990 | 0 |
| 1991 | 3 |
| 1992 | 3 |
| 1993 | 4 |
| 1994 | 4 |
| 1995 | 3 |
| 1996 | 3 |
| 1997 | 8 |
| 1998 | 3 |
| 1999 | 3 |

Total Exposure for Gulf of Mexico (1985-1999):

| | |
|---|---|
| Annual Dock Calls (300 boats x 2 calls/day x 365 d) | 2.19E+05 |
| Est. 85-99 Supply Vessel Activity in GOM (calls) | 3.29E+06 |
| Coefficient of Uncertainty in Exposure | 0.33 |

Statistical Analysis:

| | |
|---|---|
| Exposure (calls) | 3,285,000 |
| Fatalities | 41 |
| k" | 42 |
| n" (calls) | 3,285,000 |
| Expected Rate (per call) | 1.42E-05 |
| Std. Dev. in Rate (per call) | 4.79219E-06 |
| Coefficient of Uncertainty in Rate | 3.38E-01 |

Supply Vessel Crew Exposure for Study System

| | |
|---|---|
| 1 trip per 3 days during production | 0.333333333 |
| Days of Production (20 years) | 7300 |
| Trips | 2433.333333 |

| | |
|---|---|
| 1 trip per 3 days during drilling/workover | 0.333333333 |
| 6 Platform Wells (20 years) | |
| Drilling & Completion (5*90 + 6*20 days) | 570 |
| Slickline (3 per well-year @ 5 days) | 1800 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 |
| Change out (1/3 per well-yr @ 50 days) | 2000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 |
| Trips | 3230 |

| | |
|---|---|
| 3 Subsea Wells (12 years) | |
| Drilling & Completion (3*90 + 90 days) | 360 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 |
| Change out (1/8 per well-yr @ 50 days) | 225 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 |
| Trips | 480 |

| | |
|---|---|
| **Docking calls (trips*2)** | **12287** |

**Spar - Helicopter Transport**

| | |
|---|---|
| Exposure (passengers) | 8.03E+04 |
| Expected Fatality Rate (per passenger) | 1.2E-06 |
| Coefficient of Uncertainty in Fatality Rate | 0.18 |

**Basis:**

OGP Helicopter Safety Report (1999) (Gulf of Mexico Fatalities)

| Year | Fatalities | Passengers |
|---|---|---|
| 1994 | 10 | 4.8E+06 |
| 1995 | 8 | 5.7E+06 |
| 1996 | 11 | 5.8E+06 |
| 1997 | 1 | 5.0E+06 |
| 1998 | 1 | 5.0E+06 |

Statistical Analysis:

| | |
|---|---|
| Exposure (passengers) | 26,265,664 |
| Fatalities | 31 |
| k" | 32 |
| n" (passengers) | 26,265,664 |
| Expected Rate (per passenger) | 1.21832E-06 |
| Coefficient of Uncertainty in Rate | 0.176776695 |

Helicopter Transport Exposure for Study System

| | |
|---|---|
| Platform Crew | 40 |
| Number of Crew Changes in 20 years (14 days) | 521 |
| Number of Passengers (round trip) | 41714 |

| | |
|---|---|
| Drilling Crew (man-hours) | 6483888 |
| Man-hours per shift (14 days) | 336 |
| Man shift changes | 19297 |
| Number of Passengers (round trip) | 38595 |

| | |
|---|---|
| **Total Number of Passengers** | **80309** |

**<u>Spar - Major Accident</u>**

| | |
|---|---|
| Exposure (platform years) | 2.0E+01 |
| Expected Fatality Rate (per platform year) | 1.7E-03 |
| Coefficient of Uncertainty in Fatality Rate | 1.00 |

**Basis:**

Number of Major Offshore Accidents in GOM in 35 years = 0

Total Offshore Exposure in GOM (35 years)

| | |
|---|---|
| Manned Platforms per Year | 500 |
| Number of Years | 35 |
| Manned Platform Years | 17500 |

Statistical Analysis:

| | |
|---|---|
| Exposure (manned platform years) | 17,500 |
| Major Accidents | 0 |
| k" | 1 |
| n" (platform years) | 17,500 |
| Expected Incident Rate (per platform year) | 5.71429E-05 |
| Coefficient of Uncertainty in Incident Rate | 1 |
| Number of Fatalities per Major Accident | 30 |
| Expected Fatality Rate (per platform year) | 0.001714286 |
| Coefficient of Uncertainty in Incident Rate | 1 |

Exposure for Study System

| | |
|---|---|
| **Manned Years** | **20** |

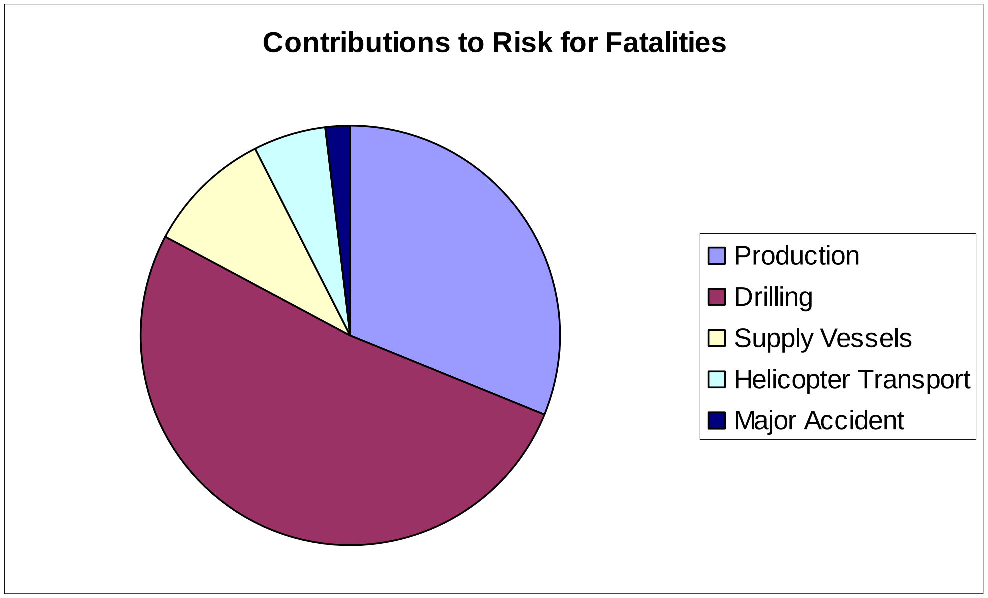
Appendix E.2

Fatality Risk Assessment for TLP

**TLP - Summary for Fatality Risk**

| | |
|---|---|
| **Expected Total Fatalities** | 1.8 |
| **Standard Deviation in Total Fatalities** | 0.3 |

| | | | Data-Based Estimate | | Expert-Based Extrapolation | | Combined (Expert+Data) | |
|---|---|---|---|---|---|---|---|---|
| **Activity** | **Exposure Units** | **Exposure (exposure units)** | **Expected Fatality Rate (per exposure unit)** | **Coefficient of Uncertainty in Fatality Rate** | **Expected Value for Bias** | **Coefficient of Uncertainty in Bias** | **Expected Value for Number of Fatalities** | **Coefficient of Uncertainty in Number of Fatalities** |
| Production | man-hours | 7.0E+06 | 7.9E-08 | 0.36 | 1.00 | 0.33 | 0.56 | 0.49 |
| Drilling | man-hours | 6.5E+06 | 1.4E-07 | 0.14 | 1.00 | 0.00 | 0.92 | 0.14 |
| Supply Vessels | docking calls | 1.2E+04 | 1.4E-05 | 0.34 | 1.00 | 0.33 | 0.17 | 0.47 |
| Helicopter Transport | passengers | 8.0E+04 | 1.2E-06 | 0.18 | 1.00 | 0.00 | 0.10 | 0.18 |
| Major Accident | platform years | 2.0E+01 | 1.7E-03 | 1.00 | 1.00 | 1.00 | 0.03 | 1.41 |




E.15 –Fatality Risk Assessment for TLP

**<u>TLP - Production Crew</u>**

| | |
|---|---|
| Exposure (man-hours) | 7.0E+06 |
| Expected Fatality Rate (per man-hour) | 7.9E-08 |
| Coefficient of Uncertainty in Fatality Rate | 0.36 |

Note: "Production Crew" includes product processing and construction activities.

**Basis:**

USCG Gulf of Mexico "Platform" Fatalities (Drilling-Related Fatalities Excluded)

| Year | Fatalities |
|---|---|
| 1992 | 4 |
| 1993 | 1 |
| 1994 | 4 |
| 1995 | 6 |
| 1996 | 2 |
| 1997 | 2 |
| 1998 | 8 |
| 1999 | 0 |

Total Exposure (man-hrs) for Gulf of Mexico (1992-1999):

| | |
|---|---|
| Annual 1998-1999 Avg. (MMS Production/Construction) | 4.16E+07 |
| Increase to account for 85% reporting | 4.89E+07 |
| Total 92-99 Man-hours (assume 98-99 avg. applies) | 3.91E+08 |
| Coefficient of Uncertainty in Exposure | 3.30E-01 |

Statistical Analysis:

| | |
|---|---|
| Exposure (man-hr) | 391,321,755 |
| Fatalities | 27 |
| k" | 28 |
| n" (man-hr) | 391,321,755 |
| Expected Rate (per man-hr) | 7.93E-08 |
| Std. Dev. in Rate (per man-hr) | 2.82865E-08 |
| Coefficient of Uncertainty in Rate | 3.57E-01 |

Production Crew Exposure for Study System

| | |
|---|---|
| Crew Size | 40 |
| Hours in 20 years | 175200 |

| | |
|---|---|
| **Total man-hours** | **7008000** |

**TLP - Drilling Crew**

| | |
|---|---|
| Exposure (man-hours) | 6.5E+06 |
| Expected Fatality Rate (per man-hour) | 1.4E-07 |
| Coefficient of Uncertainty in Fatality Rate | 0.14 |

**Basis:**

IADC Gulf of Mexico Statistics (1989-1999):

| IADC Gulf of Mexico Statistics | | | Fatalities Reported to USCG* |
|---|---|---|---|
| Year | Hours Worked | Fatalities | |
| 1989 | 33,211,815 | 11 | 15 |
| 1990 | 34,624,227 | 8 | 4 |
| 1991 | 28,210,398 | 2 | 0 |
| 1992 | 20,024,172 | 0 | 1 |
| 1993 | 23,603,277 | 3 | 3 |
| 1994 | 29,733,657 | 5 | 6 |
| 1995 | 32,386,695 | 3 | 3 |
| 1996 | 32,827,738 | 3 | 4 |
| 1997 | 41,222,488 | 8 | 6 |
| 1998 | 43,437,749 | 6 | 2 |
| 1999 | 33,011,864 | 0 | 3 |

*USCG Reported: Fatalities on MODUs and Drilling-Related Fatalities on Fixed Platforms

Statistical Analysis:

| | |
|---|---|
| Exposure (man-hr) | 352,294,080 |
| Coefficient of Uncertainty in Exposure | 0 |
| Fatalities | 49 |
| k" | 50 |
| n" (man-hr) | 352,294,080 |
| Expected Rate (per man-hr) | 1.42E-07 |
| Std. Dev. in Rate (per man-hr) | 2.00715E-08 |
| Coefficient of Uncertainty in Rate | 1.41E-01 |

Driller Exposure for Study System

| 6 Platform Wells (20 years) | days | crew | man-days |
|---|---|---|---|
| Drilling & Completion (5*90 + 6*20 days) | 570 | 65 | 37050 |
| Slickline (3 per well-year @ 5 days) | 1800 | 4 | 7200 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Change out (1/3 per well-yr @ 50 days) | 2000 | 40 | 80000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 | 40 | 48000 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 | 40 | 20800 |

| 3 Subsea Wells (12 years) | days | crew | man-days |
|---|---|---|---|
| Drilling & Completion (3*90 + 90 days) | 360 | 65 | 23400 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 | 4 | 720 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 | 8 | 1152 |
| Change out (1/8 per well-yr @ 50 days) | 225 | 8 | 1800 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 | 40 | 7200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 | 40 | 6240 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 | 40 | 7800 |

| | |
|---|---|
| Total (man-days): | 270162 |
| **Total man-hours** | **6483888** |

**TLP - Supply Vessel Crews**

| | |
|---|---|
| Exposure (docking calls) | 1.2E+04 |
| Expected Fatality Rate (per call) | 1.4E-05 |
| Coefficient of Uncertainty in Fatality Rate | 0.34 |

**Basis:**

USCG Gulf of Mexico "Offshore Supply Vessel" Fatalities

| Year | Fatalities |
|---|---|
| 1985 | 2 |
| 1986 | 1 |
| 1987 | 1 |
| 1988 | 0 |
| 1989 | 3 |
| 1990 | 0 |
| 1991 | 3 |
| 1992 | 3 |
| 1993 | 4 |
| 1994 | 4 |
| 1995 | 3 |
| 1996 | 3 |
| 1997 | 8 |
| 1998 | 3 |
| 1999 | 3 |

Total Exposure for Gulf of Mexico (1985-1999):

| | |
|---|---|
| Annual Dock Calls (300 boats x 2 calls/day x 365 d) | 2.19E+05 |
| Est. 85-99 Supply Vessel Activity in GOM (calls) | 3.29E+06 |
| Coefficient of Uncertainty in Exposure | 0.33 |

Statistical Analysis:

| | |
|---|---|
| Exposure (calls) | 3,285,000 |
| Fatalities | 41 |
| k" | 42 |
| n" (calls) | 3,285,000 |
| Expected Rate (per call) | 1.42E-05 |
| Std. Dev. in Rate (per call) | 4.79219E-06 |
| Coefficient of Uncertainty in Rate | 3.38E-01 |

Supply Vessel Crew Exposure for Study System

| | |
|---|---|
| 1 trip per 3 days during production | 0.333333333 |
| Days of Production (20 years) | 7300 |
| Trips | 2433.333333 |

| | |
|---|---|
| 1 trip per 3 days during drilling/workover | 0.333333333 |
| 6 Platform Wells (20 years) | |
| Drilling & Completion (5*90 + 6*20 days) | 570 |
| Slickline (3 per well-year @ 5 days) | 1800 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 |
| Change out (1/3 per well-yr @ 50 days) | 2000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 |
| Trips | 3230 |

| | |
|---|---|
| 3 Subsea Wells (12 years) | |
| Drilling & Completion (3*90 + 90 days) | 360 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 |
| Change out (1/8 per well-yr @ 50 days) | 225 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 |
| Trips | 480 |

| | |
|---|---|
| **Docking calls (trips*2)** | **12287** |

**TLP - Helicopter Transport**

| | |
|---|---|
| Exposure (passengers) | 8.03E+04 |
| Expected Fatality Rate (per passenger) | 1.2E-06 |
| Coefficient of Uncertainty in Fatality Rate | 0.18 |

**Basis:**

OGP Helicopter Safety Report (1999) (Gulf of Mexico Fatalities)

| Year | Fatalities | Passengers |
|---|---|---|
| 1994 | 10 | 4.8E+06 |
| 1995 | 8 | 5.7E+06 |
| 1996 | 11 | 5.8E+06 |
| 1997 | 1 | 5.0E+06 |
| 1998 | 1 | 5.0E+06 |

Statistical Analysis:

| | |
|---|---|
| Exposure (passengers) | 26,265,664 |
| Fatalities | 31 |
| k" | 32 |
| n" (passengers) | 26,265,664 |
| Expected Rate (per passenger) | 1.21832E-06 |
| Coefficient of Uncertainty in Rate | 0.176776695 |

Helicopter Transport Exposure for Study System

| | |
|---|---|
| Platform Crew | 40 |
| Number of Crew Changes in 20 years (14 days) | 521 |
| Number of Passengers (round trip) | 41714 |

| | |
|---|---|
| Drilling Crew (man-hours) | 6483888 |
| Man-hours per shift (14 days) | 336 |
| Man shift changes | 19297 |
| Number of Passengers (round trip) | 38595 |

| | |
|---|---|
| **Total Number of Passengers** | **80309** |

**TLP - Major Accident**

| | |
|---|---|
| Exposure (platform years) | 2.0E+01 |
| Expected Fatality Rate (per platform year) | 1.7E-03 |
| Coefficient of Uncertainty in Fatality Rate | 1.00 |

**Basis:**

Number of Major Offshore Accidents in GOM in 35 years = 0

Total Offshore Exposure in GOM (35 years)

| | |
|---|---|
| Manned Platforms per Year | 500 |
| Number of Years | 35 |
| Manned Platform Years | 17500 |

Statistical Analysis:

| | |
|---|---|
| Exposure (manned platform years) | 17,500 |
| Major Accidents | 0 |
| k" | 1 |
| n" (platform years) | 17,500 |
| Expected Incident Rate (per platform year) | 5.71429E-05 |
| Coefficient of Uncertainty in Incident Rate | 1 |
| Number of Fatalities per Major Accident | 30 |
| Expected Fatality Rate (per platform year) | 0.001714286 |
| Coefficient of Uncertainty in Incident Rate | 1 |

Exposure for Study System

| | |
|---|---|
| **Manned Years** | **20** |

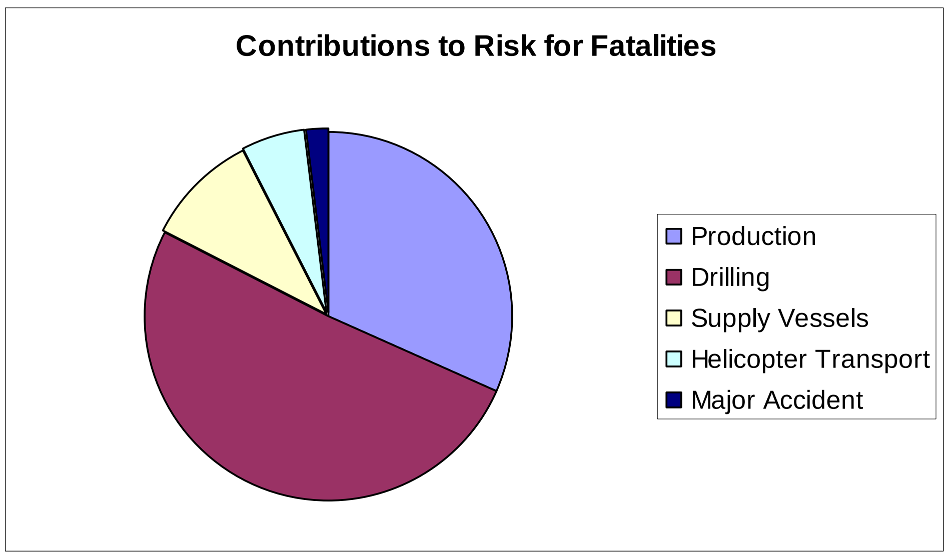
Appendix E.3

Fatality Risk Assessment for Hub/Host Jacket

**Jacket - Summary for Fatality Risk**

| | |
|---|---|
| **Expected Total Fatalities** | 1.8 |
| **Standard Deviation in Total Fatalities** | 0.3 |

| | | | Data-Based Estimate | | Expert-Based Extrapolation | | Combined (Expert+Data) | |
|---|---|---|---|---|---|---|---|---|
| **Activity** | **Exposure Units** | **Exposure (exposure units)** | **Expected Fatality Rate (per exposure unit)** | **Coefficient of Uncertainty in Fatality Rate** | **Expected Value for Bias** | **Coefficient of Uncertainty in Bias** | **Expected Value for Number of Fatalities** | **Coefficient of Uncertainty in Number of Fatalities** |
| Production | man-hours | 7.0E+06 | 7.9E-08 | 0.36 | 1.00 | 0.33 | 0.56 | 0.49 |
| Drilling | man-hours | 6.3E+06 | 1.4E-07 | 0.14 | 1.00 | 0.00 | 0.89 | 0.14 |
| Supply Vessels | docking calls | 1.2E+04 | 1.4E-05 | 0.34 | 1.00 | 0.33 | 0.17 | 0.47 |
| Helicopter Transport | passengers | 7.9E+04 | 1.2E-06 | 0.18 | 1.00 | 0.00 | 0.10 | 0.18 |
| Major Accident | platform years | 2.0E+01 | 1.7E-03 | 1.00 | 1.00 | 1.00 | 0.03 | 1.41 |




E.24 –Fatality Risk Assessment for Hub/Host Jacket

**Jacket - Production Crew**

| | |
|---|---|
| Exposure (man-hours) | 7.0E+06 |
| Expected Fatality Rate (per man-hour) | 7.9E-08 |
| Coefficient of Uncertainty in Fatality Rate | 0.36 |

Note: “Production Crew” includes product processing and construction activities.

**Basis:**

USCG Gulf of Mexico "Platform" Fatalities (Drilling-Related Fatalities Excluded)

| Year | Fatalities |
|---|---|
| 1992 | 4 |
| 1993 | 1 |
| 1994 | 4 |
| 1995 | 6 |
| 1996 | 2 |
| 1997 | 2 |
| 1998 | 8 |
| 1999 | 0 |

Total Exposure (man-hrs) for Gulf of Mexico (1992-1999):

| | |
|---|---|
| Annual 1998-1999 Avg. (MMS Production/Construction) | 4.16E+07 |
| Increase to account for 85% reporting | 4.89E+07 |
| Total 92-99 Man-hours (assume 98-99 avg. applies) | 3.91E+08 |
| Coefficient of Uncertainty in Exposure | 3.30E-01 |

Statistical Analysis:

| | |
|---|---|
| Exposure (man-hr) | 391,321,755 |
| Fatalities | 27 |
| k" | 28 |
| n" (man-hr) | 391,321,755 |
| Expected Rate (per man-hr) | 7.93E-08 |
| Std. Dev. in Rate (per man-hr) | 2.82865E-08 |
| Coefficient of Uncertainty in Rate | 3.57E-01 |

Production Crew Exposure for Study System

| | |
|---|---|
| Crew Size | 40 |
| Hours in 20 years | 175200 |

| | |
|---|---|
| **Total man-hours** | **7008000** |

**Jacket - Drilling Crew**

| | |
|---|---|
| Exposure (man-hours) | 6.3E+06 |
| Expected Fatality Rate (per man-hour) | 1.4E-07 |
| Coefficient of Uncertainty in Fatality Rate | 0.14 |

**Basis:**

IADC Gulf of Mexico Statistics (1989-1999):

| IADC Gulf of Mexico Statistics | | | Fatalities Reported to USCG* |
|---|---|---|---|
| Year | Hours Worked | Fatalities | |
| 1989 | 33,211,815 | 11 | 15 |
| 1990 | 34,624,227 | 8 | 4 |
| 1991 | 28,210,398 | 2 | 0 |
| 1992 | 20,024,172 | 0 | 1 |
| 1993 | 23,603,277 | 3 | 3 |
| 1994 | 29,733,657 | 5 | 6 |
| 1995 | 32,386,695 | 3 | 3 |
| 1996 | 32,827,738 | 3 | 4 |
| 1997 | 41,222,488 | 8 | 6 |
| 1998 | 43,437,749 | 6 | 2 |
| 1999 | 33,011,864 | 0 | 3 |

*USCG Reported: Fatalities on MODUs and Drilling-Related Fatalities on Fixed Platforms

Statistical Analysis:

| | |
|---|---|
| Exposure (man-hr) | 352,294,080 |
| Coefficient of Uncertainty in Exposure | 0 |
| Fatalities | 49 |
| k" | 50 |
| n" (man-hr) | 352,294,080 |
| Expected Rate (per man-hr) | 1.42E-07 |
| Std. Dev. in Rate (per man-hr) | 2.00715E-08 |
| Coefficient of Uncertainty in Rate | 1.41E-01 |

Driller Exposure for Study System

| 6 Platform Wells (20 years) | **days** | **crew** | **man-days** |
|---|---|---|---|
| Drilling & Completion (5*90 + 6*20 days) | 570 | 50 | 28500 |
| Slickline (3 per well-year @ 5 days) | 1800 | 4 | 7200 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Change out (1/3 per well-yr @ 50 days) | 2000 | 40 | 80000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 | 40 | 48000 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 | 40 | 20800 |

| 3 Subsea Wells (12 years) | **days** | **crew** | **man-days** |
|---|---|---|---|
| Drilling & Completion (3*90 + 90 days) | 360 | 65 | 23400 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 | 4 | 720 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 | 8 | 1152 |
| Change out (1/8 per well-yr @ 50 days) | 225 | 8 | 1800 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 | 40 | 7200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 | 40 | 6240 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 | 40 | 7800 |

| | |
|---|---|
| Total (man-days): | 261612 |
| **Total man-hours** | **6278688** |

**Jacket - Supply Vessel Crews**

| | |
|---|---|
| Exposure (docking calls) | 1.2E+04 |
| Expected Fatality Rate (per call) | 1.4E-05 |
| Coefficient of Uncertainty in Fatality Rate | 0.34 |

**Basis:**

USCG Gulf of Mexico "Offshore Supply Vessel" Fatalities

| Year | Fatalities |
|---|---|
| 1985 | 2 |
| 1986 | 1 |
| 1987 | 1 |
| 1988 | 0 |
| 1989 | 3 |
| 1990 | 0 |
| 1991 | 3 |
| 1992 | 3 |
| 1993 | 4 |
| 1994 | 4 |
| 1995 | 3 |
| 1996 | 3 |
| 1997 | 8 |
| 1998 | 3 |
| 1999 | 3 |

Total Exposure for Gulf of Mexico (1985-1999):

| | |
|---|---|
| Annual Dock Calls (300 boats x 2 calls/day x 365 d) | 2.19E+05 |
| Est. 85-99 Supply Vessel Activity in GOM (calls) | 3.29E+06 |
| Coefficient of Uncertainty in Exposure | 0.33 |

Statistical Analysis:

| | |
|---|---|
| Exposure (calls) | 3,285,000 |
| Fatalities | 41 |
| k" | 42 |
| n" (calls) | 3,285,000 |
| Expected Rate (per call) | 1.42E-05 |
| Std. Dev. in Rate (per call) | 4.79219E-06 |
| Coefficient of Uncertainty in Rate | 3.38E-01 |

Supply Vessel Crew Exposure for Study System

| | |
|---|---|
| 1 trip per 3 days during production | 0.333333333 |
| Days of Production (20 years) | 7300 |
| Trips | 2433.333333 |

| | |
|---|---|
| 1 trip per 3 days during drilling/workover | 0.333333333 |
| 6 Platform Wells (20 years) | |
| Drilling & Completion (5*90 + 6*20 days) | 570 |
| Slickline (3 per well-year @ 5 days) | 1800 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 |
| Change out (1/3 per well-yr @ 50 days) | 2000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 |
| Trips | 3230 |

| | |
|---|---|
| 3 Subsea Wells (12 years) | |
| Drilling & Completion (3*90 + 90 days) | 360 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 |
| Change out (1/8 per well-yr @ 50 days) | 225 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 |
| Trips | 480 |

| | |
|---|---|
| **Docking calls (trips*2)** | **12287** |

**Jacket - Helicopter Transport**

| | |
|---|---|
| Exposure (passengers) | 7.9E+04 |
| Expected Fatality Rate (per passenger) | 1.2E-06 |
| Coefficient of Uncertainty in Fatality Rate | 0.18 |

**Basis:**

OGP Helicopter Safety Report (1999) (Gulf of Mexico Fatalities)

| Year | Fatalities | Passengers |
|---|---|---|
| 1994 | 10 | 4.8E+06 |
| 1995 | 8 | 5.7E+06 |
| 1996 | 11 | 5.8E+06 |
| 1997 | 1 | 5.0E+06 |
| 1998 | 1 | 5.0E+06 |

Statistical Analysis:

| | |
|---|---|
| Exposure (passengers) | 26,265,664 |
| Fatalities | 31 |
| k" | 32 |
| n" (passengers) | 26,265,664 |
| Expected Rate (per passenger) | 1.21832E-06 |
| Coefficient of Uncertainty in Rate | 0.176776695 |

Helicopter Transport Exposure for Study System

| | |
|---|---|
| Platform Crew | 40 |
| Number of Crew Changes in 20 years (14 days) | 521 |
| Number of Passengers (round trip) | 41714 |

| | |
|---|---|
| Drilling Crew (man-hours) | 6278688 |
| Man-hours per shift (14 days) | 336 |
| Man shift changes | 18687 |
| Number of Passengers (round trip) | 37373 |

| | |
|---|---|
| **Total Number of Passengers** | **79087** |

**Jacket - Major Accident**

| | |
|---|---|
| Exposure (platform years) | 2.0E+01 |
| Expected Fatality Rate (per platform year) | 1.7E-03 |
| Coefficient of Uncertainty in Fatality Rate | 1.00 |

**Basis:**

Number of Major Offshore Accidents in GOM in 35 years = 0

Total Offshore Exposure in GOM (35 years)

| | |
|---|---|
| Manned Platforms per Year | 500 |
| Number of Years | 35 |
| Manned Platform Years | 17500 |

Statistical Analysis:

| | |
|---|---|
| Exposure (manned platform years) | 17,500 |
| Major Accidents | 0 |
| k" | 1 |
| n" (platform years) | 17,500 |
| Expected Incident Rate (per platform year) | 5.71429E-05 |
| Coefficient of Uncertainty in Incident Rate | 1 |
| Number of Fatalities per Major Accident | 30 |
| Expected Fatality Rate (per platform year) | 0.001714286 |
| Coefficient of Uncertainty in Incident Rate | 1 |

Exposure for Study System

| | |
|---|---|
| **Manned Years** | **20** |

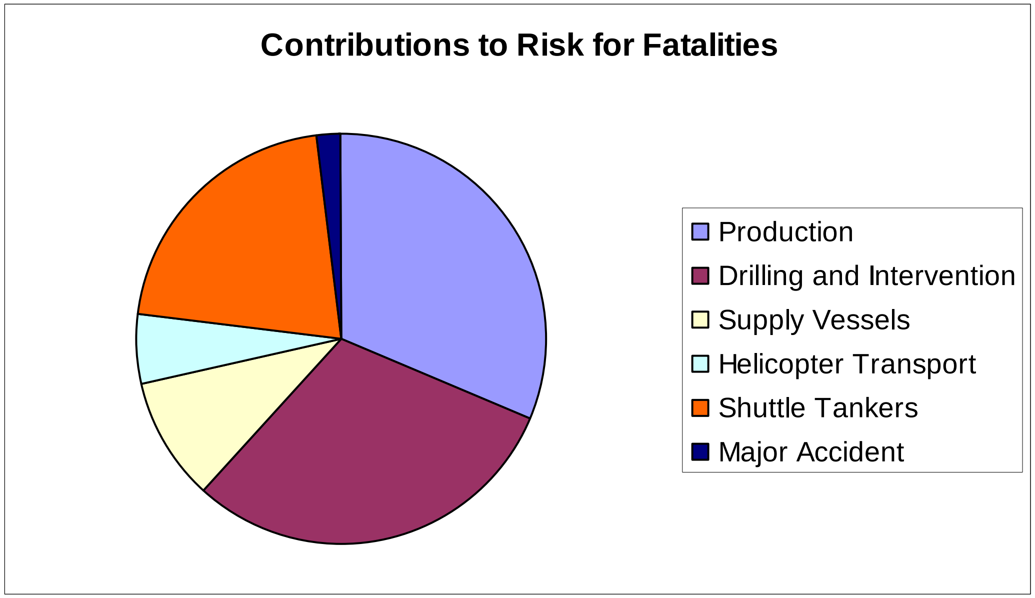
Appendix E.4

Fatality Risk Assessment for FPSO

**FPSO - Summary for Fatality Risk**

**Expected Total Fatalities** **1.8**
**Standard Deviation in Total Fatalities** **0.4**

| Activity | Exposure Units | Exposure (exposure units) | Data-Based Estimate: Expected Fatality Rate (per exposure unit) | Data-Based Estimate: Coefficient of Uncertainty in Fatality Rate | Expert-Based Extrapolation: Expected Value for Bias | Expert-Based Extrapolation: Coefficient of Uncertainty in Bias | Combined (Expert+Data): Expected Value for Number of Fatalities | Combined (Expert+Data): Coefficient of Uncertainty in Number of Fatalities |
|---|---|---|---|---|---|---|---|---|
| Production | Man-hours | 7.0E+06 | 7.9E-08 | 0.36 | 1.00 | 0.33 | 0.56 | 0.49 |
| Drilling and Intervention | Man-hours | 3.8E+06 | 1.4E-07 | 0.14 | 1.00 | 0.00 | 0.53 | 0.14 |
| Supply Vessels | docking calls | 1.2E+04 | 1.4E-05 | 0.34 | 1.00 | 0.33 | 0.17 | 0.47 |
| Helicopter Transport | passengers | 7.8E+04 | 1.2E-06 | 0.18 | 1.00 | 0.00 | 0.10 | 0.18 |
| Shuttle Tankers | docking calls | 3.2E+03 | 1.2E-04 | 0.49 | 1.00 | 0.33 | 0.38 | 0.59 |
| Major Accident | platform years | 2.0E+01 | 1.7E-03 | 1.00 | 1.00 | 1.00 | 0.03 | 1.41 |




E.33 –Fatality Risk Assessment for FPSO

**FPSO - Production Crew**

| | |
|---|---|
| Exposure (man-hours) | 7.0E+06 |
| Expected Fatality Rate (per man-hour) | 7.9E-08 |
| Coefficient of Uncertainty in Fatality Rate | 0.36 |

Note: “Production Crew” includes product processing and construction activities.

**Basis:**

USCG Gulf of Mexico "Platform" Fatalities (Drilling-Related Fatalities Excluded)

| Year | Fatalities |
|---|---|
| 1992 | 4 |
| 1993 | 1 |
| 1994 | 4 |
| 1995 | 6 |
| 1996 | 2 |
| 1997 | 2 |
| 1998 | 8 |
| 1999 | 0 |

Total Exposure (man-hrs) for Gulf of Mexico (1992-1999):

| | |
|---|---|
| Annual 1998-1999 Avg. (MMS Production/Construction) | 4.16E+07 |
| Increase to account for 85% reporting | 4.89E+07 |
| Total 92-99 Man-hours (assume 98-99 avg. applies) | 3.91E+08 |
| Coefficient of Uncertainty in Exposure | 3.30E-01 |

Statistical Analysis:

| | |
|---|---|
| Exposure (man-hr) | 391,321,755 |
| Fatalities | 27 |
| k" | 28 |
| n" (man-hr) | 391,321,755 |
| Expected Rate (per man-hr) | 7.93E-08 |
| Std. Dev. in Rate (per man-hr) | 2.82865E-08 |
| Coefficient of Uncertainty in Rate | 3.57E-01 |

Production Crew Exposure for Study System

| | |
|---|---|
| Crew Size | 40 |
| Hours in 20 years | 175200 |

| | |
|---|---|
| **Total man-hours** | **7008000** |

**FPSO - Drilling Crew**

| | |
|---|---|
| Exposure (man-hours) | 3.8E+06 |
| Expected Fatality Rate (per man-hour) | 1.4E-07 |
| Coefficient of Uncertainty in Fatality Rate | 0.14 |

**Basis:**

IADC Gulf of Mexico Statistics (1989-1999):

| IADC Gulf of Mexico Statistics | | | Fatalities Reported to USCG* |
|---|---|---|---|
| Year | Hours Worked | Fatalities | |
| 1989 | 33,211,815 | 11 | 15 |
| 1990 | 34,624,227 | 8 | 4 |
| 1991 | 28,210,398 | 2 | 0 |
| 1992 | 20,024,172 | 0 | 1 |
| 1993 | 23,603,277 | 3 | 3 |
| 1994 | 29,733,657 | 5 | 6 |
| 1995 | 32,386,695 | 3 | 3 |
| 1996 | 32,827,738 | 3 | 4 |
| 1997 | 41,222,488 | 8 | 6 |
| 1998 | 43,437,749 | 6 | 2 |
| 1999 | 33,011,864 | 0 | 3 |

*USCG Reported: Fatalities on MODUs and Drilling-Related Fatalities on Fixed Platforms

Statistical Analysis:

| | |
|---|---|
| Exposure (man-hr) | 352,294,080 |
| Coefficient of Uncertainty in Exposure | 0 |
| Fatalities | 49 |
| k" | 50 |
| n" (man-hr) | 352,294,080 |
| Expected Rate (per man-hr) | 1.42E-07 |
| Std. Dev. in Rate (per man-hr) | 2.00715E-08 |
| Coefficient of Uncertainty in Rate | 1.41E-01 |

Driller Exposure for Study System

| 6 Subsea Wells (20 years) | **days** | **crew** | **man-days** |
|---|---|---|---|
| Drilling & Completion (3*90 + 120 days) | 390 | 65 | 25350 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 600 | 4 | 2400 |
| Hydraulic (1/5 per well-yr @ 20 days) | 480 | 8 | 3840 |
| Change out (1/8 per well-yr @ 50 days) | 750 | 8 | 6000 |
| Recompletion (1/10 per well-yr @ 50 days) | 600 | 40 | 24000 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 | 40 | 20800 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 650 | 40 | 26000 |

| 3 Subsea Wells (12 years) | **days** | **crew** | **man-days** |
|---|---|---|---|
| Drilling & Completion (3*90 + 90 days) | 360 | 65 | 23400 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 | 4 | 720 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 | 8 | 1152 |
| Change out (1/8 per well-yr @ 50 days) | 225 | 8 | 1800 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 | 40 | 7200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 | 40 | 6240 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 | 40 | 7800 |

| | |
|---|---|
| Total (man-days): | 156702 |
| **Total man-hours** | **3.76E+6** |

**FPSO - Supply Vessel Crews**

| | |
|---|---|
| Exposure (docking calls) | 1.2E+04 |
| Expected Fatality Rate (per call) | 1.4E-05 |
| Coefficient of Uncertainty in Fatality Rate | 0.34 |

**Basis:**

USCG Gulf of Mexico "Offshore Supply Vessel" Fatalities

| Year | Fatalities |
|---|---|
| 1985 | 2 |
| 1986 | 1 |
| 1987 | 1 |
| 1988 | 0 |
| 1989 | 3 |
| 1990 | 0 |
| 1991 | 3 |
| 1992 | 3 |
| 1993 | 4 |
| 1994 | 4 |
| 1995 | 3 |
| 1996 | 3 |
| 1997 | 8 |
| 1998 | 3 |
| 1999 | 3 |

Total Exposure for Gulf of Mexico (1985-1999):

| | |
|---|---|
| Annual Dock Calls (300 boats x 2 calls/day x 365 d) | 2.19E+05 |
| Est. 85-99 Supply Vessel Activity in GOM (calls) | 3.29E+06 |
| Coefficient of Uncertainty in Exposure | 0.33 |

Statistical Analysis:

| | |
|---|---|
| Exposure (calls) | 3,285,000 |
| Fatalities | 41 |
| k" | 42 |
| n" (calls) | 3,285,000 |
| Expected Rate (per call) | 1.42E-05 |
| Std. Dev. in Rate (per call) | 4.79219E-06 |
| Coefficient of Uncertainty in Rate | 3.38E-01 |

Supply Vessel Crew Exposure for Study System

| | |
|---|---|
| 1 trip per 3 days during production | 0.333333333 |
| Days of Production (20 years) | 7300 |
| Trips | 2433.333333 |

| | |
|---|---|
| 1 trip per 3 days during drilling/workover | 0.333333333 |
| 6 Platform Wells (20 years) | |
| Drilling & Completion (5*90 + 6*20 days) | 570 |
| Slickline (3 per well-year @ 5 days) | 1800 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 |
| Change out (1/3 per well-yr @ 50 days) | 2000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 |
| Trips | 3230 |

| | |
|---|---|
| 3 Subsea Wells (12 years) | |
| Drilling & Completion (3*90 + 90 days) | 360 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 |
| Change out (1/8 per well-yr @ 50 days) | 225 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 |
| Trips | 480 |

| | |
|---|---|
| **Docking calls (trips*2)** | **12287** |

**FPSO - Helicopter Transport**

| | |
|---|---|
| Exposure (passengers) | 7.8E+04 |
| Expected Fatality Rate (per passenger) | 1.2E-06 |
| Coefficient of Uncertainty in Fatality Rate | 0.18 |

**Basis:**

OGP Helicopter Safety Report (1999) (Gulf of Mexico Fatalities)

| Year | Fatalities | Passengers |
|---|---|---|
| 1994 | 10 | 4.8E+06 |
| 1995 | 8 | 5.7E+06 |
| 1996 | 11 | 5.8E+06 |
| 1997 | 1 | 5.0E+06 |
| 1998 | 1 | 5.0E+06 |

Statistical Analysis:

| | |
|---|---|
| Exposure (passengers) | 26,265,664 |
| Fatalities | 31 |
| k" | 32 |
| n" (passengers) | 26,265,664 |
| Expected Rate (per passenger) | 1.21832E-06 |
| Coefficient of Uncertainty in Rate | 0.176776695 |

Helicopter Transport Exposure for Study System

| | |
|---|---|
| Platform Crew | 40 |
| Number of Crew Changes in 20 years (14 days) | 521 |
| Number of Passengers (round trip) | 41714 |

| | |
|---|---|
| Marine Crew | 20 |
| Number of Crew Changes in 20 years (21 days) | 348 |
| Number of Passengers (round trip) | 13905 |

| | |
|---|---|
| Drilling Crew (man-hours) | 3760848 |
| Man-hours per shift (14 days) | 336 |
| Man shift changes | 11193 |
| Number of Passengers (round trip) | 22386 |

| | |
|---|---|
| **Total Number of Passengers** | **78005** |

**FPSO - Tanker Operations**

| | |
|---|---|
| Exposure (docking calls) | 3.2E+03 |
| Expected Fatality Rate (per call) | 1.2E-04 |
| Coefficient of Uncertainty in Fatality Rate | 0.49 |

**Basis:**

USCG Gulf of Mexico "Tank Ship" Fatalities (Tank Ships < 50k dead weight tons excluded)

| Year | Fatalities |
|---|---|
| 1985 | 0 |
| 1986 | 0 |
| 1987 | 0 |
| 1988 | 0 |
| 1989 | 0 |
| 1990 | 0 |
| 1991 | 0 |
| 1992 | 0 |
| 1993 | 0 |
| 1994 | 3 |
| 1995 | 1 |
| 1996 | 0 |
| 1997 | 0 |
| 1998 | 2 |
| 1999 | 0 |

Total Exposure for Gulf of Mexico (1985-1999):

| | |
|---|---|
| Annual Dock Calls | 4.40E+03 |
| Est. 85-99 Tanker Activity in GOM (calls) | 6.60E+04 |
| Coefficient of Uncertainty in Exposure | 0.33 |

Statistical Analysis:

| | |
|---|---|
| Exposure (calls) | 66,000 |
| Fatalities | 6 |
| k" | 7 |
| n" (calls) | 66,000 |
| Expected Rate (per call) | 1.18E-04 |
| Std. Dev. in Rate (per call) | 5.79394E-05 |
| Coefficient of Uncertainty in Rate | 4.93E-01 |

Shuttle Tanker Docking Calls

| | |
|---|---|
| Shuttle Tanker Cargo (bbl) | 450000 |
| Total Production (bbl) | 719000000 |
| **Total Docking Calls (2 per trip)** | **3196** |

**FPSO - Major Accident**

| | |
|---|---|
| Exposure (platform years) | 2.0E+01 |
| Expected Fatality Rate (per platform year) | 1.7E-03 |
| Coefficient of Uncertainty in Fatality Rate | 1.00 |

**Basis:**

Number of Major Offshore Accidents in GOM in 35 years = 0

Total Offshore Exposure in GOM (35 years)

| | |
|---|---|
| Manned Platforms per Year | 500 |
| Number of Years | 35 |
| Manned Platform Years | 17500 |

Statistical Analysis:

| | |
|---|---|
| Exposure (manned platform years) | 17,500 |
| Major Accidents | 0 |
| k" | 1 |
| n" (platform years) | 17,500 |
| Expected Incident Rate (per platform year) | 5.71429E-05 |
| Coefficient of Uncertainty in Incident Rate | 1 |
| Number of Fatalities per Major Accident | 30 |
| Expected Fatality Rate (per platform year) | 0.001714286 |
| Coefficient of Uncertainty in Incident Rate | 1 |

Exposure for Study System

| | |
|---|---|
| **Manned Years** | **20** |

Appendix F

Oil Spill Risk Assessments



F.1 – Summary of Oil Spill Data

Table F.1 Oil Spill Data: Summary of Raw Data and Refinements for this Study

| | | **Refinements to Raw Data** | | | |
|---|---|---|---|---|---|
| **Sub-System** | **Data Source** | **Spar** | **TLP** | **Hub/Host Jacket** | **FPSO** |
| **Well Systems – Platform** | Frequencies for different spill sizes from MMS Database of "Well and Header System" spills in the Gulf of Mexico for the years 1985-1998. Frequencies normalized by the total volume of oil produced. | Exclude data prior to 1990 to account for changes in operating procedures due to implementation of API RP14C. | Exclude data prior to 1990 to account for changes in operating procedures due to implementation of API RP14C. | Exclude data prior to 1990 to account for changes in operating procedures due to implementation of API RP14C. | Not Applicable |
| **Well Systems – Subsea** | Frequencies for different spill sizes from MMS Database of "Well and Header System" spills in the Gulf of Mexico for the years 1985-1998. Frequencies normalized by the total volume of oil produced. | Exclude data prior to 1990 to account for changes in operating procedures due to implementation of API RP14C.<br>Double expected frequency for leaks to account for greater potential for sand erosion and cutouts due to high flow rates and detection difficulties for sand. | Exclude data prior to 1990 to account for changes in operating procedures due to implementation of API RP14C.<br>Double expected frequency for leaks to account for greater potential for sand erosion and cutouts due to high flow rates and detection difficulties for sand. | Exclude data prior to 1990 to account for changes in operating procedures due to implementation of API RP14C.<br>Double expected frequency for leaks to account for greater potential for sand erosion and cutouts due to high flow rates and detection difficulties for sand. | Exclude data prior to 1990 to account for changes in operating procedures due to implementation of API RP14C.<br>Double expected frequency for leaks to account for greater potential for sand erosion and cutouts due to high flow rates and detection difficulties for sand. |
| **Dry Tree Risers** | Leak frequency for dry tree risers during production taken from OTC Paper (Wolford et al. 1997). Distribution of spill sizes taken from MMS Database of "Pipeline" spills in the Gulf of Mexico for the years 1992-1998. Frequencies normalized by riser-years (or well-years). | No Changes (Note that the possibility of spills larger than 100,000 bbl was evaluated even though none have occurred in the data record. The estimated frequency for this type of an event was negligibly small because it requires a combined failure of the dual risers and the subsea safety valve.) | No Changes (Note that the possibility of spills larger than 100,000 bbl was evaluated even though none have occurred in the data record. The estimated frequency for this type of an event was negligibly small because it requires a combined failure of the dual risers and the subsea safety valve.) | Not Applicable | Not Applicable |

Table F.1 Oil Spill Data: Summary of Raw Data and Refinements for this Study

| | | Refinements to Raw Data | | | |
|---|---|---|---|---|---|
| **Sub-System** | **Data Source** | **Spar** | **TLP** | **Hub/Host Jacket** | **FPSO** |
| **Flowlines** | Frequencies for different spill sizes from USCG Database of spills from "Pipelines" for the years 1992-1998. Frequencies normalized by the length of pipeline and by time (mile-years). The total miles of oil/condensate pipeline in the Gulf of Mexico estimated from MMS and State of Louisiana information. | Limit maximum possible spill size per incident to 10,000 bbl because (1) flowline inventory is small (< 10,000 bbl total in parallel lines) and (2) safety systems should shut production in within 45 minutes of a leak occurring (5 hours at 2,000 bbl/hr total in both lines gives 10,000 bbl). | Limit maximum possible spill size per incident to 10,000 bbl because (1) flowline inventory is small (< 10,000 bbl total in parallel lines) and (2) safety systems should shut production in within 45 minutes of a leak occurring (5 hours at 2,000 bbl/hr total in both lines gives 10,000 bbl). | Limit maximum possible spill size per incident to 10,000 bbl because (1) flowline inventory is small (< 10,000 bbl total in parallel lines) and (2) safety systems should shut production in within 45 minutes of a leak occurring (5 hours at 2,000 bbl/hr total in both lines gives 10,000 bbl). | Limit maximum possible spill size per incident to 10,000 bbl because (1) flowline inventory is small (< 10,000 bbl total in parallel lines) and (2) safety systems should shut production in within 45 minutes of a leak occurring (5 hours at 2,000 bbl/hr total in both lines gives 10,000 bbl). |
| **Import Flowline Risers** | Leak frequency from PARLOC (1993) pipeline database, filtered for flexible pipelines and then for risers. Data are for static versus dynamic risers. Distribution of spill sizes taken from MMS Database of "Pipeline" spills in the Gulf of Mexico for the years 1992-1998. Frequencies normalized by riser-years. | Limit maximum possible spill size to 10,000 bbl using same rationale as for flowlines. | Limit maximum possible spill size to 10,000 bbl using same rationale as for flowlines. | Not Applicable | Limit maximum possible spill size to 10,000 bbl using same rationale as for flowlines. |

Table F.1 Oil Spill Data: Summary of Raw Data and Refinements for this Study

| | | Refinements to Raw Data | | | |
|---|---|---|---|---|---|
| **Sub-System** | **Data Source** | **Spar** | **TLP** | **Hub/Host Jacket** | **FPSO** |
| **Topsides** | Frequencies for different spill sizes from MMS Database of "Platform" spills in the Gulf of Mexico for the years 1985-1998. Frequencies normalized by the total oil production reported by MMS. Spills include both process and non-process spills from the topsides. Spills involving supply vessels not included (information about these obtained from USCG database, as described below) and spills involving drilling/workover activities not included (information accounted for in drilling and intervention category). | Exclude data prior to 1990 to account for changes in operating procedures due to implementation of API RP14C.<br><br>Reduce spill frequency for the 1,000 to 10,000 bbl category to $1.0x10^{-4}$ per year to account for the inventory spilled in a total structural failure. | Exclude data prior to 1990 to account for changes in operating procedures due to implementation of API RP14C.<br><br>Reduce spill frequency for the 1,000 to 10,000 bbl category to $1.0x10^{-4}$ per year to account for the inventory spilled in a total structural failure. | Exclude data prior to 1990 to account for changes in operating procedures due to implementation of API RP14C.<br><br>Reduce spill frequency for the 1,000 to 10,000 bbl category to $1.0x10^{-4}$ per year to account for the inventory spilled in a total structural failure.<br><br>Increase the processed volume by 2.5% of transshipped volume (or 10% of maximum produced volume) to account for additional spill risk from handling the transshipped product. | Exclude data prior to 1990 to account for changes in operating procedures due to implementation of API RP14C.<br><br>Limit maximum possible spill size per incident to 1,000 bbl because there is limited inventory of product and other fluids in the topsides that can be spilled at any one time.<br><br>Reduce spill frequency for the 1 to 10 bbl category by ten due to (1) capability to contain spills on deck due to the solid decking and combing and (2) location of fuel tanks in hull. |
| **Export Pipeline Risers** | Oil: Leak frequency from PARLOC (1993) pipeline database, filtered for flexible pipelines and then for risers. Data are for static versus dynamic risers. Distribution of spill sizes taken from MMS Database of "Pipeline" spills in the Gulf of Mexico for the years 1992-1998. Frequencies normalized by riser-years.<br><br>Gas: Included in Pipelines. | Limit maximum possible spill size to 100,000 bbl and use a triangular probability distribution (decreasing with increasing size) in the 10,000 to 100,000 bbl category because of same rationale as for pipelines.<br><br>See Gas Pipelines | Limit maximum possible spill size to 100,000 bbl and use a triangular probability distribution (decreasing with increasing size) in the 10,000 to 100,000 bbl category because of same rationale as for pipelines.<br><br>See Gas Pipelines | Not Applicable<br><br>See Gas Pipelines | Not Applicable<br><br>See Gas Pipelines |

Table F.1 Oil Spill Data: Summary of Raw Data and Refinements for this Study

| | | Refinements to Raw Data | | | |
|---|---|---|---|---|---|
| **Sub-System** | **Data Source** | **Spar** | **TLP** | **Hub/Host Jacket** | **FPSO** |
| **Pipelines** | Oil: Frequencies for different spill sizes from USCG Database of spills from "Pipelines" for the years 1992-1998. Spills from liquid pipelines (oil and condensate) separated from those for natural gas pipelines. Frequencies normalized by the length of pipeline and by time (mile-years). Total miles of oil/condensate pipeline in Gulf of Mexico estimated from MMS and State of Louisiana information. | Limit maximum possible spill size to 100,000 bbl and use a lower triangular probability distribution in the 10,000 to 100,000 bbl category because (1) hydrostatic pressures in deeper water and "P-traps" due to bottom contours limit the volume of inventory that can leak and (2) it is not credible that pumping would continue for more than several hours after a leak occurs (6,200 bbl/hr production rate) due to detection systems and operational requirements. | Limit maximum possible spill size to 100,000 bbl and use a lower triangular probability distribution in the 10,000 to 100,000 bbl category because (1) hydrostatic pressures in deeper water and "P-traps" due to bottom contours limit the volume of inventory that can leak and (2) it is not credible that pumping would continue for more than several hours after a leak occurs (6,200 bbl/hr production rate) due to detection systems and operational requirements. | Limit maximum possible spill size to 100,000 bbl and use a lower triangular probability distribution in the 10,000 to 100,000 bbl category because (1) hydrostatic pressures in deeper water and "P-traps" due to bottom contours limit the volume of inventory that can leak and (2) it is not credible that pumping would continue for more than several hours after a leak occurs (6,200 bbl/hr production rate) due to detection systems and operational requirements. | Not Applicable |
| | Gas: Frequencies from USCG Database of spills from "Pipelines" for 1992-1998. Reported spills from natural gas pipelines separated from those for liquid pipelines. Frequencies normalized by the length of pipeline and by time (mile-years). Total miles of natural gas pipeline estimated from MMS and State of Louisiana information. | Considered a negligible contribution to oil spill risk due to small volumes of condensate and small likelihood of spills (only two spills occurred in the data record and both were less than 10 bbl in size), and not considered further in the analysis. | Considered a negligible contribution to oil spill risk due to small volumes of condensate and small likelihood of spills (only two spills occurred in the data record and both were less than 10 bbl in size), and not considered further in the analysis. | Considered a negligible contribution to oil spill risk due to small volumes of condensate and small likelihood of spills (only two spills occurred in the data record and both were less than 10 bbl in size), and not considered further in the analysis. | Considered a negligible contribution to oil spill risk due to small volumes of condensate and small likelihood of spills (only two spills occurred in the data record and both were less than 10 bbl in size), and not considered further in the analysis. |

Table F.1 Oil Spill Data: Summary of Raw Data and Refinements for this Study

| | | Refinements to Raw Data | | | |
|---|---|---|---|---|---|
| **Sub-System** | **Data Source** | **Spar** | **TLP** | **Hub/Host Jacket** | **FPSO** |
| **Shuttle Tanker** | Frequencies for different spill sizes from USCG Database of spills from "Tank Ships" in the Gulf of Mexico and related waters for the years 1985-1999. Frequencies normalized by the number of port or docking calls, including calls to terminals, lightering zones and LOOP. The total number of tanker docking calls in the Gulf of Mexico for the years 1985-1999 estimated from oil import information in the NRC Marine Board lightering study (1998) and assuming average sizes for tankers. Estimates checked with Skaugen Petrotrans. | Not Applicable | Not Applicable | Not Applicable | Exclude pre-1992 data to reflect impact of OPA 90.<br>Exclude spills related to bunkering since it is not required for FPSO (unlike tankers being lightered), and exclude spills for tankers with cargos of dry bulk, chemicals and gas since these are not relevant to crude oil transport.<br>Due to lack of large-spill incidents in Gulf of Mexico, statistically combine these data with ITOPF data for tanker spills world-wide from 1992-1999 to estimate frequencies for spills greater than 10,000 bbl. Factor world-wide spill frequencies down to reflect differences in tanker operations in the Gulf of Mexico versus the world.<br>Use a triangular probability distribution (decreasing with increasing size) in the 100,000 to 500,000 bbl category to account for compartmentalization of cargo tanks. |

Table F.1 Oil Spill Data: Summary of Raw Data and Refinements for this Study

| | | Refinements to Raw Data | | | |
|---|---|---|---|---|---|
| **Sub-System** | **Data Source** | **Spar** | **TLP** | **Hub/Host Jacket** | **FPSO** |
| **FPSO Cargo Tank** | This category represents a catastrophic, structural failure of the FPSO due to a hurricane or a high-energy collision with a vessel other than the shuttle tanker. All other spills from the FPSO cargo tanks are accounted for in the Shuttle Tanker category (from lightering data). Frequency of occurrence estimated from existing information on FPSO performance: no occurrences of a "system failure" leading to a major breach of an FPSO cargo tank in approximately 500 FPSO-years of operating experience. | Not Applicable | Not Applicable | Not Applicable | Reduce frequency of occurrence by a factor of ten since floating production systems are generally designed to achieve a probability of total system failure that is on the order of $10^{-4}$ per year or smaller.<br><br>Distribute the frequency of total system failure across the different spill size categories according to the storage present in the cargo tanks and the likelihood of a partial versus complete loss of the cargo. Assume that 90% of these incidents will lead to spills smaller than 100,000 bbls. Also, assume that the most common operating condition is 350,000 bbl stored in the cargo tanks. |

Table F.1 Oil Spill Data: Summary of Raw Data and Refinements for this Study

| | | Refinements to Raw Data | | | |
|---|---|---|---|---|---|
| **Sub-System** | **Data Source** | **Spar** | **TLP** | **Hub/Host Jacket** | **FPSO** |
| **Supply Vessels** | Frequencies for different spill sizes from USCG Database of spills from "Offshore Supply Vessels" in the Gulf of Mexico and related waters for the years 1985-1999. Frequencies normalized by the number of port or docking calls. The total number of docking calls in the Gulf of Mexico for the years 1985-1999 roughly estimated from discussions with Edison Chouest. | Limit maximum possible spill size to 1,000 bbl to be consistent with cargo capacity for typical supply vessels (less than 1,000 bbl). | Limit maximum possible spill size to 1,000 bbl to be consistent with cargo capacity for typical supply vessels (less than 1,000 bbl). | Limit maximum possible spill size to 1,000 bbl to be consistent with cargo capacity for typical supply vessels (less than 1,000 bbl). | Limit maximum possible spill size to 1,000 bbl to be consistent with cargo capacity for typical supply vessels (less than 1,000 bbl). |
| **Drilling and Intervention** | Frequencies for different spill sizes from MMS Database of "Platform" spills due to "Drilling" and "Workover and Completion" activities (includes exploratory and development drilling) in the Gulf of Mexico, for the years 1980-1999. Frequencies normalized by total number of man-days of drill-crew activity because crew-size provides rough indication of activity-level in the operations. Drill-crew activity for the Gulf of Mexico obtained from IADC statistics for the 1990's, and assumed to be representative for the years 1980 to 1999. | No Changes (Note that the possibility of spills larger than 10,000 bbl was evaluated even though none have occurred in the data record. The estimated frequency for this type of an event was negligibly small during development drilling.) | No Changes (Note that the possibility of spills larger than 10,000 bbl was evaluated even though none have occurred in the data record. The probability of this type of an event was considered to be negligibly small during development drilling.) | No Changes (Note that the possibility of spills larger than 10,000 bbl was evaluated even though none have occurred in the data record. The probability of this type of an event was considered to be negligibly small during development drilling.) | No Changes (Note that the possibility of spills larger than 10,000 bbl was evaluated even though none have occurred in the data record. The probability of this type of an event was considered to be negligibly small during development drilling.) |

Appendix F.1

Oil Spill Risk Assessment for Spar

**Spar - Risk Summary**

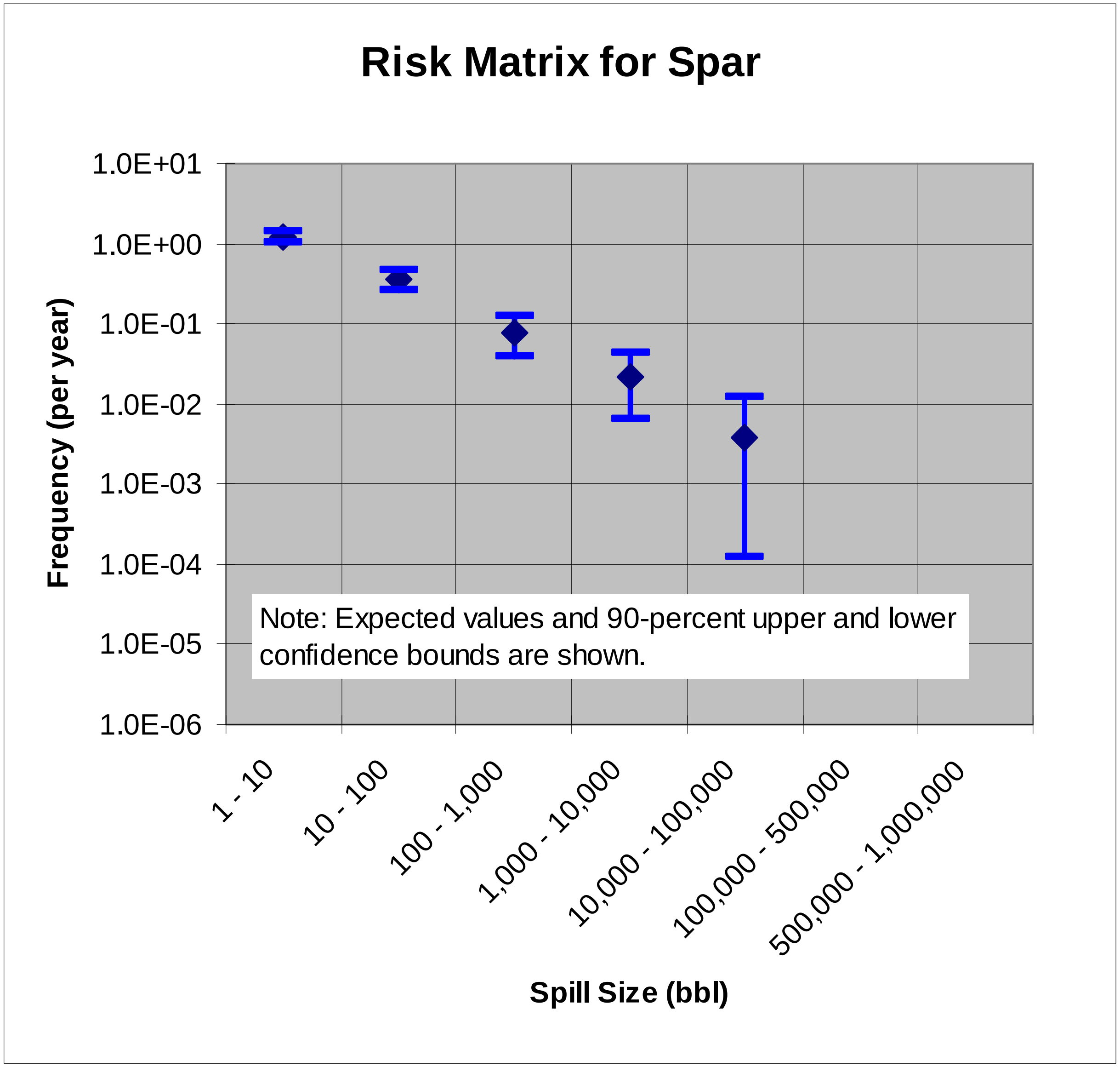
**Overall System Risk Results for 20-year Life:**

| | |
|---|---|
| Expected Total (bbl) | 3.759E+03 |
| Std. Dev. in Total (bbl) | 1.9E+03 |

| | |
|---|---|
| Expected Max (bbl) | 2.7E+03 |
| Std. Dev. in Max (bbl) | 1.7E+03 |

| | Sub-system Risk Results for 20-year Life | | | |
|---|---|---|---|---|
| | Expected Total (bbl) | Std. Dev. in Total (bbl) | Expected Maximum (bbl) | Std Dev. in Maximum (bbl) |
| Well Systems - Platform | 59 | 46 | 51 | 40 |
| Well Systems - Subsea | 78 | 83 | 64 | 68 |
| Dry Tree Risers | 15 | 16 | 15 | 16 |
| Flowlines | 107 | 109 | 105 | 106 |
| Import Flowline Risers | 61 | 62 | 60 | 61 |
| Topsides | 525 | 148 | 208 | 59 |
| Export Pipeline Risers | 106 | 76 | 106 | 76 |
| Pipelines | 2809 | 1861 | 2429 | 1661 |
| Supply Vessels | 10 | 4 | 9 | 4 |
| Drilling and Intervention | 67 | 41 | 63 | 40 |

F.10 – Oil Spill Risk Assessment for Spar




F.11 – Oil Spill Risk Assessment for Spar

**Spar - Frequency Summary**

**Summary Information for Frequencies**

| | Total System Frequency | | | | | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Expected Value (per year) | Coefficient of Uncertainty | k for Gamma Distribution | n for Gamma Distribution | Lower 90% (per year) | Upper 90% (per year) |
| 1 - 10 | 1.2E+00 | 9.6E-02 | 1.1E+02 | 9.1E+01 | 1.0E+00 | 1.4E+00 |
| 10 - 100 | 3.6E-01 | 1.7E-01 | 3.4E+01 | 9.5E+01 | 2.7E-01 | 4.7E-01 |
| 100 - 1,000 | 7.7E-02 | 3.4E-01 | 8.5E+00 | 1.1E+02 | 3.9E-02 | 1.2E-01 |
| 1,000 - 10,000 | 2.2E-02 | 5.4E-01 | 3.4E+00 | 1.6E+02 | 6.6E-03 | 4.4E-02 |
| 10,000 - 100,000 | 3.7E-03 | 1.1E+00 | 8.5E-01 | 2.3E+02 | 1.2E-04 | 1.2E-02 |
| 100,000 - 500,000 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0.0E+00 | | | | | |

| | Expected Frequency by Sub-system (per year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Well Systems - Platform | Well Systems - Subsea | Dry Tree Risers | Flowlines | Import Flowline Risers | Topsides | Export Pipeline Risers | Pipelines | Supply Vessels | Drilling and Intervention |
| 1 - 10 | 4.7E-02 | 0.0E+00 | 2.3E-04 | 4.5E-03 | 2.5E-03 | 1.0E+00 | 2.0E-03 | 5.4E-02 | 1.4E-02 | 5.5E-02 |
| 10 - 100 | 2.0E-02 | 0.0E+00 | 2.0E-04 | 3.9E-03 | 2.2E-03 | 2.7E-01 | 1.8E-03 | 4.7E-02 | 7.7E-03 | 9.5E-03 |
| 100 - 1,000 | 6.7E-03 | 0.0E+00 | 7.7E-05 | 1.5E-03 | 8.4E-04 | 4.5E-02 | 6.8E-04 | 1.8E-02 | 6.2E-04 | 3.7E-03 |
| 1,000 - 10,000 | 0.0E+00 | 0.0E+00 | 7.7E-05 | 1.5E-03 | 8.4E-04 | 1.0E-04 | 6.8E-04 | 1.8E-02 | 0.0E+00 | 5.3E-04 |
| 10,000 - 100,000 | 0.0E+00 | 0.0E+00 | 1.5E-05 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 1.4E-04 | 3.6E-03 | 0.0E+00 | 0.0E+00 |
| 100,000 - 500,000 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |
| 500,000 - 1,000,000 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |

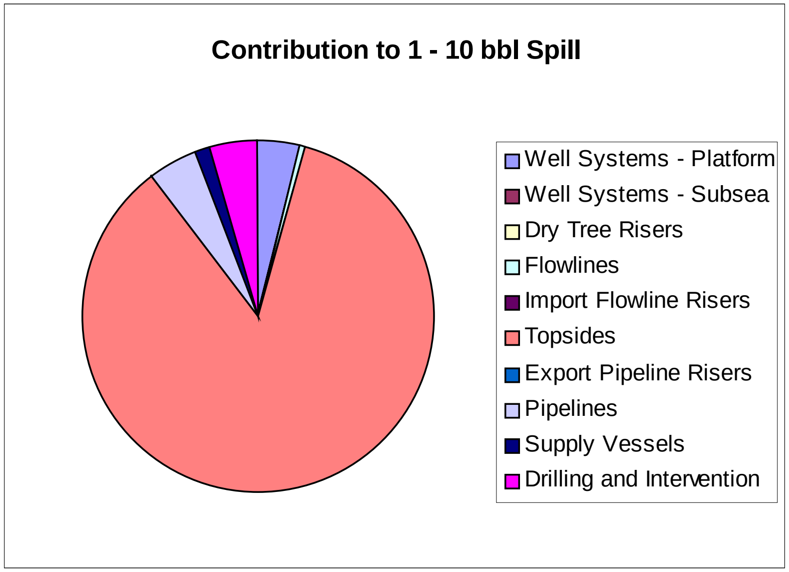
**Summary Information for Spar Production Frequencies**

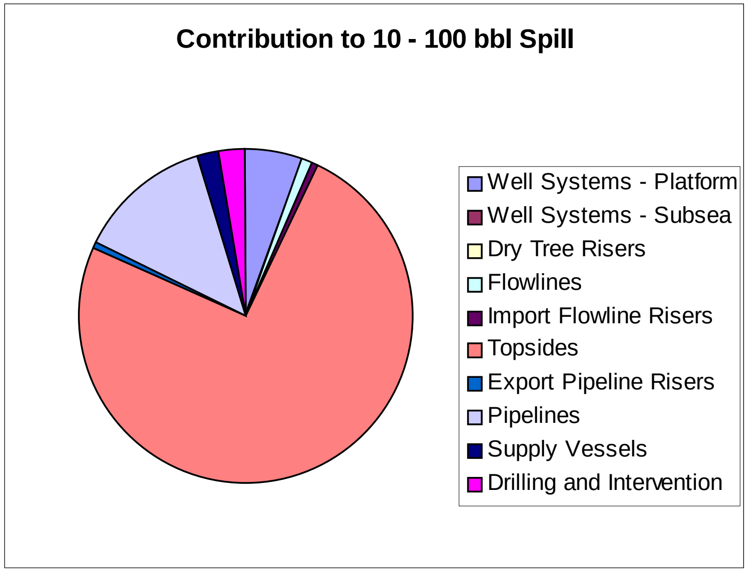
| | Production System Frequency | | | | | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Expected Value (per year) | Coefficient of Uncertainty | k for Gamma Distribution | n for Gamma Distribution | Lower 90% (per year) | Upper 90% (per year) |
| 1 - 10 | 1.1E+00 | 9.8E-02 | 1.0E+02 | 9.2E+01 | 9.6E-01 | 1.3E+00 |
| 10 - 100 | 3.1E-01 | 1.8E-01 | 3.0E+01 | 9.8E+01 | 2.2E-01 | 4.1E-01 |
| 100 - 1,000 | 5.8E-02 | 4.1E-01 | 6.1E+00 | 1.0E+02 | 2.5E-02 | 1.0E-01 |
| 1,000 - 10,000 | 3.0E-03 | 6.8E-01 | 2.2E+00 | 7.2E+02 | 6.0E-04 | 7.0E-03 |
| 10,000 - 100,000 | 1.5E-05 | 1.4E+00 | 5.0E-01 | 3.3E+04 | 6.0E-08 | 5.9E-05 |
| 100,000 - 500,000 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0.0E+00 | | | | | |

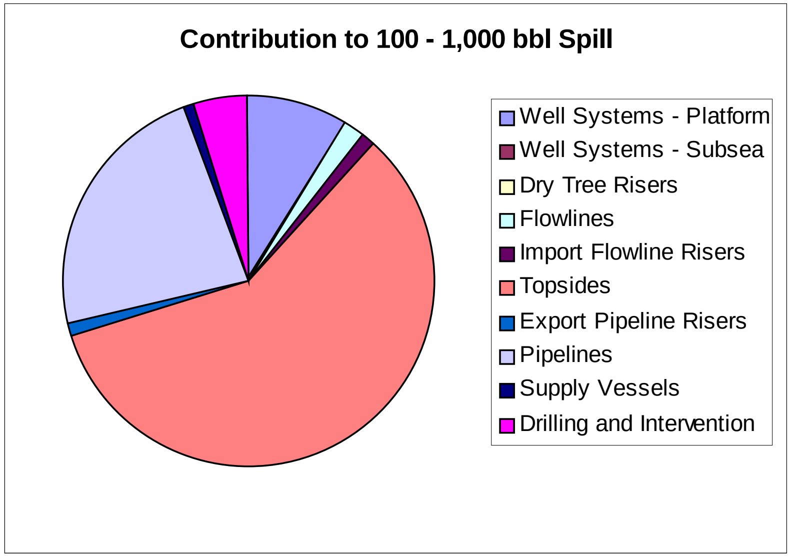
**Summary Information for Spar Transportation Frequencies**

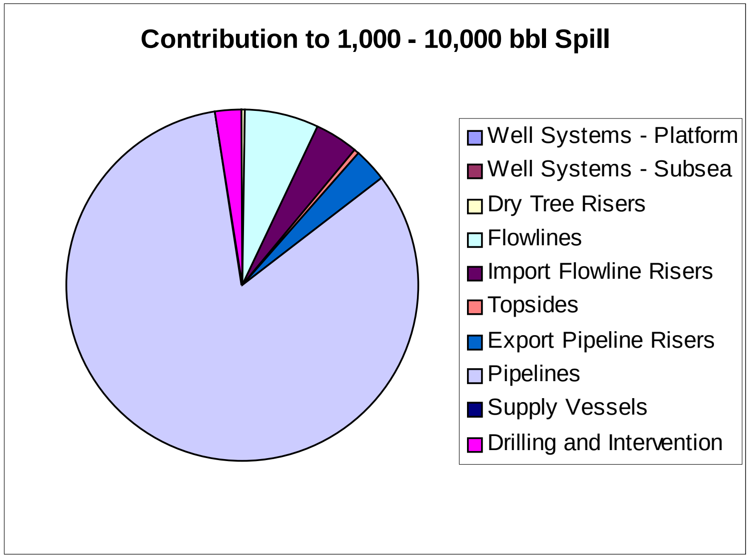
| | Transportation System Frequency | | | | | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Expected Value (per year) | Coefficient of Uncertainty | k for Gamma Distribution | n for Gamma Distribution | Lower 90% (per year) | Upper 90% (per year) |
| 1 - 10 | 5.6E-02 | 5.0E-01 | 4.0E+00 | 7.1E+01 | 1.9E-02 | 1.1E-01 |
| 10 - 100 | 4.9E-02 | 5.1E-01 | 3.8E+00 | 7.9E+01 | 1.6E-02 | 9.5E-02 |
| 100 - 1,000 | 1.9E-02 | 6.2E-01 | 2.6E+00 | 1.4E+02 | 4.4E-03 | 4.1E-02 |
| 1,000 - 10,000 | 1.9E-02 | 6.2E-01 | 2.6E+00 | 1.4E+02 | 4.4E-03 | 4.1E-02 |
| 10,000 - 100,000 | 3.7E-03 | 1.1E+00 | 8.4E-01 | 2.3E+02 | 1.2E-04 | 1.2E-02 |
| 100,000 - 500,000 | | | | | | |
| 500,000 - 1,000,000 | | | | | | |

Spar - Contribution to Total Frequency for Different Spill Sizes



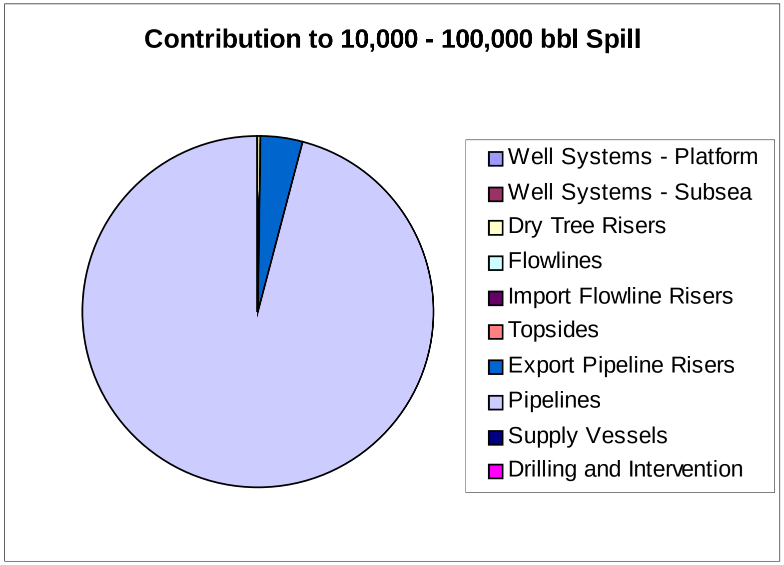



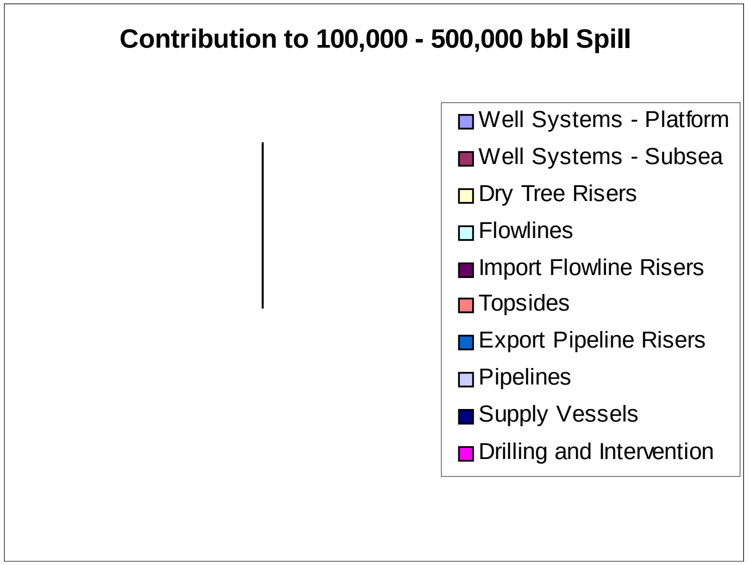



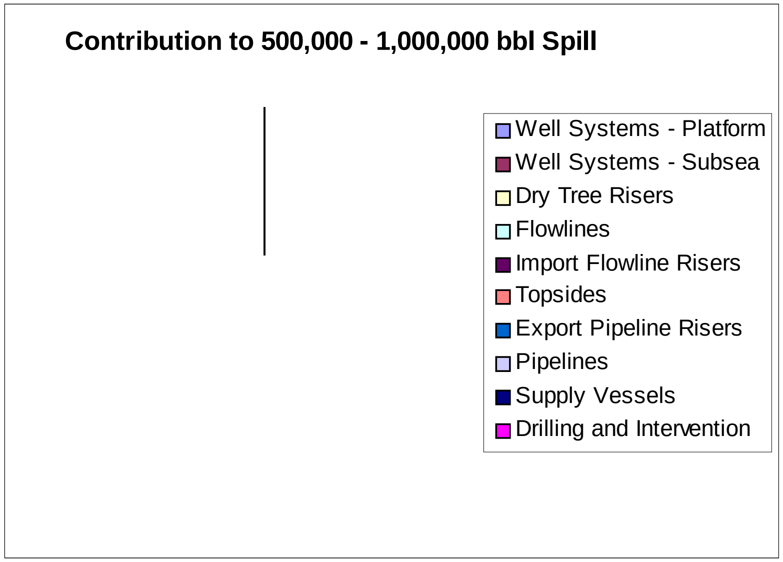




F.14 – Oil Spill Risk Assessment for Spar

Spar - Contribution to Total Frequency for Different Spill Sizes




F.15 – Oil Spill Risk Assessment for Spar

**Spar - Well Systems (Platform)**

| Exposure (bbl produced) | 4.13E+08 |
|---|---|

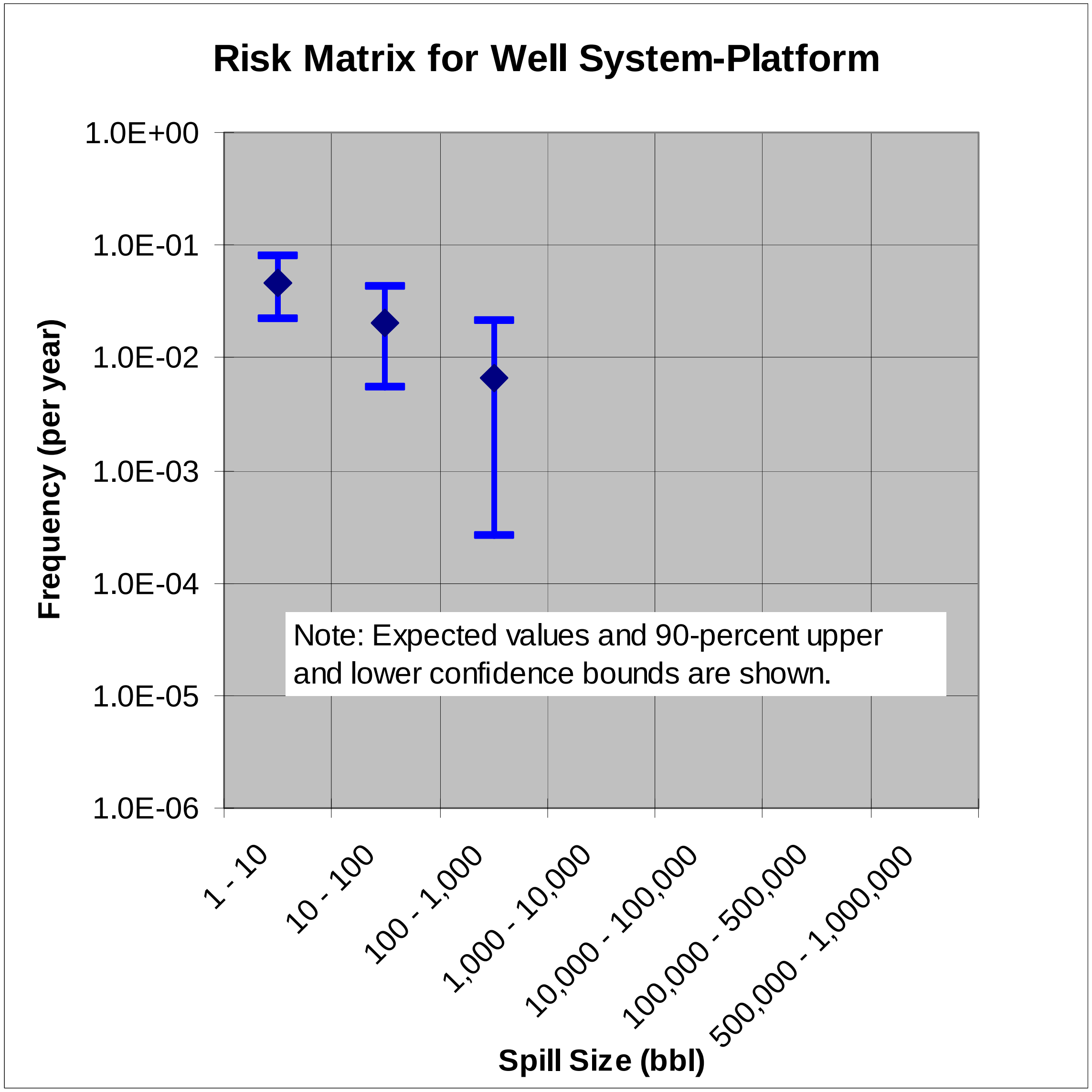
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Spill Size (bbl) | Expected Frequency (per bbl) | Coefficient of Uncertainty for Frequency | Expected Bias | Coefficient of Uncertainty for Bias | Expected Frequency (per bbl) | Coefficient of Uncertainty for Frequency |
| 1 - 10 | 3 | 2.3E-09 | 0.38 | 1.0E+00 | 0.00 | 2.3E-09 | 0.38 |
| 10 - 100 | 32 | 9.8E-10 | 0.58 | 1.0E+00 | 0.00 | 9.8E-10 | 0.58 |
| 100 - 1,000 | 320 | 3.3E-10 | 1.05 | 1.0E+00 | 0.33 | 3.3E-10 | 1.00 |
| 1,000 - 10,000 | 3200 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| Expected Total (bbl) | 5.9E+01 |
|---|---|
| Std. Dev. in Total (bbl) | 4.6E+01 |

| Expected Max (bbl) | 5.1E+01 |
|---|---|
| Std. Dev. in Max (bbl) | 4.0E+01 |


Risk Matrix for Well System-Platform
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
Frequency (per year)
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Reported incidents of oil spills from "well and header systems" in the Gulf of Mexico were taken from the MMS pipeline and platform spill database (provided by Cheryl Anderson of MMS) for the years 1980 to 1999. The data are summarized below. Use only data from 1990 to present to account for changes in operating procedures due to implementation of API RP14C.

Equipment includes subsurface safety valves, wellhead assemblies, chokes, jumpers and injection lines, pressure sensors, surface safety valves, header valves and check valves.

Assume risk is proportional to the volume of production - total production data are available for GOM from 1985-1998.

| Total Production bbls in GOM Data: | |
|---|---|
| Expected Value (bbl) | 3.1E+09 |
| Coefficient of Uncertainty | 0 |
| Standard Deviation (bbl) | 0 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per bbl) | k" | n" (bbl) | Expected Value (/bbl) | Std. Dev. (/bbl) | Coefficient of Uncertainty |
| 1 - 10 | 6 | 2.0E-09 | 7 | 3.1E+09 | 2.3E-09 | 8.6E-10 | 0.377964473 |
| 10 - 100 | 2 | 6.5E-10 | 3 | 3.1E+09 | 9.8E-10 | 5.6E-10 | 0.577350269 |
| 100 - 1,000 | 0 | 0.0E+00 | 1 | 3.1E+09 | 3.3E-10 | 3.3E-10 | 1 |
| 1,000 - 10,000 | 0 | 0.0E+00 | | | | | |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because study well systems are similar to those in data base.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data for the largest spill size category since there have been no occurrences for this spill size on the fixed production systems in the database and its frequency on floating production systems is uncertain.

Exposure for Study System:

**Platform Well Production (bbl)** **4.13E+08**

**Spills from Well and Header Systems in the GoM**
**(Source: MMS - TIMS Database)**

| | | | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Total Productio n (bbl)** | **Barrels Spilled per 1E6 Bbl Produced** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1980 | 2 | 7 | | | 2 | 7 | 3.4 | | | | | | |
| 1981 | 3 | 12 | | | 3 | 12 | 4.0 | | | | | | |
| 1982 | 5 | 14 | | | 5 | 14 | 2.7 | | | | | | |
| 1983 | 2 | 31 | | | | | | 2 | 31 | 15.5 | | | |
| 1984 | 1 | 3 | | | 1 | 3 | 3.0 | | | | | | |
| 1985 | 2 | 43 | 351133870 | 0.12 | 1 | 3 | 3.0 | 1 | 40 | 40.0 | | | |
| 1986 | 2 | 5 | 356398376 | 0.01 | 2 | 5 | 2.5 | | | | | | |
| 1987 | 3 | 6 | 328243087 | 0.02 | 3 | 6 | 2.0 | | | | | | |
| 1988 | 5 | 73 | 301704812 | 0.24 | 4 | 18 | 4.5 | 1 | 55 | 55.0 | | | |
| 1989 | 2 | 18 | 281160011 | 0.06 | 1 | 6 | 6.0 | 1 | 12 | 12.0 | | | |
| 1990 | 0 | 0 | 274955773 | 0.00 | | | | | | | | | |
| 1991 | 0 | 0 | 295129769 | 0.00 | | | | | | | | | |
| 1992 | 3 | 74 | 305282682 | 0.24 | 1 | 8 | 8.0 | 2 | 66 | 33.0 | | | |
| 1993 | 0 | 0 | 309229380 | 0.00 | | | | | | | | | |
| 1994 | 2 | 6 | 314743342 | 0.02 | 2 | 6 | 3.0 | | | | | | |
| 1995 | 1 | 1 | 345525211 | 0.00 | 1 | 1 | 1.0 | | | | | | |
| 1996 | 2 | 3 | 369309647 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1997 | 0 | 0 | 411795024 | 0.00 | | | | | | | | | |
| 1998 | 0 | 0 | 444466377 | 0.00 | | | | | | | | | |
| 1999 | 0 | 0 | | | | | | | | | | | |
| **TOTAL** | **35** | **295** | **4.69E+09** | **4.88E-02** | **28** | **91** | **3** | **7** | **204** | **29** | **0** | **0** | **0** |

**Spar - Well Systems (Subsea)**

| | |
|---|---|
| **Exposure (bbl produced)** | **2.73E+08** |

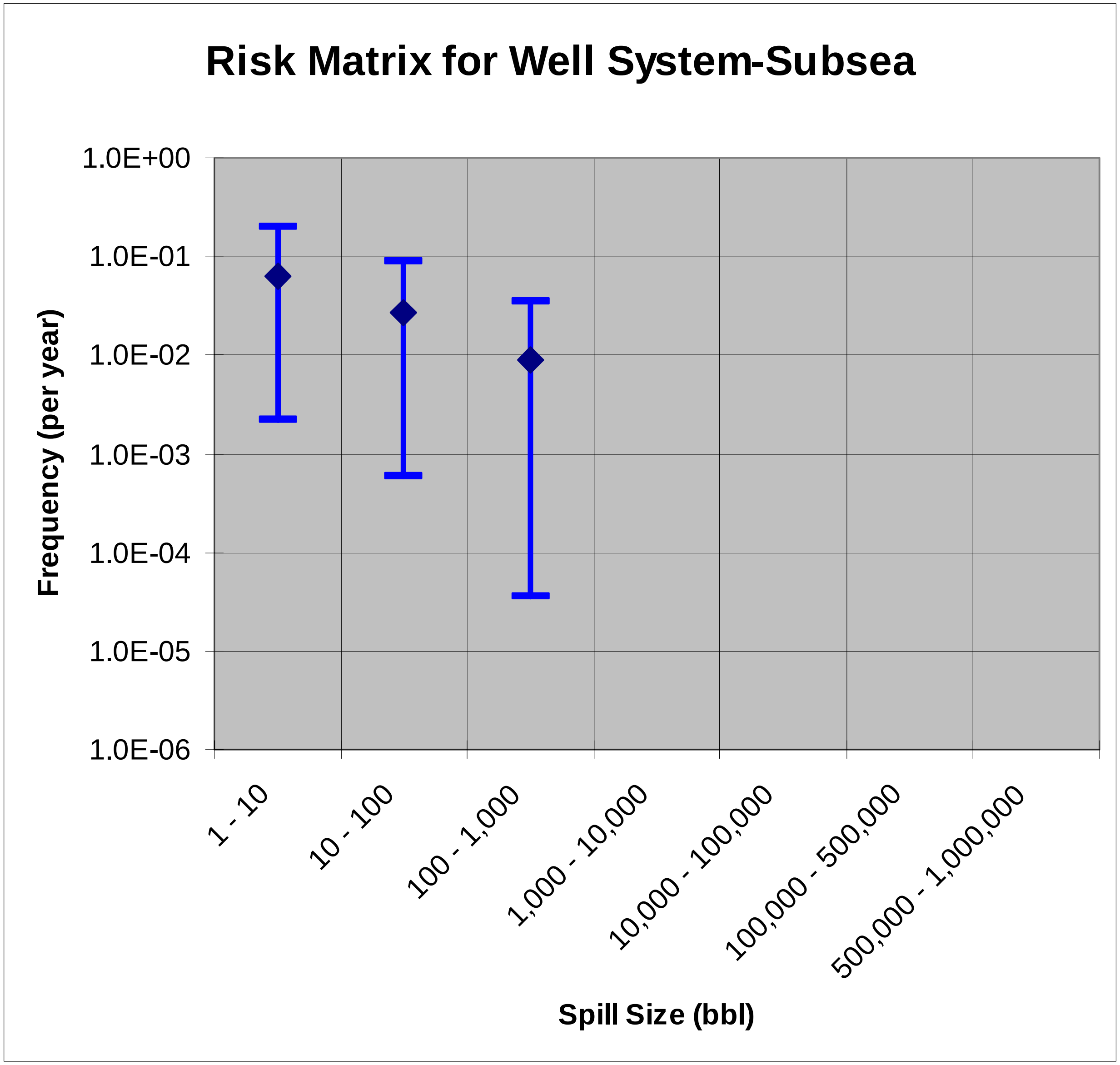
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 4.6E-09 | 1.07 | 2.0E+00 | 1.00 | 2.3E-09 | 0.38 |
| 10 - 100 | 32 | 2.0E-09 | 1.15 | 2.0E+00 | 1.00 | 9.8E-10 | 0.58 |
| 100 - 1,000 | 320 | 6.5E-10 | 1.41 | 2.0E+00 | 1.00 | 3.3E-10 | 1.00 |
| 1,000 - 10,000 | 3200 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **7.8E+01** |
| **Std. Dev. in Total (bbl)** | **8.3E+01** |

| | |
|---|---|
| **Expected Max (bbl)** | **6.4E+01** |
| **Std. Dev. in Max (bbl)** | **6.8E+01** |




F.21 – Oil Spill Risk Assessment for Spar

**Basis:**

Reported incidents of oil spills from "well and header systems" in the Gulf of Mexico were taken from the MMS pipeline and platform spill database (provided by Cheryl Anderson of MMS) for the years 1980 to 1999. The data are summarized below. Use only data from 1990 to present to account for changes in operating

Equipment includes subsurface safety valves, wellhead assemblies, chokes, jumpers and injection lines, pressure sensors, surface safety valves, header valves and check valves.

Assume risk is proportional to the volume of production - total production data are available for GOM from 1985-1998.

Total Production bbls in GOM Data:

| | |
|---|---|
| Expected Value (bbl) | 3.1E+09 |
| Coefficient of Uncertainty | 0 |
| Standard Deviation (bbl) | 0 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per bbl) | k" | n" (bbl) | Expected Value (/bbl) | Std. Dev. (/bbl) | Coefficient of Uncertainty |
| 1 - 10 | 6 | 2.0E-09 | 7 | 3.1E+09 | 2.3E-09 | 8.6E-10 | 0.377964473 |
| 10 - 100 | 2 | 6.5E-10 | 3 | 3.1E+09 | 9.8E-10 | 5.6E-10 | 0.577350269 |
| 100 - 1,000 | 0 | 0.0E+00 | 1 | 3.1E+09 | 3.3E-10 | 3.3E-10 | 1 |
| 1,000 - 10,000 | 0 | 0.0E+00 | | | | | |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Double expected frequency for leaks to account for greater potential for sand erosion and cutouts due to high flow rates and detection difficulties for sand.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since wells in database are mostly platform wells and not subsea wells.

Exposure for Study System:

**Subsea Well Production (bbl)** **2.73E+08**

| Spills from Well and Header Systems in the GoM (Source: MMS - TIMS Database) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | |
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Total Production (bbl) | Barrels Spilled per 1E6 Bbl Produced | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1980 | 2 | 7 | | | 2 | 7 | 3.4 | | | | | | |
| 1981 | 3 | 12 | | | 3 | 12 | 4.0 | | | | | | |
| 1982 | 5 | 14 | | | 5 | 14 | 2.7 | | | | | | |
| 1983 | 2 | 31 | | | | | | 2 | 31 | 15.5 | | | |
| 1984 | 1 | 3 | | | 1 | 3 | 3.0 | | | | | | |
| 1985 | 2 | 43 | 351133870 | 0.12 | 1 | 3 | 3.0 | 1 | 40 | 40.0 | | | |
| 1986 | 2 | 5 | 356398376 | 0.01 | 2 | 5 | 2.5 | | | | | | |
| 1987 | 3 | 6 | 328243087 | 0.02 | 3 | 6 | 2.0 | | | | | | |
| 1988 | 5 | 73 | 301704812 | 0.24 | 4 | 18 | 4.5 | 1 | 55 | 55.0 | | | |
| 1989 | 2 | 18 | 281160011 | 0.06 | 1 | 6 | 6.0 | 1 | 12 | 12.0 | | | |
| 1990 | 0 | 0 | 274955773 | 0.00 | | | | | | | | | |
| 1991 | 0 | 0 | 295129769 | 0.00 | | | | | | | | | |
| 1992 | 3 | 74 | 305282682 | 0.24 | 1 | 8 | 8.0 | 2 | 66 | 33.0 | | | |
| 1993 | 0 | 0 | 309229380 | 0.00 | | | | | | | | | |
| 1994 | 2 | 6 | 314743342 | 0.02 | 2 | 6 | 3.0 | | | | | | |
| 1995 | 1 | 1 | 345525211 | 0.00 | 1 | 1 | 1.0 | | | | | | |
| 1996 | 2 | 3 | 369309647 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1997 | 0 | 0 | 411795024 | 0.00 | | | | | | | | | |
| 1998 | 0 | 0 | 444466377 | 0.00 | | | | | | | | | |
| 1999 | 0 | 0 | | | | | | | | | | | |
| **TOTAL** | **35** | **295** | **4.69E+09** | **4.88E-02** | **28** | **91** | **3** | **7** | **204** | **29** | **0** | **0** | **0** |

**Spar - Dry Tree Risers**

| Exposure (riser-years) | 120 |
|---|---|

**Input Information**

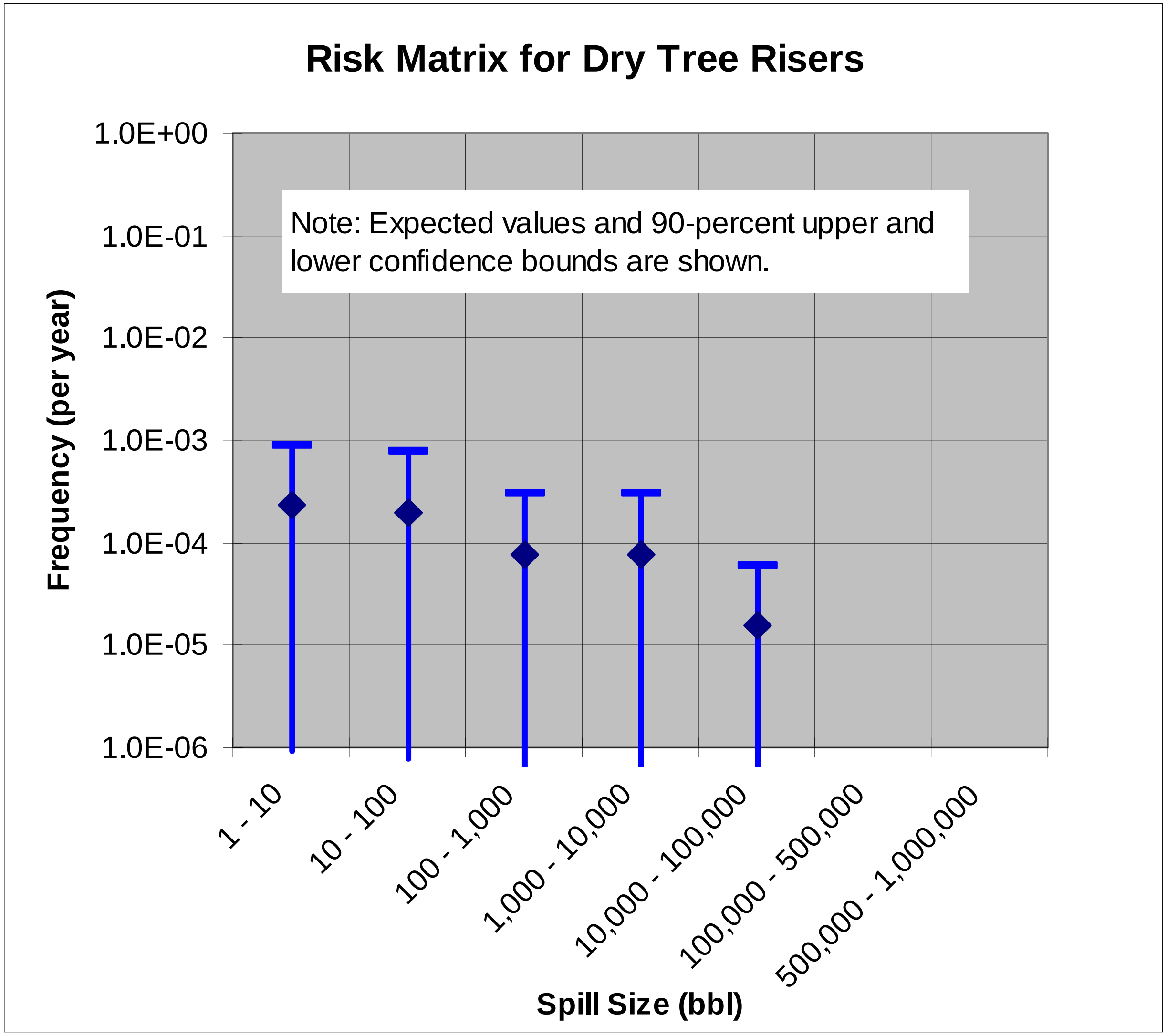
| Spill Size Range (bbl) | Spill Size (bbl) | Combined (Expert+Data) Estimate: Expected Frequency (per riser-year) | Combined (Expert+Data) Estimate: Coefficient of Uncertainty for Frequency | Expert-Based Extrapolation Bias: Expected Bias | Expert-Based Extrapolation Bias: Coefficient of Uncertainty for Bias | Data-Based Estimate: Expected Frequency (per riser-year) | Data-Based Estimate: Coefficient of Uncertainty for Frequency |
|---|---|---|---|---|---|---|---|
| 1 - 10 | 3 | 3.8E-05 | 1.41 | 1.0E+00 | 1.00 | 3.8E-05 | 1.00 |
| 10 - 100 | 32 | 3.3E-05 | 1.41 | 1.0E+00 | 1.00 | 3.3E-05 | 1.00 |
| 100 - 1,000 | 320 | 1.3E-05 | 1.41 | 1.0E+00 | 1.00 | 1.3E-05 | 1.00 |
| 1,000 - 10,000 | 3200 | 1.3E-05 | 1.41 | 1.0E+00 | 1.00 | 1.3E-05 | 1.00 |
| 10,000 - 100,000 | 32000 | 2.6E-06 | 1.41 | 1.0E+00 | 1.00 | 2.6E-06 | 1.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| Expected Total (bbl) | 1.5E+01 |
|---|---|
| Std. Dev. in Total (bbl) | 1.6E+01 |

| Expected Max (bbl) | 1.5E+01 |
|---|---|
| Std. Dev. in Max (bbl) | 1.6E+01 |

F.24 – Oil Spill Risk Assessment for Spar




F.25 – Oil Spill Risk Assessment for Spar

**Basis:**

Use OTC 8518 (Wolford et al. 1997) information for leak frequency from dual-cased production risers: $6.0 \times 10^{-5}$ loss-of-well control events (including during production and well intervention) per riser-year based on fault tree analysis - use $1 \times 10^{-4}$ leaks per riser-year as an approximation for the study system.

| Leak Frequency for riser (per riser year): | |
|---|---|
| Expected Value (OTC Paper) | 1.00E-04 |
| Coefficient of Uncertainty (Few data to support | 1.00 |
| Standard Deviation | 0.0001 |

Distribute spill sizes from risers using the pipeline spill-size distribution for spills less than 100,000 bbl in size (see Pipeline worksheet for details).

| Spill Size Range (bbl) | Expected Pipeline Frequency (per mile-year) | Leak Distribution for no SSV Failure | Expected Riser Frequency (per riser year) | Coefficient of Uncertainty in Frequency |
|---|---|---|---|---|
| 1 - 10 | 3.72E-04 | 38% | 3.85E-05 | 1.00 |
| 10 - 100 | 3.22E-04 | 33% | 3.33E-05 | 1.00 |
| 100 - 1,000 | 1.24E-04 | 13% | 1.28E-05 | 1.00 |
| 1,000 - 10,000 | 1.24E-04 | 13% | 1.28E-05 | 1.00 |
| 10,000 - 100,000 | 2.48E-05 | 3% | 2.56E-06 | 1.00 |
| 100,000 - 500,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |
| 500,000 - 1,000,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |
| | | Total: | 1.00E-04 | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because estimated frequency was for similar types of risers.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the data because there are no actual occurrences of these types of events from dual risers for deepwater floating production systems.
- While a large spill (>100,000 bbl spill) could occur if there is a leak from the riser system and a failure of the subsea safety valve (SSV), this possibility is considered to be so remote as to be negligible. For example, the probability of failure for an SSV is estimated to be about 0.001 giving approximately a 0.0001x0.001 or 1x10-7 frequency per riser year for this type of an event, which would contribute very little to the expected oil spill volume. Therefore, the frequencies for spills greater than 100,000 bbl are assumed to be zero.

| Exposure for Study System: | |
|---|---|
| Number of Dry Tree Risers | 6 |
| Service Life (years) | 20 |
| **Exposure (riser-years)** | **120** |

**Spar - Flowlines**

| | |
|---|---|
| **Exposure (mile-years)** | **240** |

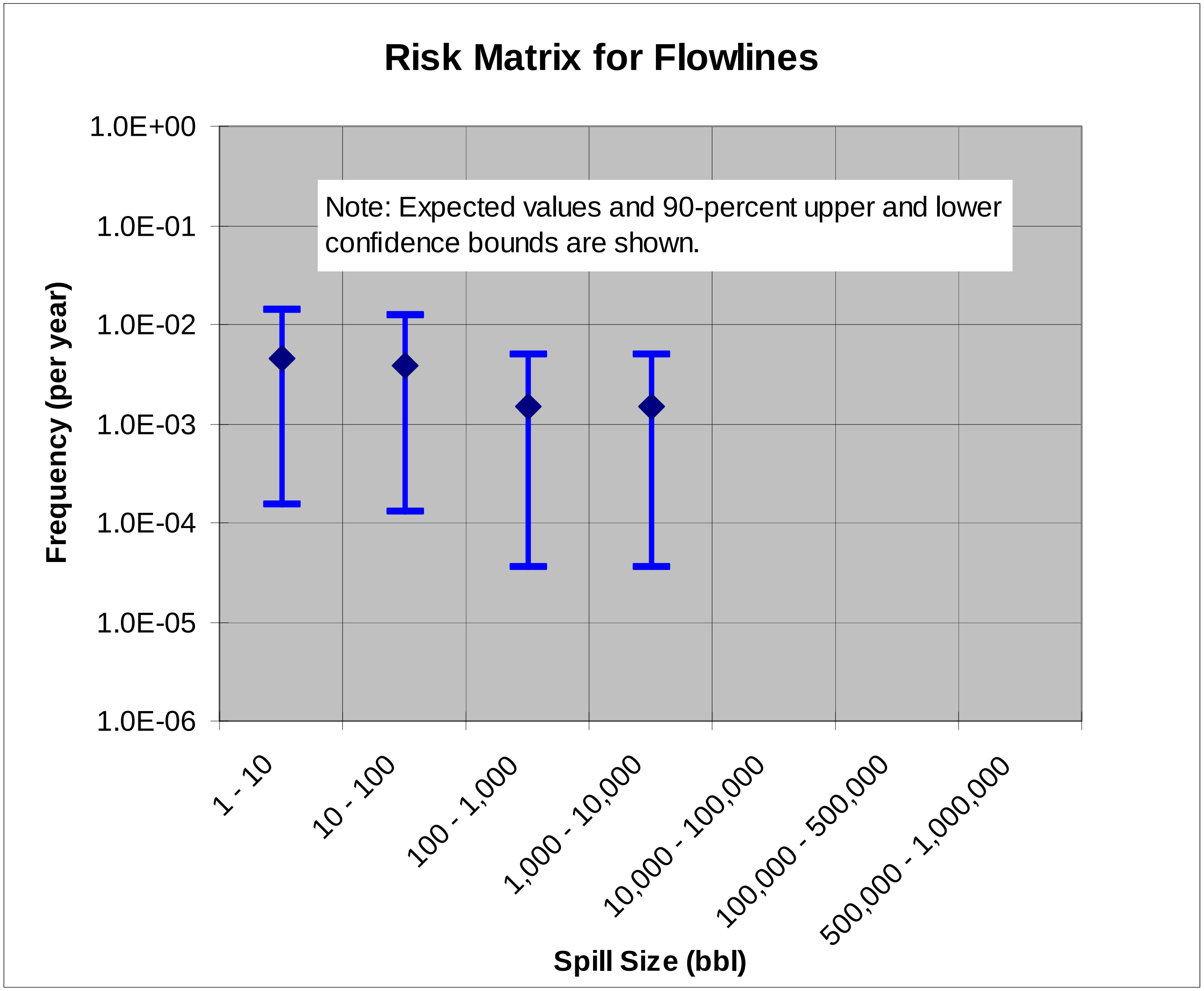
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per mile-year)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per mile-year)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 3.7E-04 | 1.08 | 1.0E+00 | 1.00 | 3.7E-04 | 4.0E-01 |
| 10 - 100 | 32 | 3.2E-04 | 1.08 | 1.0E+00 | 1.00 | 3.2E-04 | 4.1E-01 |
| 100 - 1,000 | 320 | 1.2E-04 | 1.14 | 1.0E+00 | 1.00 | 1.2E-04 | 5.5E-01 |
| 1,000 - 10,000 | 3200 | 1.2E-04 | 1.14 | 1.0E+00 | 1.00 | 1.2E-04 | 5.5E-01 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 2.5E-05 | 1.1E+00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.0E+00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.0E+00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **1.1E+02** |
| **Std. Dev. in Total (bbl)** | **1.1E+02** |

| | |
|---|---|
| **Expected Max (bbl)** | **1.1E+02** |
| **Std. Dev. in Max (bbl)** | **1.1E+02** |


Risk Matrix for Flowlines
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
Frequency (per year)
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Reported incidents of oil pipeline leaks in the Gulf of Mexico were taken from the USCG spill database for the years 1992 to 1998. The data are summarized below.

Total Pipeline Miles in GOM federal and state waters estimated from MMS and Lousiana data making the following assumptions:
Federal Waters Sum: Include "unknown" mileage in all years
State Waters Sum: Start with 2,500 miles from Mariano Hinojosa (Louisiana) in 2000; Maintain constant State/Federal Percentage for Earlier Years
Percent Inactive: Assume 17 percent today, 0 percent in 1948 and increase it linearly with time
Total Active: Reduce both federal and state together with same percentage inactive
Total Active Liquid: Assume 30 percent of pipeline length is liquid versus gas (NRC Marine Board Study 1994)
Result - 44,715 mile-years from 1992 to 1998
As a check, Marine Board Study in 1994 reported 17,000 total miles with 30 % oil/condensate, giving 5,100 miles for 7 years or 35,700 mile-years.

Total Mile Years in Data:

| | |
|---|---|
| Expected Value | 44715 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 14756 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per mile-yr) | k" | n" (mile-yr) | Expected Value (per mile-yr) | Std. Dev. (per mile-yr) | c.o.v. |
| 1 - 10 | 14 | 3.1E-04 | 15 | 44715 | 3.7E-04 | 1.5E-04 | 0.40 |
| 10 - 100 | 12 | 2.7E-04 | 13 | 44715 | 3.2E-04 | 1.3E-04 | 0.41 |
| 100 - 1,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 1,000 - 10,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 10,000 - 100,000 | 0 | 0.0E+00 | 1 | 44715 | 2.5E-05 | 2.7E-05 | 1.08 |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because flowliness for study systems will be similar to pipelines in database, although they will be in deeper water than average pipelines in database.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since most of the pipelines in the historical database are in shallower water than the flowlines for the study system. The deepwater effect may lead to a reduction in the frequency of spills (fewer anchor drags and dropped objects), but the difference was not considered to be significant enough (an EQE 1998 study estimated the frequency of spills for deepwater segments of pipeline would be approximately 70-percent of that for shallow water pipeline segments) to be reflected in the expected bias.
- Limit maximum possible spill size per incident to 10,000 bbl because (1) flowline inventory is small (< 10,000 bbl total in parallel lines) and (2) safety systems should shut production in within 45 minutes of a leak occurring (5 hours at 2,000 bbl/hr total in both lines gives 10,000 bbl).

Study System Exposure:

| | |
|---|---|
| Length per Line (miles) | 10 |
| Number of Lines | 2 |
| Service Life (yrs) | 12 |
| **Exposure (mile-years)** | **240** |

| Spills from Pipelines in the GoM and its Waterways (Source: USCG - Marine Casuality and Pollution Database with input from MMS) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | |
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1992 | 10 | 3055 | 3 | 10 | 3.3 | 4 | 123 | 30.8 | 2 | 922 | 461.0 | 1 | 2000 | 2000.0 |
| 1993 | 2 | 5 | 2 | 5 | 2.5 | | | | | | | | | |
| 1994 | 2 | 4554 | | | | 1 | 10 | 10.0 | | | | 1 | 4544 | 4544.0 |
| 1995 | 5 | 32 | 3 | 8 | 2.7 | 2 | 24 | 12.0 | | | | | | |
| 1996 | 2 | 28 | 1 | 2 | 2.0 | 1 | 26 | 26.0 | | | | | | |
| 1997 | 5 | 223 | 2 | 9 | 4.5 | 2 | 51 | 25.5 | 1 | 163 | 163.0 | | | |
| 1998 | 8 | 10214 | 3 | 9 | 3.0 | 2 | 39 | 19.5 | 1 | 743 | 743.0 | 2 | 9423 | 4711.5 |
| **TOTAL** | **34** | **18111** | **14** | **43** | **3.1** | **12** | **273** | **22.8** | **4** | **1828** | **457.0** | **4** | **15967** | **3991.8** |

**Spar - Import Flowline Risers**

| | |
|---|---|
| **Exposure (riser-years)** | **24** |

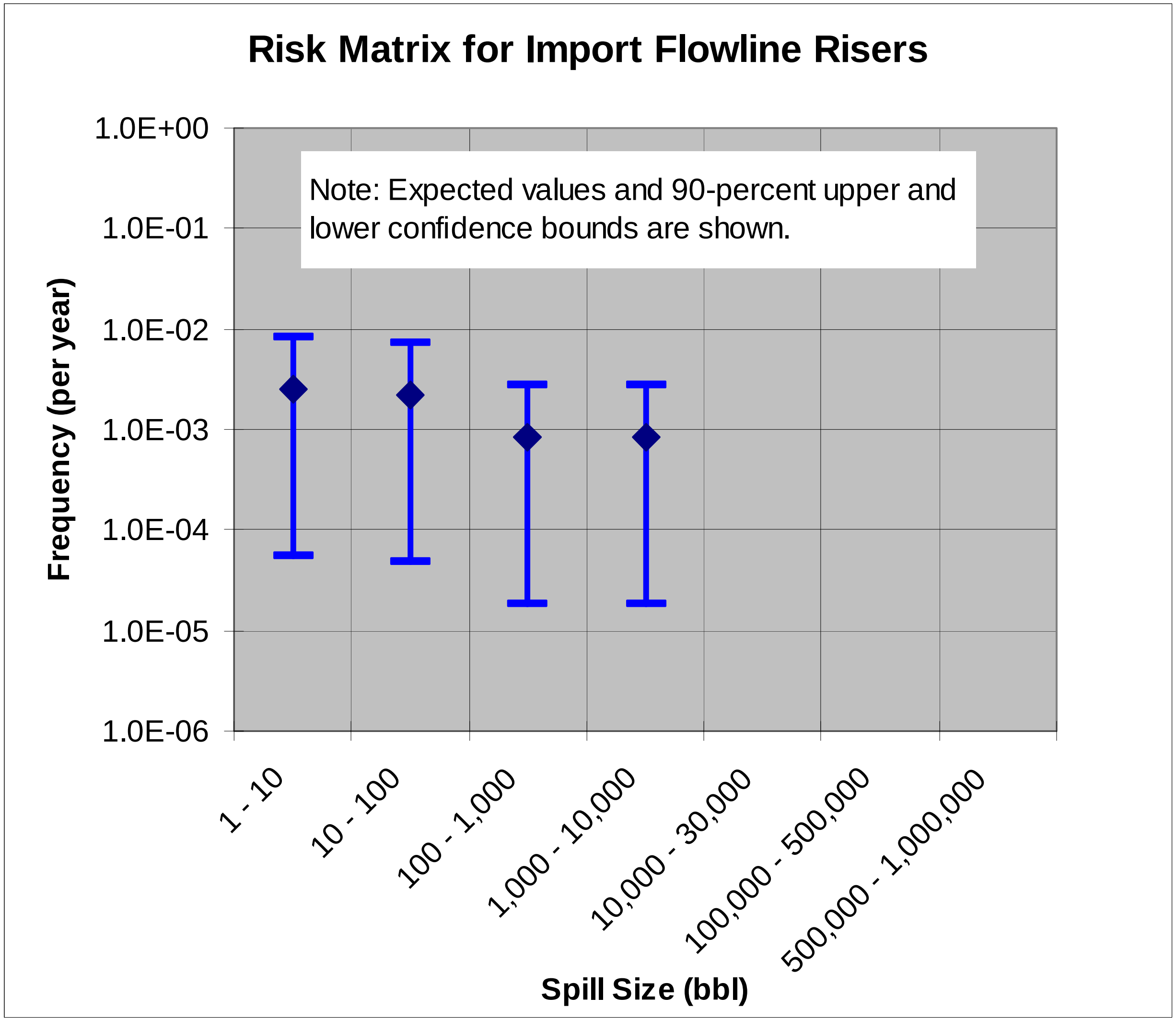
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per riser-year)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per riser-year)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 2.1E-03 | 1.15 | 1.0E+00 | 1.00 | 2.1E-03 | 0.58 |
| 10 - 100 | 32 | 1.8E-03 | 1.15 | 1.0E+00 | 1.00 | 1.8E-03 | 0.58 |
| 100 - 1,000 | 320 | 7.0E-04 | 1.15 | 1.0E+00 | 1.00 | 7.0E-04 | 0.58 |
| 1,000 - 10,000 | 3200 | 7.0E-04 | 1.15 | 1.0E+00 | 1.00 | 7.0E-04 | 0.58 |
| 10,000 - 30,000 | 32000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **6.1E+01** |
| **Std. Dev. in Total (bbl)** | **6.2E+01** |

| | |
|---|---|
| **Expected Max (bbl)** | **6.0E+01** |
| **Std. Dev. in Max (bbl)** | **6.1E+01** |


Risk Matrix for Import Flowline Risers
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
Frequency (per year)
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 30,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Use Parloc 93 information for leak frequency from risers, normalized by riser-years: 2 leaks in 565 riser-years for risers with a diameter greater than 8 inches.

Statistical Analysis:

| | |
|---|---|
| Exposure (riser-years) | 565 |
| Leaks | 2 |
| k" | 3 |
| n" (riser-years) | 565 |
| Expected Rate (per riser-year) | 5.31E-03 |
| Coefficient of Uncertainty in Rate | 0.577 |

Distribute spill sizes from risers using the flowline spill-size distribution (see Flowline worksheet for details).

| Spill Size Range (bbl) | Expected Flowline Frequency (per mile-year) | Flowline Leak Distribution | Expected Riser Frequency (per riser year) | Coefficient of Uncertainty in Frequency |
|---|---|---|---|---|
| 1 - 10 | 3.72E-04 | 39% | 2.10E-03 | 0.58 |
| 10 - 100 | 3.22E-04 | 34% | 1.82E-03 | 0.58 |
| 100 - 1,000 | 1.24E-04 | 13% | 6.99E-04 | 0.58 |
| 1,000 - 10,000 | 1.24E-04 | 13% | 6.99E-04 | 0.58 |
| 10,000 - 100,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |
| 100,000 - 500,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |
| 500,000 - 1,000,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because import risers will be in deeper water (which may increase the frequency) but more modern (which may decrease the frequency) than the risers in the database.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since the risers in the historical database are not very representative of import risers on floating production systems in deepwater.

- Limit maximum possible spill size per incident to 10,000 bbl because (1) flowline inventory is small (< 10,000 bbl total in parallel lines) and (2) safety systems should shut production in within 45 minutes of a leak occurring (5 hours at 2,000 bbl/hr total in both lines gives 10,000 bbl).

Study System Import Risers:

| | |
|---|---|
| 2 Import from Flowlines | 2 |
| Years of Service | 12 |
| **Total Riser-Years:** | **24** |

**Spar - Topsides**

| | |
|---|---|
| **Exposure (bbl produced)** | **6.86E+08** |

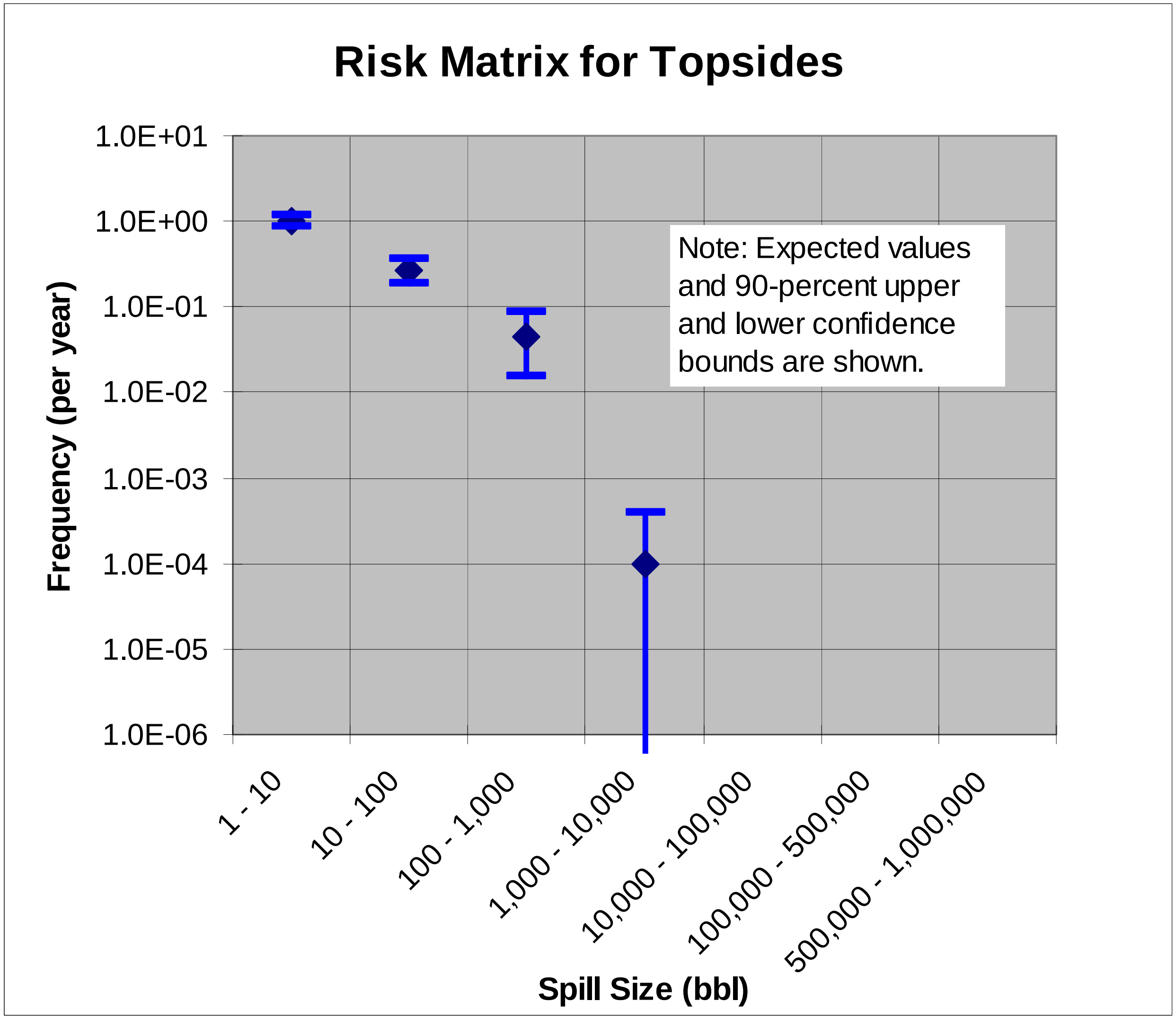
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 3.0E-08 | 0.10 | 1.0E+00 | 0.00 | 3.0E-08 | 0.10 |
| 10 - 100 | 32 | 7.8E-09 | 0.20 | 1.0E+00 | 0.00 | 7.8E-09 | 0.20 |
| 100 - 1,000 | 320 | 1.3E-09 | 0.50 | 1.0E+00 | 0.00 | 1.3E-09 | 0.50 |
| 1,000 - 10,000 | 3200 | 2.9E-12 | 1.41 | 9.0E-03 | 1.00 | 3.3E-10 | 1.00 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **5.2E+02** |
| **Std. Dev. in Total (bbl)** | **1.5E+02** |

| | |
|---|---|
| **Expected Max (bbl)** | **2.1E+02** |
| **Std. Dev. in Max (bbl)** | **5.9E+01** |




F.35 – Oil Spill Risk Assessment for Spar

**Basis:**

Reported incidents of oil spills from "platforms" in the Gulf of Mexico were taken from the MMS pipeline and platform spill database (provided by Cheryl Anderson of MMS) for the years 1980 to 1999. The data are summarized below. Use only data from 1990 to present to account for changes in operating procedures due to implementation of API RP14C.

Process equipment included in data: separators, flare line systems, heaters/treaters, sump systems, pumps, storage tanks, compressors, pig launchers, valves and piping.

Substances included in spill data: oil, condensate, fuel, glycol.

Incidents involving supply vessels and barges (e.g., transfer of fluids to/from a vessel) have been filtered out and are not included in this analysis. The USCG data base is considered to be a more comprehensive source of information about these incidents and activities (included in Supply Vessels worksheet).

Assume risk is proportional to the volume of production - total production data are available for GOM from 1985-1998.

Total GOM Production bbls in Data:

| | |
|---|---|
| Expected Value (bbl) | 3.1E+09 |
| Coefficient of Uncertainty | 0 |
| Standard Deviation (bbl) | 0 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per bbl) | k" | n" (bbl) | Expected Value (/bbl) | Std. Dev. (/bbl) | Coefficient of Uncertainty |
| 1 - 10 | 90 | 2.9E-08 | 91 | 3.1E+09 | 3.0E-08 | 3.1E-09 | 0.105 |
| 10 - 100 | 23 | 7.5E-09 | 24 | 3.1E+09 | 7.8E-09 | 1.6E-09 | 0.204 |
| 100 - 1,000 | 3 | 9.8E-10 | 4 | 3.1E+09 | 1.3E-09 | 6.5E-10 | 0.500 |
| 1,000 - 10,000 | 0 | 0.0E+00 | 1 | 3.1E+09 | 3.3E-10 | 3.3E-10 | 1.000 |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias for spills less than 1,000 bbl because estimated frequencies are for similar types of process systems. Reduce spill frequency for the 1,000 to 10,000 bbl category to $1.0\text{x}10^{-4}$ per year to account for the inventory spilled in a total structural failure.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the data for the 1,000 to 10,000 bbl category because there are no actual occurrences of this type of an event in the data record for any platforms including deepwater floating production systems.

Exposure for Study System:

| | |
|---|---|
| Production from Platform Wells (bbl) | 4.13E+08 |
| Production from Subsea Wells (bbl) | 2.73E+08 |
| **Total Production (bbl)** | **6.86E+08** |

**Spills from Oil/Gas Process Activities in the GoM**

**(Source: MMS - TIMS Database)**

| | | | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | | 10,000 - 100,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Total Production (bbl)** | **Barrels Spilled per 1E6 bbl Produced** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1980 | 27 | 1678 | | | 23 | 73 | 3.2 | 3 | 149 | 49.7 | | | | 1 | 1456 | 1456.0 | | | |
| 1981 | 21 | 135 | | | 19 | 62 | 3.3 | 2 | 73 | 36.5 | | | | | | | | | |
| 1982 | 26 | 79 | | | 25 | 67 | 2.7 | 1 | 12 | 12.0 | | | | | | | | | |
| 1983 | 48 | 280 | | | 43 | 127 | 3.0 | 5 | 153 | 30.6 | | | | | | | | | |
| 1984 | 39 | 172 | | | 38 | 122 | 3.2 | 1 | 50 | 50.0 | | | | | | | | | |
| 1985 | 34 | 141 | 351133870 | 0.40 | 32 | 100 | 3.1 | 2 | 41 | 20.5 | | | | | | | | | |
| 1986 | 24 | 75 | 356398376 | 0.21 | 24 | 75 | 3.1 | | | | | | | | | | | | |
| 1987 | 19 | 84 | 328243087 | 0.26 | 17 | 49 | 2.9 | 2 | 35 | 17.5 | | | | | | | | | |
| 1988 | 12 | 103 | 301704812 | 0.34 | 10 | 33 | 3.3 | 2 | 70 | 35.0 | | | | | | | | | |
| 1989 | 12 | 355 | 281160011 | 1.26 | 10 | 44 | 4.4 | 1 | 11 | 11.0 | 1 | 300 | 300.0 | | | | | | |
| 1990 | 15 | 91 | 274955773 | 0.33 | 13 | 47 | 3.6 | 2 | 44 | 22.0 | | | | | | | | | |
| 1991 | 11 | 477 | 295129769 | 1.62 | 7 | 33 | 4.7 | 3 | 94 | 31.3 | 1 | 350 | 350.0 | | | | | | |
| 1992 | 9 | 32 | 305282682 | 0.10 | 9 | 32 | 3.6 | | | | | | | | | | | | |
| 1993 | 9 | 42 | 309229380 | 0.14 | 8 | 23 | 2.9 | 1 | 19 | 19.0 | | | | | | | | | |
| 1994 | 6 | 16 | 314743342 | 0.05 | 6 | 16 | 2.7 | | | | | | | | | | | | |
| 1995 | 16 | 594 | 345525211 | 1.72 | 11 | 41 | 3.7 | 4 | 118 | 29.5 | 1 | 435 | 435.0 | | | | | | |
| 1996 | 21 | 271 | 369309647 | 0.73 | 15 | 52 | 3.5 | 6 | 219 | 36.5 | | | | | | | | | |
| 1997 | 13 | 260 | 411795024 | 0.63 | 10 | 33 | 3.3 | 2 | 57 | 28.5 | 1 | 170 | 170.0 | | | | | | |
| 1998 | 16 | 314 | 444466377 | 0.71 | 11 | 35 | 3.2 | 5 | 279 | 55.8 | | | | | | | | | |
| 1999 | 10 | 78 | | | 7 | 25 | 3.6 | 3 | 53 | 17.7 | | | | | | | | | |
| **TOTAL** | **388** | **5277** | **4.69E+09** | **6.09E-01** | **338** | **1089** | **3** | **45** | **1477** | **33** | **4** | **1255** | **314** | **1** | **1456** | **1456** | **0** | **0** | **0** |

**Spar - Export Pipeline Risers**

| Exposure (riser-years) | 20 |
|---|---|

**Input Information**

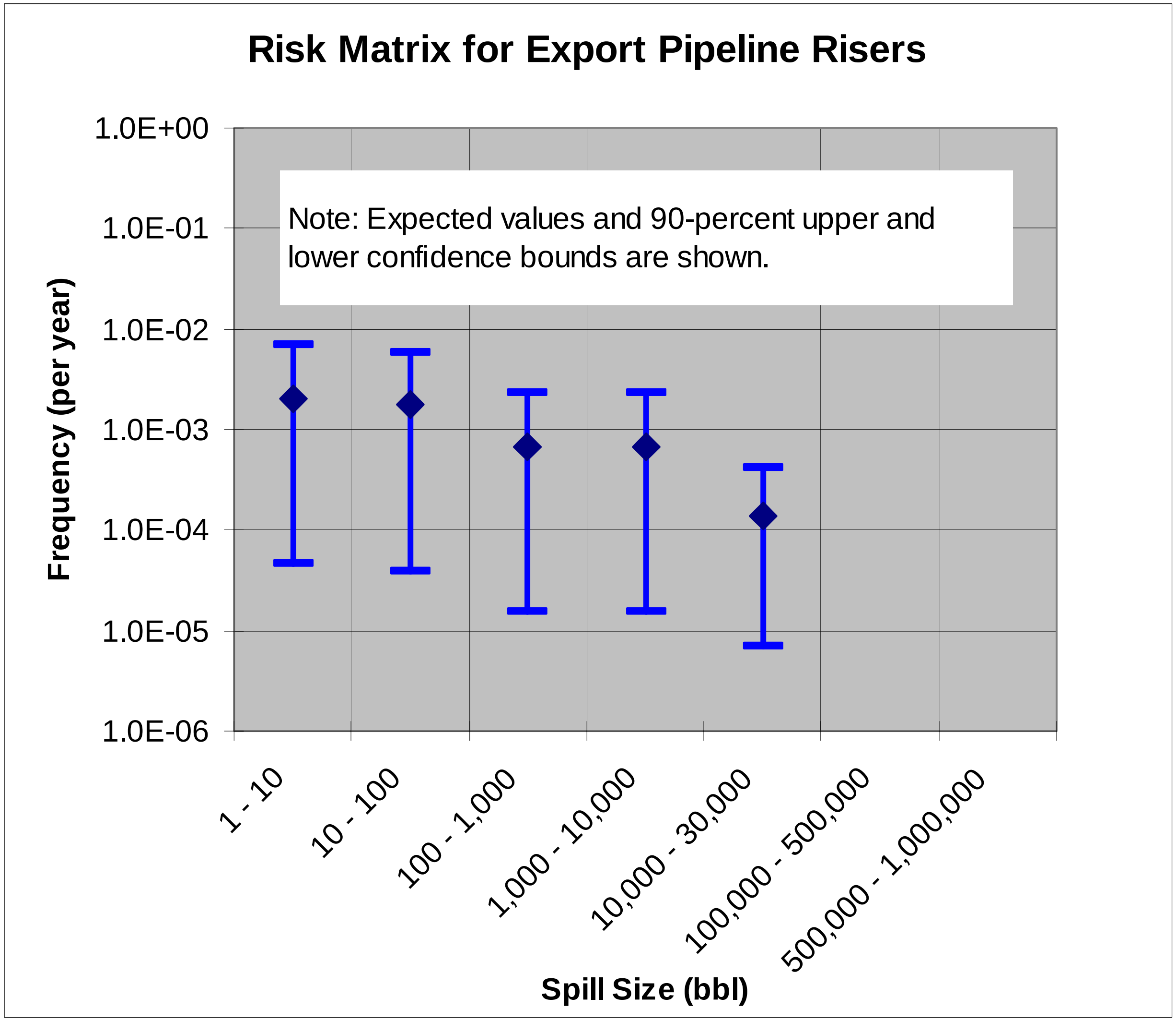
| Spill Size Range (bbl) | Spill Size (bbl) | Combined (Expert+Data) Estimate: Expected Frequency (per riser-year) | Combined (Expert+Data) Estimate: Coefficient of Uncertainty for Frequency | Expert-Based Extrapolation Bias: Expected Bias | Expert-Based Extrapolation Bias: Coefficient of Uncertainty for Bias | Data-Based Estimate: Expected Frequency (per riser-year) | Data-Based Estimate: Coefficient of Uncertainty for Frequency |
|---|---|---|---|---|---|---|---|
| 1 - 10 | 3 | 2.0E-03 | 1.15 | 1.0E+00 | 1.00 | 2.0E-03 | 0.58 |
| 10 - 100 | 32 | 1.8E-03 | 1.15 | 1.0E+00 | 1.00 | 1.8E-03 | 0.58 |
| 100 - 1,000 | 320 | 6.8E-04 | 1.15 | 1.0E+00 | 1.00 | 6.8E-04 | 0.58 |
| 1,000 - 10,000 | 3200 | 6.8E-04 | 1.15 | 1.0E+00 | 1.00 | 6.8E-04 | 0.58 |
| 10,000 - 30,000 | 21000 | 1.4E-04 | 1.00 | 1.0E+00 | 1.00 | 1.4E-04 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| Expected Total (bbl) | 1.1E+02 |
|---|---|
| Std. Dev. in Total (bbl) | 7.6E+01 |

| Expected Max (bbl) | 1.1E+02 |
|---|---|
| Std. Dev. in Max (bbl) | 7.6E+01 |

F.38 – Oil Spill Risk Assessment for Spar




F.39 – Oil Spill Risk Assessment for Spar

Use Parloc 93 information for leak frequency from risers, normalized by riser-years: 2 leaks in 565 riser-years for risers with a diameter greater than 8 inches.

Statistical Analysis:

| | |
|---|---|
| Exposure (riser-years) | 565 |
| Leaks | 2 |
| k" | 3 |
| n" (riser-years) | 565 |
| Expected Rate (per riser-year) | 5.31E-03 |
| Coefficient of Uncertainty in Rate | 0.577 |

Distribute spill sizes from risers using the pipeline spill-size distribution (see Pipeline worksheet for details).

| Spill Size Range (bbl) | Expected Pipeline Frequency (per mile-year) | Pipeline Leak Distribution | Expected Riser Frequency (per riser year) | Coefficient of Uncertainty in Frequency |
|---|---|---|---|---|
| 1 - 10 | 3.72E-04 | 38% | 2.04E-03 | 0.58 |
| 10 - 100 | 3.22E-04 | 33% | 1.77E-03 | 0.58 |
| 100 - 1,000 | 1.24E-04 | 13% | 6.81E-04 | 0.58 |
| 1,000 - 10,000 | 1.24E-04 | 13% | 6.81E-04 | 0.58 |
| 10,000 - 100,000 | 2.48E-05 | 3% | 1.36E-04 | 0.00 |
| 100,000 - 500,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |
| 500,000 - 1,000,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because import risers will be in deeper water (which may increase the frequency) but more modern (which may decrease the frequency) than the risers in the database.

- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since the risers in the historical database are not very representative of export risers on floating production systems in deepwater.

- Limit maximum possible spill size to 100,000 bbl and use a triangular probability distribution (decreasing with increasing size) in the 10,000 to 100,000 bbl category because (1) hydrostatic pressures in deeper water and “P-traps” due to bottom contours limit the volume of inventory that can leak and (2) it is not credible that pumping from the Spar would continue for more than several hours after a leak occurs (6,200 bbl/hr production rate) due to detection systems and operational requirements. Therefore, the representative spill-size for the largest category (10,000 to 100,000 bbls) is obtained by assuming that the logarithm of the spill size has a triangular distribution (versus a uniform distribution) with the maximum likelihood at 10,000 bbls and the minimum likelihood at 100,000 bbls, giving a representative value of 21,000 bbls. (Note that this same approach is used for the largest spill-size category for FPSO shuttle tankers.)

Exposure for Study System:

| | |
|---|---|
| 1 Export Riser | 1 |
| Years of Service | 20 |
| **Total Riser-Years:** | **20** |

**Spar - Pipelines**

| | |
|---|---|
| **Exposure (mile-years)** | **2900** |

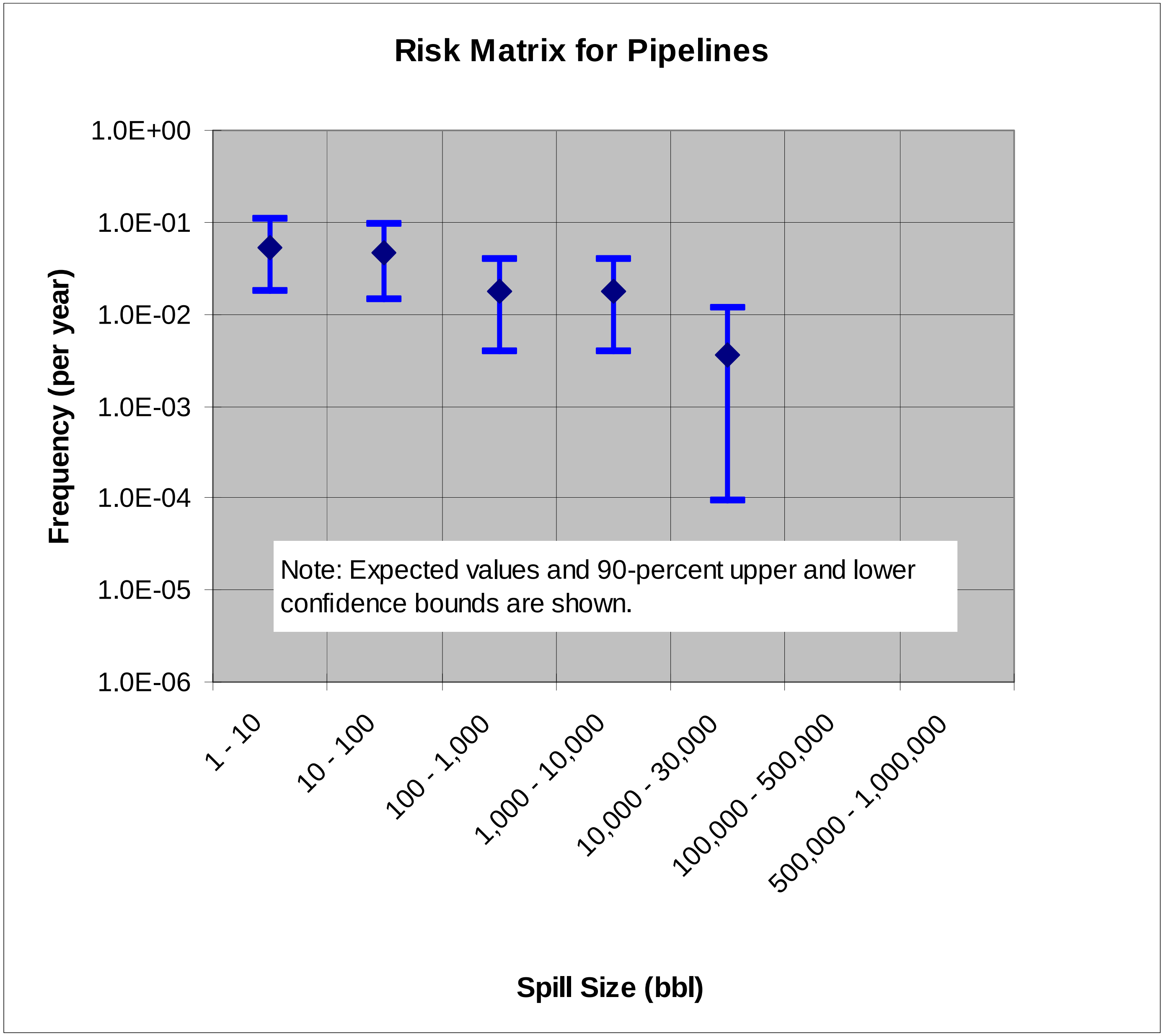
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per mile-year)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per mile-year)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 3.7E-04 | 0.52 | 1.0E+00 | 0.33 | 3.7E-04 | 0.40 |
| 10 - 100 | 32 | 3.2E-04 | 0.53 | 1.0E+00 | 0.33 | 3.2E-04 | 0.41 |
| 100 - 1,000 | 320 | 1.2E-04 | 0.64 | 1.0E+00 | 0.33 | 1.2E-04 | 0.55 |
| 1,000 - 10,000 | 3200 | 1.2E-04 | 0.64 | 1.0E+00 | 0.33 | 1.2E-04 | 0.55 |
| 10,000 - 100,000 | 21000 | 2.5E-05 | 1.13 | 1.0E+00 | 0.33 | 2.5E-05 | 1.08 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **2.8E+03** |
| **Std. Dev. in Total (bbl)** | **1.9E+03** |

| | |
|---|---|
| **Expected Max (bbl)** | **2.4E+03** |
| **Std. Dev. in Max (bbl)** | **1.7E+03** |


Risk Matrix for Pipelines
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
Frequency (per year)
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 30,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Reported incidents of oil pipeline leaks in the Gulf of Mexico were taken from the USCG spill database for the years 1992 to 1998. The data are summarized below.

Total Pipeline Miles in GOM federal and state waters estimated from MMS and Lousiana data making the following assumptions:
Federal Waters Sum: Include "unknown" mileage in all years
State Waters Sum: Start with 2,500 miles from Mariano Hinojosa (Louisiana) in 2000; Maintain constant State/Federal Percentage for Earlier Years
Percent Inactive: Assume 17 percent today, 0 percent in 1948 and increase it linearly with time
Total Active: Reduce both federal and state together with same percentage inactive
Total Active Liquid: Assume 30 percent of pipeline length is liquid versus gas (NRC Marine Board Study 1994)
Result - 44,715 mile-years from 1992 to 1998
As a check, Marine Board Study in 1994 reported 17,000 total miles with 30 % oil/condensate, giving 5,100 miles for 7 years or 35,700 mile-years.

Total Mile Years in Data:

| | |
|---|---|
| Expected Value | 44715 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 14756 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per mile-yr) | k" | n" (mile-yr) | Expected Value (per mile-yr) | Std. Dev. (per mile-yr) | c.o.v. |
| 1 - 10 | 14 | 3.1E-04 | 15 | 44715 | 3.7E-04 | 1.5E-04 | 0.40 |
| 10 - 100 | 12 | 2.7E-04 | 13 | 44715 | 3.2E-04 | 1.3E-04 | 0.41 |
| 100 - 1,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 1,000 - 10,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 10,000 - 100,000 | 0 | 0.0E+00 | 1 | 44715 | 2.5E-05 | 2.7E-05 | 1.08 |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because pipelines for study systems will be similar to pipelines in database, although they will be in deeper water on average.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data since most of the pipelines in the historical database are in shallower water on average than the pipeline for the study system. The deepwater effect may lead to a reduction in the frequency of spills (fewer anchor drags and dropped objects), but the difference was not considered to be significant enough (an EQE 1998 study estimated the frequency of spills for deepwater segments of pipeline would be approximately 70-percent of that for shallow water pipeline segments) to be reflected in the expected bias.

- Limit maximum possible spill size to 100,000 bbl and use a triangular probability distribution (decreasing with increasing size) in the 10,000 to 100,000 bbl category because (1) hydrostatic pressures in deeper water and "P-traps" due to bottom contours limit the volume of inventory that can leak and (2) it is not credible that pumping from the Spar would continue for more than several hours after a leak occurs (6,200 bbl/hr production rate) due to detection systems and operational requirements. Therefore, the representative spill-size for the largest category (10,000 to 100,000 bbls) is obtained by assuming that the logarithm of the spill size has a triangular distribution (versus a uniform distribution) with the maximum likelihood at 10,000 bbls and the minimum likelihood at 100,000 bbls, giving a representative value of 21,000 bbls. (Note that this same approach is used for the largest spill-size category for FPSO shuttle tankers.)

Exposure for Study System (mile-years):

| | |
|---|---|
| to Hub (miles) | 45 |
| to Shore from Hub (miles) | 80 |
| to Terminal from Shore (miles) | 20 |
| Total Length (miles) | 145 |
| **Mile Years (20 years)** | **2900** |

**Spills from Pipelines in the GoM and its Waterways**
**(Source: USCG - Marine Casuality and Pollution Database with input from MMS)**

| | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1992 | 10 | 3055 | 3 | 10 | 3.3 | 4 | 123 | 30.8 | 2 | 922 | 461.0 | 1 | 2000 | 2000.0 |
| 1993 | 2 | 5 | 2 | 5 | 2.5 | | | | | | | | | |
| 1994 | 2 | 4554 | | | | 1 | 10 | 10.0 | | | | 1 | 4544 | 4544.0 |
| 1995 | 5 | 32 | 3 | 8 | 2.7 | 2 | 24 | 12.0 | | | | | | |
| 1996 | 2 | 28 | 1 | 2 | 2.0 | 1 | 26 | 26.0 | | | | | | |
| 1997 | 5 | 223 | 2 | 9 | 4.5 | 2 | 51 | 25.5 | 1 | 163 | 163.0 | | | |
| 1998 | 8 | 10214 | 3 | 9 | 3.0 | 2 | 39 | 19.5 | 1 | 743 | 743.0 | 2 | 9423 | 4711.5 |
| **TOTAL** | **34** | **18111** | **14** | **43** | **3.1** | **12** | **273** | **22.8** | **4** | **1828** | **457.0** | **4** | **15967** | **3991.8** |

**Spar - Supply Vessels**

| Exposure (docking calls) | 12287 |
|---|---|

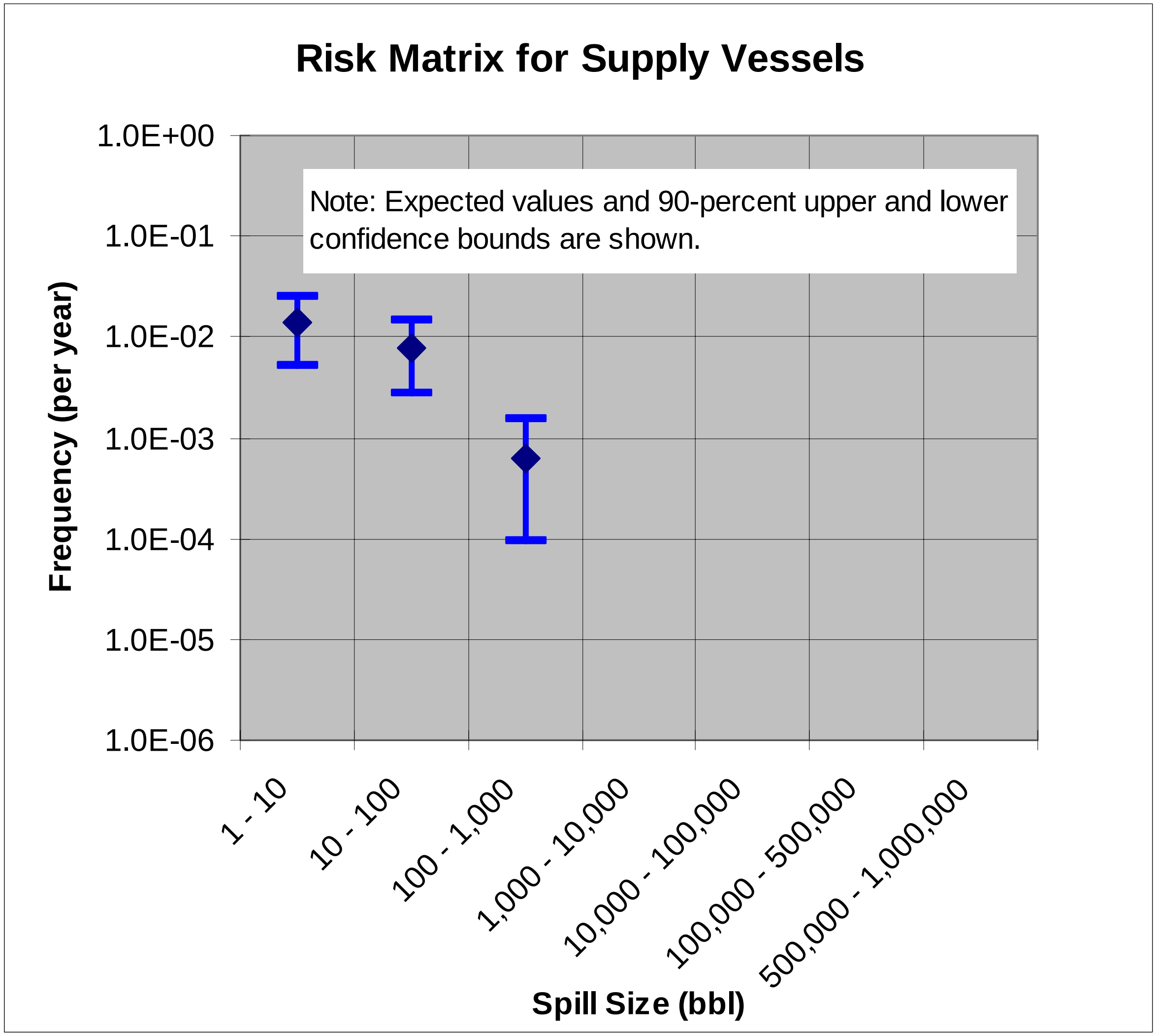
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Spill Size (bbl) | Expected Frequency (per call) | Coefficient of Uncertainty for Frequency | Expected Bias | Coefficient of Uncertainty for Bias | Expected Frequency (per call) | Coefficient of Uncertainty for Frequency |
| 1 - 10 | 3 | 2.2E-05 | 0.46 | 1.0E+00 | 0.33 | 2.2E-05 | 0.32 |
| 10 - 100 | 32 | 1.2E-05 | 0.48 | 1.0E+00 | 0.33 | 1.2E-05 | 0.34 |
| 100 - 1,000 | 320 | 1.0E-06 | 0.75 | 1.0E+00 | 0.33 | 1.0E-06 | 0.67 |
| 1,000 - 10,000 | 3200 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 3.4E-07 | 1.08 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| Expected Total (bbl) | 9.7E+00 |
|---|---|
| Std. Dev. in Total (bbl) | 3.8E+00 |

| Expected Max (bbl) | 9.1E+00 |
|---|---|
| Std. Dev. in Max (bbl) | 3.5E+00 |


Risk Matrix for Supply Vessels
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
Frequency (per year)
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Risk of a spill from a supply vessel is assumed to be proportional to the number of docking or port calls (in field and at the terminal) because this is where most spills occur due to the number of operations (including offloading) and difficulties in navigation (traffic and shore).

The USCG database of spills from offshore supply vessels (OSVs) was used to estimate the frequency of different spill sizes. Data from the years 1985-1999 were used in this analysis.

The data base was searched for petroleum spills from supply vessels. Substances considered included crude, fuel, diesel, lubricating oil and drilling mud.

Incidents were included from the following locations to represent the "Gulf of Mexico": Gulf of Mexico, Sabine/Neches River, Corpus Christi Ship Channel and Harbor, Galveston Bay, Houston Ship Channel, Lower and Upper Mississippi River, and Intercoastal Waterway - Gulf.

The database includes incidents related to vessel transit and docking calls at platorms and ports. A rough picture of supply vessel activity in the GOM (based on discussions with Edison Chouest): 300 boats making an average of 2 dock calls per day = 300x2x365 = 219,000 docking calls per year.

| Total Docking Calls in Data (15 yrs): | |
|---|---|
| Expected Value | 3285000 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 1084050 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per call) | k" | n" (calls) | Expected Value (/call) | Std. Dev. (/call) | c.o.v. |
| 1 - 10 | 65 | 2.0E-05 | 66 | 3285000 | 2.2E-05 | 7.2E-06 | 0.32 |
| 10 - 100 | 36 | 1.1E-05 | 37 | 3285000 | 1.2E-05 | 4.3E-06 | 0.34 |
| 100 - 1,000 | 2 | 6.1E-07 | 3 | 3285000 | 1.0E-06 | 6.8E-07 | 0.67 |
| 1,000 - 10,000 | 0 | 0.0E+00 | 1 | 3285000 | 3.4E-07 | 3.6E-07 | 1.08 |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data because supply vessels for these systems will be larger and more modern (dynamically-positioned) than the typical vessels that comprise the historical data.
- Limit maximum possible spill size to 1,000 bbl to be consistent with cargo capacity for typical supply vessels (less than 1,000 bbl).

Exposure for Study System:

| | |
|---|---|
| 1 trip per 3 days during production | 0.333333333 |
| Days of Production (20 years) | 7300 |
| Trips | 2433.333333 |
| | |
| 1 trip per 3 days during drilling/workover | 0.333333333 |
| 6 Platform Wells (20 years) | |
| Drilling & Completion (5*90 + 6*20 days) | 570 |
| Slickline (3 per well-year @ 5 days) | 1800 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 |
| Change out (1/3 per well-yr @ 50 days) | 2000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 |
| Trips | 3230 |
| | |
| 3 Subsea Wells (12 years) | |
| Drilling & Completion (3*90 + 90 days) | 360 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 |
| Change out (1/8 per well-yr @ 50 days) | 225 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 |
| Trips | 480 |
| | |
| **Docking calls (trips*2)** | **12287** |

**Spills from OSV Activities in the GoM and its Waterways**
**(Source: USCG - Marine Casuality and Pollution Database)**

| | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | | 10,000 - 100,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1985 | 0 | 0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1986 | 7 | 34 | 6 | 17 | 2.8 | 1 | 17 | 17.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1987 | 4 | 42 | 3 | 6 | 2.0 | 1 | 36 | 36.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1988 | 3 | 40 | 2 | 10 | 5.0 | 1 | 30 | 30.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1989 | 5 | 30 | 4 | 9 | 2.3 | 1 | 21 | 21.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1990 | 10 | 78 | 7 | 24 | 3.4 | 3 | 54 | 18.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1991 | 11 | 78 | 9 | 37 | 4.1 | 2 | 41 | 20.5 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1992 | 3 | 39 | 2 | 7 | 3.5 | 1 | 32 | 32.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1993 | 8 | 191 | 3 | 9 | 3.0 | 5 | 182 | 36.4 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1994 | 10 | 21 | 10 | 21 | 2.1 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1995 | 10 | 534 | 3 | 9 | 3.0 | 6 | 211 | 35.2 | 1 | 314 | 314.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1996 | 9 | 161 | 5 | 18 | 3.6 | 4 | 143 | 35.8 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1997 | 10 | 103 | 6 | 26 | 4.3 | 4 | 77 | 19.3 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1998 | 9 | 257 | 4 | 11 | 2.8 | 4 | 116 | 29.0 | 1 | 130 | 130.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1999 | 4 | 193 | 1 | 3 | 3.0 | 3 | 190 | 63.3 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| **TOTAL** | **103** | **1801** | **65** | **207** | **3** | **36** | **1150** | **32** | **2** | **444** | **222** | **0** | **0** | **0** | **0** | **0** | **0** |

**Spar - Drilling and Intervention**

| | |
|---|---|
| **Exposure (man-days)** | **246912** |

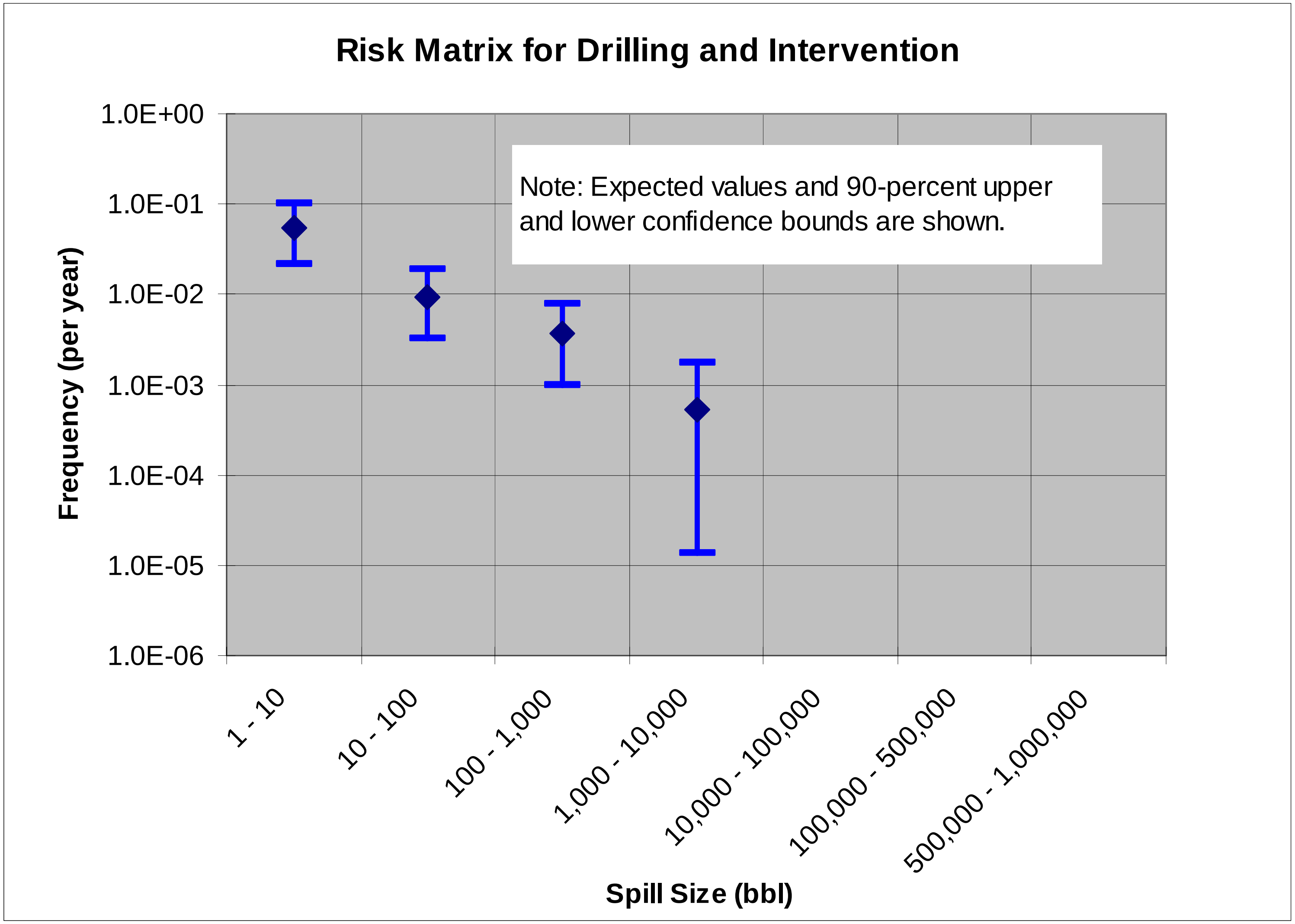
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per man-day)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per man-day)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 4.4E-06 | 0.46 | 1.0E+00 | 0.33 | 4.4E-06 | 0.31 |
| 10 - 100 | 32 | 7.7E-07 | 0.51 | 1.0E+00 | 0.33 | 7.7E-07 | 0.39 |
| 100 - 1,000 | 320 | 3.0E-07 | 0.59 | 1.0E+00 | 0.33 | 3.0E-07 | 0.49 |
| 1,000 - 10,000 | 3200 | 4.3E-08 | 1.13 | 1.0E+00 | 0.33 | 4.3E-08 | 1.08 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **6.7E+01** |
| **Std. Dev. in Total (bbl)** | **4.1E+01** |

| | |
|---|---|
| **Expected Max (bbl)** | **6.3E+01** |
| **Std. Dev. in Max (bbl)** | **4.0E+01** |




F.51 – Oil Spill Risk Assessment for Spar

**Basis:**

Risk of a spill from drilling and well intervention is assumed to be proportional to the number of man-days of operations. This approach means that operations that require a larger crew will have a greater risk of oil spill because more activities and difficulties are involved. It is also used here because information about man-days of drill crew operations in the GOM is available from IADC, an average of 1.3 million man-days per year in the 1990's. One concern is that the IADC information includes activities in state waters while the MMS data may only include OCS waters, therefore the denominator may be overestimated slightly.

The MMS platform data base (1980-1999) was used to identify drilling activity-related incidents. These incidents include exploratory drilling, development drilling and well workovers and completions. Substances reported in the data base include crude, fuel, diesel, drilling fluids and drilling mud. Rig types include both platform and MODU rigs.

| Total man-days in Data (20 yrs): | |
|---|---|
| Expected Value | 26000000 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 8580000 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per man-day) | k" | n" (man-day) | Expected Value (per man-day) | Std. Dev. (per man-day) | c.o.v. |
| 1 - 10 | 103 | 4.0E-06 | 104 | 26000000 | 4.4E-06 | 1.4E-06 | 0.31 |
| 10 - 100 | 17 | 6.5E-07 | 18 | 26000000 | 7.7E-07 | 3.0E-07 | 0.39 |
| 100 - 1,000 | 6 | 2.3E-07 | 7 | 26000000 | 3.0E-07 | 1.5E-07 | 0.49 |
| 1,000 - 10,000 | 0 | 0.0E+00 | 1 | 26000000 | 4.3E-08 | 4.6E-08 | 1.08 |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data because there are relatively few historical data available for deep-water drilling in the Gulf of Mexico (compared to shallow-water drilling).
- Although they have not occurred in the data record, the possiblity for spills larger than 10,000 bbl was evaluated. The estimated frequency was considered to be negligibly small because the reservoir characteristics will be relatively well known since significant exploration and development drilling will have taken place before the production life begins.

Exposure for Study System:

| 6 Platform Wells (20 years) | days | crew | man-days |
|---|---|---|---|
| Drilling & Completion (5*90 + 6*20 days) | 570 | 40 | 22800 |
| Slickline (3 per well-year @ 5 days) | 1800 | 4 | 7200 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Change out (1/3 per well-yr @ 50 days) | 2000 | 40 | 80000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 | 40 | 48000 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 | 40 | 20800 |
| | | | |
| 3 Subsea Wells (12 years) | | | |
| Drilling & Completion (3*90 + 90 days) | 360 | 40 | 14400 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 | 4 | 720 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 | 8 | 1152 |
| Change out (1/8 per well-yr @ 50 days) | 225 | 8 | 1800 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 | 40 | 7200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 | 40 | 6240 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 | 40 | 7800 |
| | | | |
| | | **Total (man-days):** | **246912** |

**Spills from Drilling Activities in the GoM**

**(Source: MMS - TIMS Database)**

| | | | | | <= 10 bbl | | | > 10 bbl & <= 100 bbl | | | 100 - 1,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Total Production** | **Barrels Spilled per 1E6 bbl Produced** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1980 | 8 | 353 | | | 6 | 17 | 2.8 | 1 | 50 | 50.0 | 1 | 286 | 286.0 |
| 1981 | 4 | 253 | | | 1 | 4 | 4.0 | 2 | 39 | 19.5 | 1 | 210 | 210.0 |
| 1982 | 13 | 50 | | | 13 | 50 | 3.8 | | | | | | |
| 1983 | 14 | 77 | | | 13 | 52 | 4.0 | 1 | 25 | 25.0 | | | |
| 1984 | 2 | 6 | | | 2 | 6 | 3.0 | | | | | | |
| 1985 | 13 | 98 | 351133870 | 0.28 | 12 | 48 | 4.0 | 1 | 50 | 50.0 | | | |
| 1986 | 7 | 31 | 356398376 | 0.09 | 7 | 31 | 4.4 | | | | | | |
| 1987 | 10 | 106 | 328243087 | 0.32 | 7 | 18 | 2.6 | 3 | 88 | 29.3 | | | |
| 1988 | 0 | 0 | 301704812 | 0.00 | | | | | | | | | |
| 1989 | 7 | 184 | 281160011 | 0.65 | 4 | 11 | 2.8 | 2 | 56 | 28.0 | 1 | 117 | 117.0 |
| 1990 | 4 | 127 | 274955773 | 0.46 | 3 | 17 | 5.7 | | | | 1 | 110 | 110.0 |
| 1991 | 4 | 14 | 295129769 | 0.05 | 4 | 14 | 3.5 | | | | | | |
| 1992 | 2 | 102 | 305282682 | 0.33 | 1 | 2 | 2.0 | 1 | 100 | 100.0 | | | |
| 1993 | 1 | 3 | 309229380 | 0.01 | 1 | 3 | 3.0 | | | | | | |
| 1994 | 1 | 3 | 314743342 | 0.01 | 1 | 3 | 3.0 | | | | | | |
| 1995 | 4 | 8 | 345525211 | 0.02 | 4 | 8 | 2.0 | | | | | | |
| 1996 | 4 | 19 | 369309647 | 0.05 | 3 | 7 | 2.3 | 1 | 12 | 12.0 | | | |
| 1997 | 2 | 3 | 411795024 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1998 | 5 | 32 | 444466377 | 0.07 | 4 | 11 | 2.8 | 1 | 21 | 21.0 | | | |
| 1999 | 2 | 7 | | | 2 | 7 | 3.5 | | | | | | |
| **TOTAL** | **107** | **1476** | **4.69E+09** | **1.56E-01** | **90** | **312** | **3** | **13** | **441** | **34** | **4** | **723** | **181** |

| Spills from Completion/Workover Activities in the GoM (Source: MMS - TIMS Database) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | <= 10 bbl | | | > 10 bbl & <= 100 bbl | | | >100 bbl | | |
| Year | Total Number of Spills | Total Volume Spilled | Total Production | Barrels Spilled per 1E6 bbl Produced | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1980 | 0 | 0 | | | | | | | | | | | |
| 1981 | 3 | 68 | | | 2 | 4 | 2.0 | 1 | 64 | 64.0 | | | |
| 1982 | 1 | 3 | | | 1 | 3 | 3.0 | | | | | | |
| 1983 | 1 | 2 | | | 1 | 2 | 2.0 | | | | | | |
| 1984 | 0 | 0 | | | | | | | | | | | |
| 1985 | 1 | 5 | 351133870 | 0.01 | 1 | 5 | 5.0 | | | | | | |
| 1986 | 0 | 0 | 356398376 | 0.00 | | | | | | | | | |
| 1987 | 1 | 3 | 328243087 | 0.01 | 1 | 3 | 3.0 | | | | | | |
| 1988 | 0 | 0 | 301704812 | 0.00 | | | | | | | | | |
| 1989 | 1 | 6 | 281160011 | 0.02 | 1 | 6 | 6.0 | | | | | | |
| 1990 | 1 | 8 | 274955773 | 0.03 | 1 | 8 | 8.0 | | | | | | |
| 1991 | 0 | 0 | 295129769 | 0.00 | | | | | | | | | |
| 1992 | 0 | 0 | 305282682 | 0.00 | | | | | | | | | |
| 1993 | 0 | 0 | 309229380 | 0.00 | | | | | | | | | |
| 1994 | 3 | 172 | 314743342 | 0.55 | 1 | 6 | 6.0 | 1 | 25 | 25.0 | 1 | 141 | 141.0 |
| 1995 | 1 | 4 | 345525211 | 0.01 | 1 | 4 | 4.0 | | | | | | |
| 1996 | 1 | 5 | 369309647 | 0.01 | 1 | 5 | 5.0 | | | | | | |
| 1997 | 2 | 3 | 411795024 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1998 | 3 | 276 | 444466377 | 0.62 | | | | 2 | 106 | 53.0 | 1 | 170 | 170.0 |
| 1999 | 0 | 0 | | | | | | | | | | | |
| **TOTAL** | **19** | **555** | **4.69E+09** | **1.03E-01** | **13** | **49** | **4** | **4** | **195** | **49** | **2** | **311** | **156** |

Appendix F.2

Oil Spill Risk Assessment for TLP

**TLP - Risk Summary**

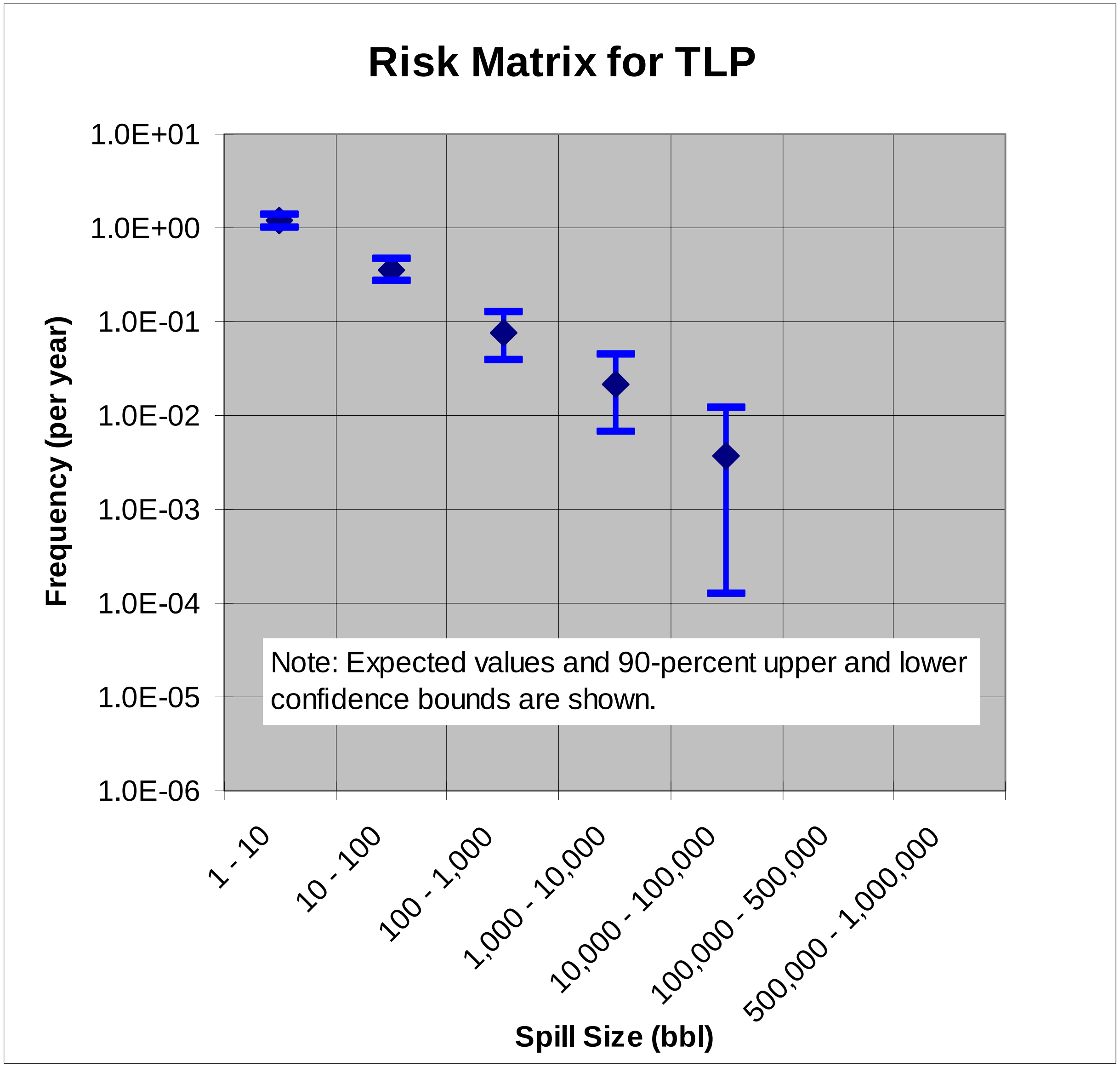
**Overall System Risk Results for 20-year Life:**

| | |
|---|---|
| Expected Total (bbl) | 3.759E+03 |
| Std. Dev. in Total (bbl) | 1.9E+03 |

| | |
|---|---|
| Expected Max (bbl) | 2.7E+03 |
| Std. Dev. in Max (bbl) | 1.7E+03 |

| | Sub-system Risk Results for 20-year Life | | | |
|---|---|---|---|---|
| | Expected Total (bbl) | Std. Dev. in Total (bbl) | Expected Maximum (bbl) | Std Dev. in Maximum (bbl) |
| Well Systems - Platform | 59 | 46 | 51 | 40 |
| Well Systems - Subsea | 78 | 83 | 64 | 68 |
| Dry Tree Risers | 15 | 16 | 15 | 16 |
| Flowlines | 107 | 109 | 105 | 106 |
| Import Flowline Risers | 61 | 62 | 60 | 61 |
| Topsides | 525 | 148 | 208 | 59 |
| Export Pipeline Risers | 106 | 76 | 106 | 76 |
| Pipelines | 2809 | 1861 | 2429 | 1661 |
| Supply Vessels | 10 | 4 | 9 | 4 |
| Drilling and Intervention | 67 | 41 | 63 | 40 |

F.57 – Oil Spill Risk Assessment for TLP




F.58 – Oil Spill Risk Assessment for TLP

### TLP - Frequency Summary

**Summary Information for Frequencies**

| | Total System Frequency | | | | | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Expected Value (per year) | Coefficient of Uncertainty | k for Gamma Distribution | n for Gamma Distribution | Lower 90% (per year) | Upper 90% (per year) |
| 1 - 10 | 1.2E+00 | 9.6E-02 | 1.1E+02 | 9.1E+01 | 1.0E+00 | 1.4E+00 |
| 10 - 100 | 3.6E-01 | 1.7E-01 | 3.4E+01 | 9.5E+01 | 2.7E-01 | 4.7E-01 |
| 100 - 1,000 | 7.7E-02 | 3.4E-01 | 8.5E+00 | 1.1E+02 | 3.9E-02 | 1.2E-01 |
| 1,000 - 10,000 | 2.2E-02 | 5.4E-01 | 3.4E+00 | 1.6E+02 | 6.6E-03 | 4.4E-02 |
| 10,000 - 100,000 | 3.7E-03 | 1.1E+00 | 8.5E-01 | 2.3E+02 | 1.2E-04 | 1.2E-02 |
| 100,000 - 500,000 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0.0E+00 | | | | | |

| | Expected Frequency by Sub-system (per year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Well Systems - Platform | Well Systems - Subsea | Dry Tree Risers | Flowlines | Import Flowline Risers | Topsides | Export Pipeline Risers | Pipelines | Supply Vessels | Drilling and Intervention |
| 1 - 10 | 4.7E-02 | 0.0E+00 | 2.3E-04 | 4.5E-03 | 2.5E-03 | 1.0E+00 | 2.0E-03 | 5.4E-02 | 1.4E-02 | 5.5E-02 |
| 10 - 100 | 2.0E-02 | 0.0E+00 | 2.0E-04 | 3.9E-03 | 2.2E-03 | 2.7E-01 | 1.8E-03 | 4.7E-02 | 7.7E-03 | 9.5E-03 |
| 100 - 1,000 | 6.7E-03 | 0.0E+00 | 7.7E-05 | 1.5E-03 | 8.4E-04 | 4.5E-02 | 6.8E-04 | 1.8E-02 | 6.2E-04 | 3.7E-03 |
| 1,000 - 10,000 | 0.0E+00 | 0.0E+00 | 7.7E-05 | 1.5E-03 | 8.4E-04 | 1.0E-04 | 6.8E-04 | 1.8E-02 | 0.0E+00 | 5.3E-04 |
| 10,000 - 100,000 | 0.0E+00 | 0.0E+00 | 1.5E-05 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 1.4E-04 | 3.6E-03 | 0.0E+00 | 0.0E+00 |
| 100,000 - 500,000 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |
| 500,000 - 1,000,000 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |

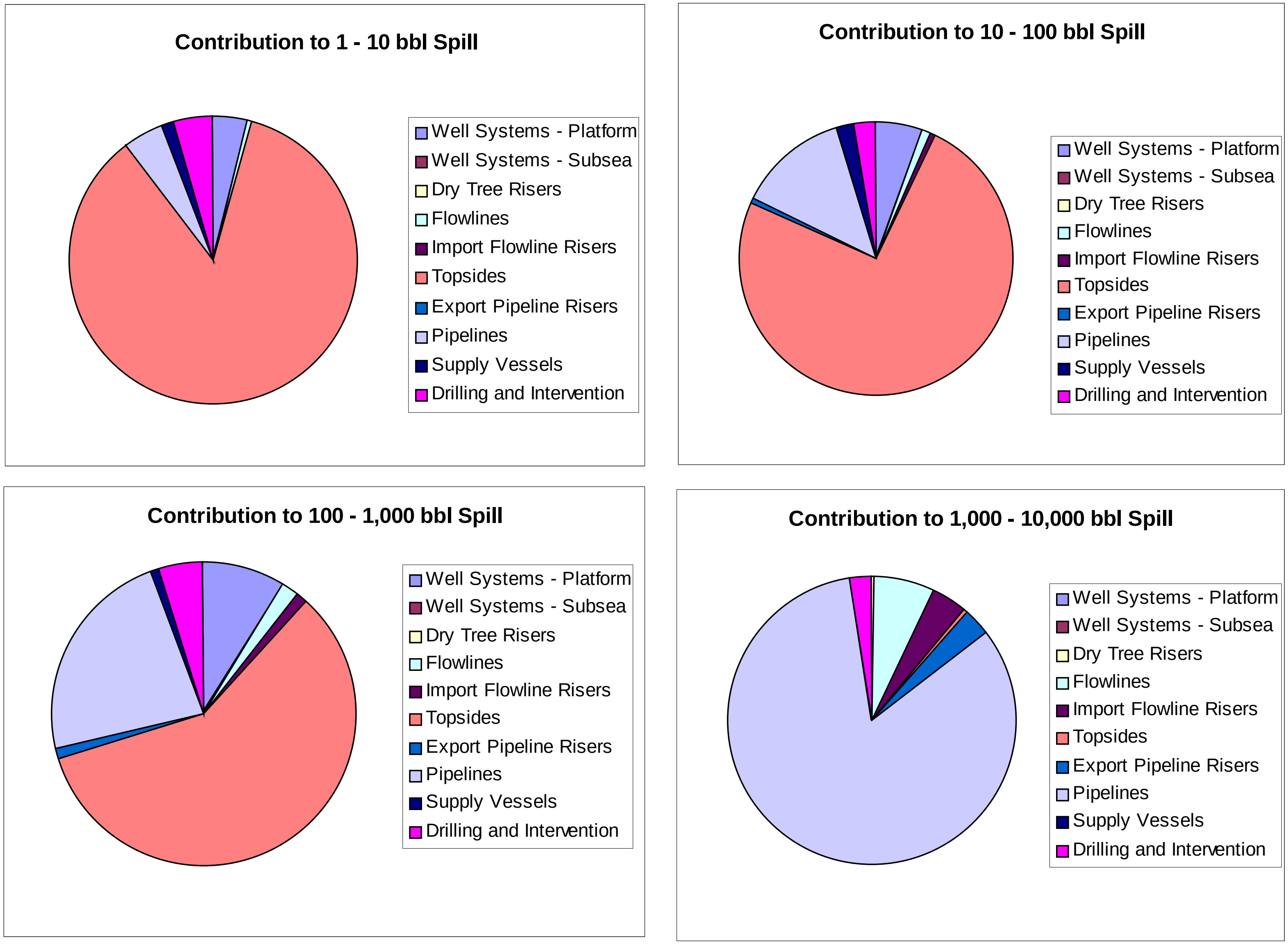
**Summary Information for TLP Production Frequencies**

| | Production System Frequency | | | | | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Expected Value (per year) | Coefficient of Uncertainty | k for Gamma Distribution | n for Gamma Distribution | Lower 90% (per year) | Upper 90% (per year) |
| 1 - 10 | 1.1E+00 | 9.8E-02 | 1.0E+02 | 9.2E+01 | 9.6E-01 | 1.3E+00 |
| 10 - 100 | 3.1E-01 | 1.8E-01 | 3.0E+01 | 9.8E+01 | 2.2E-01 | 4.1E-01 |
| 100 - 1,000 | 5.8E-02 | 4.1E-01 | 6.1E+00 | 1.0E+02 | 2.5E-02 | 1.0E-01 |
| 1,000 - 10,000 | 3.0E-03 | 6.8E-01 | 2.2E+00 | 7.2E+02 | 6.0E-04 | 7.0E-03 |
| 10,000 - 100,000 | 1.5E-05 | 1.4E+00 | 5.0E-01 | 3.3E+04 | 6.0E-08 | 5.9E-05 |
| 100,000 - 500,000 | | | | | | |
| 500,000 - 1,000,000 | | | | | | |

**Summary Information for TLP Transportation Frequencies**

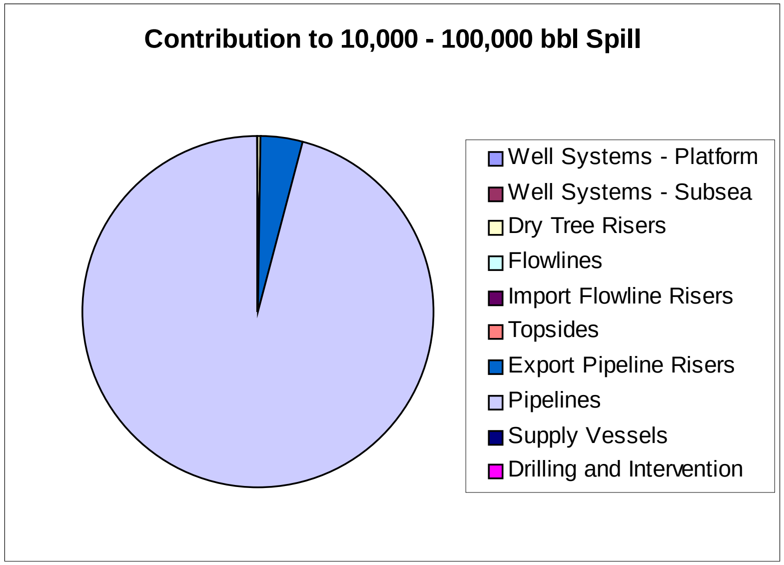
| | Transportation System Frequency | | | | | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Expected Value (per year) | Coefficient of Uncertainty | k for Gamma Distribution | n for Gamma Distribution | Lower 90% (per year) | Upper 90% (per year) |
| 1 - 10 | 5.6E-02 | 5.0E-01 | 4.0E+00 | 7.1E+01 | 1.9E-02 | 1.1E-01 |
| 10 - 100 | 4.9E-02 | 5.1E-01 | 3.8E+00 | 7.9E+01 | 1.6E-02 | 9.5E-02 |
| 100 - 1,000 | 1.9E-02 | 6.2E-01 | 2.6E+00 | 1.4E+02 | 4.4E-03 | 4.1E-02 |
| 1,000 - 10,000 | 1.9E-02 | 6.2E-01 | 2.6E+00 | 1.4E+02 | 4.4E-03 | 4.1E-02 |
| 10,000 - 100,000 | 3.7E-03 | 1.1E+00 | 8.4E-01 | 2.3E+02 | 1.2E-04 | 1.2E-02 |
| 100,000 - 500,000 | | | | | | |
| 500,000 - 1,000,000 | | | | | | |

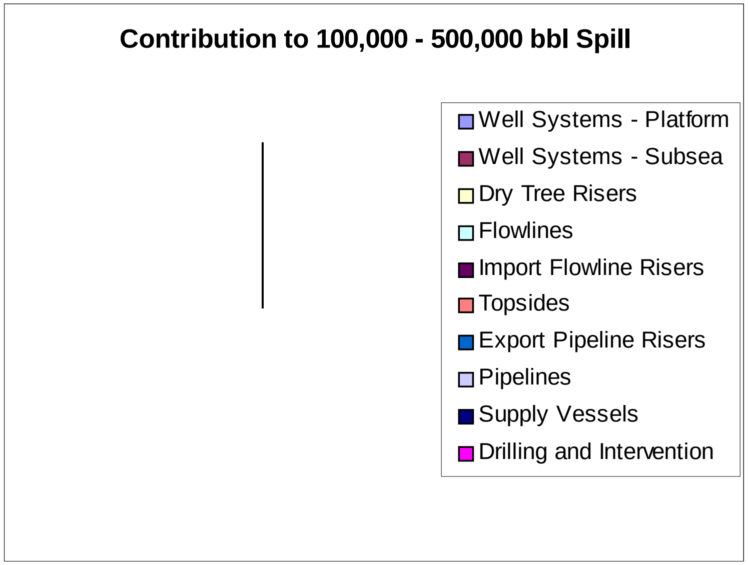
TLP - Contribution to Total Frequency for Different Spill Sizes

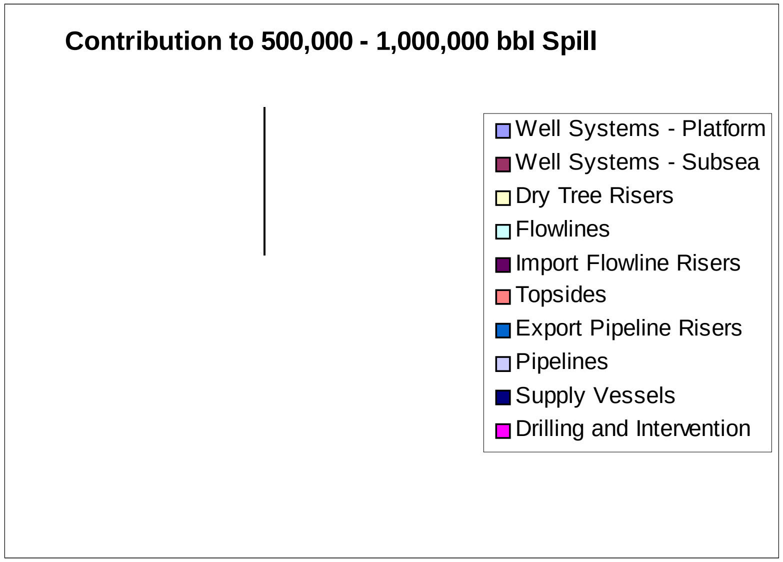



F.61 – Oil Spill Risk Assessment for TLP

TLP - Contribution to Total Frequency for Different Spill Sizes




F.62 – Oil Spill Risk Assessment for TLP

**TLP - Well Systems (Platform)**

| | |
|---|---|
| **Exposure (bbl produced)** | **4.13E+08** |

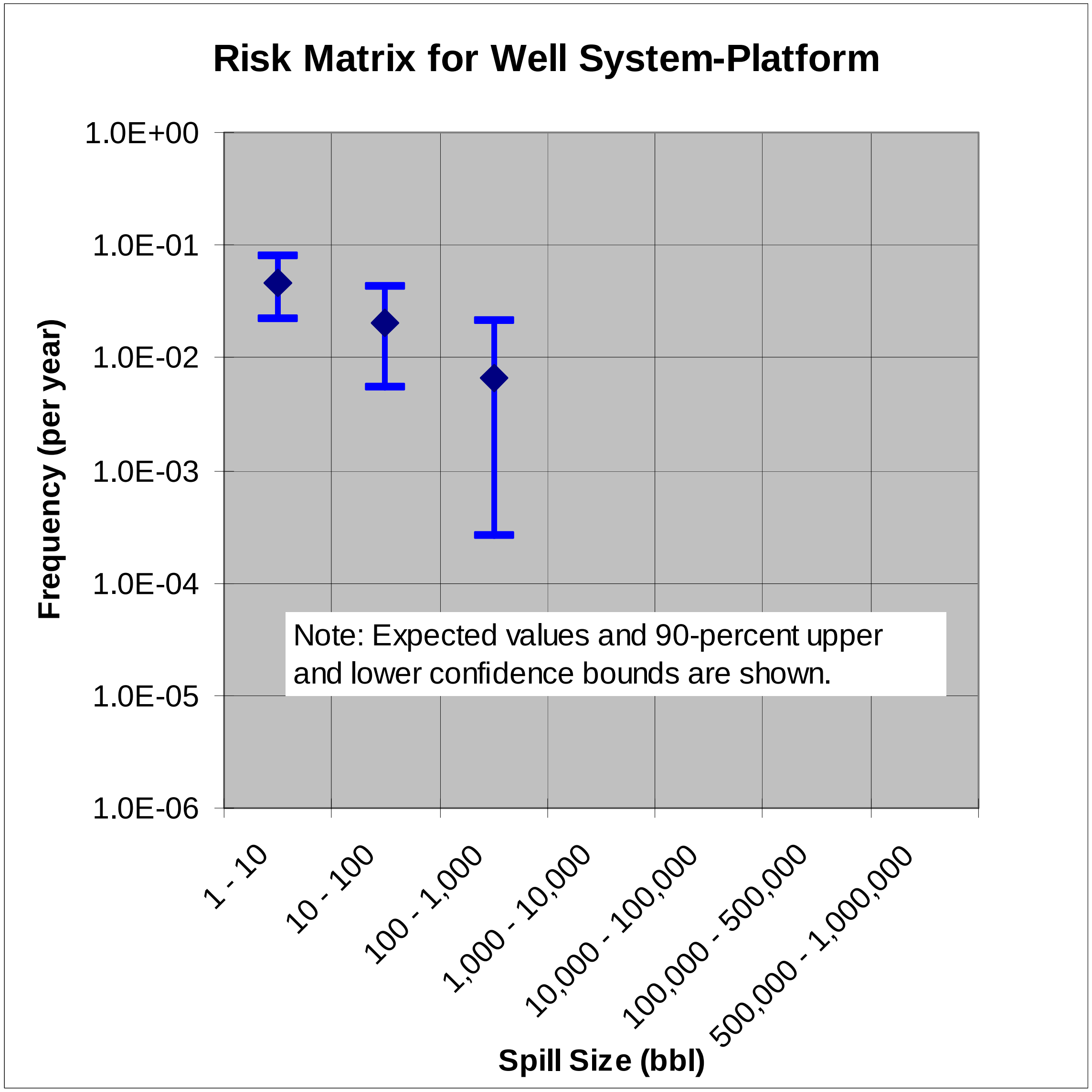
**Input Information**

| Spill Size Range (bbl) | Spill Size (bbl) | Combined (Expert+Data) Estimate: Expected Frequency (per bbl) | Combined (Expert+Data) Estimate: Coefficient of Uncertainty for Frequency | Expert-Based Extrapolation Bias: Expected Bias | Expert-Based Extrapolation Bias: Coefficient of Uncertainty for Bias | Data-Based Estimate: Expected Frequency (per bbl) | Data-Based Estimate: Coefficient of Uncertainty for Frequency |
|---|---|---|---|---|---|---|---|
| 1 - 10 | 3 | 2.3E-09 | 0.38 | 1.0E+00 | 0.00 | 2.3E-09 | 0.38 |
| 10 - 100 | 32 | 9.8E-10 | 0.58 | 1.0E+00 | 0.00 | 9.8E-10 | 0.58 |
| 100 - 1,000 | 320 | 3.3E-10 | 1.05 | 1.0E+00 | 0.33 | 3.3E-10 | 1.00 |
| 1,000 - 10,000 | 3200 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **5.9E+01** |
| **Std. Dev. in Total (bbl)** | **4.6E+01** |

| | |
|---|---|
| **Expected Max (bbl)** | **5.1E+01** |
| **Std. Dev. in Max (bbl)** | **4.0E+01** |




F.64 – Oil Spill Risk Assessment for TLP

**Basis:**

Reported incidents of oil spills from "well and header systems" in the Gulf of Mexico were taken from the MMS pipeline and platform spill database (provided by Cheryl Anderson of MMS) for the years 1980 to 1999. The data are summarized below. Use only data from 1990 to present to account for changes in operating procedures due to implementation of API RP14C.

Equipment includes subsurface safety valves, wellhead assemblies, chokes, jumpers and injection lines, pressure sensors, surface safety valves, header valves and check valves.

Assume risk is proportional to the volume of production - total production data are available for GOM from 1985-1998.

| Total Production bbls in GOM Data: | |
|---|---|
| Expected Value (bbl) | 3.1E+09 |
| Coefficient of Uncertainty | 0 |
| Standard Deviation (bbl) | 0 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per bbl) | k" | n" (bbl) | Expected Value (/bbl) | Std. Dev. (/bbl) | Coefficient of Uncertainty |
| 1 - 10 | 6 | 2.0E-09 | 7 | 3.1E+09 | 2.3E-09 | 8.6E-10 | 0.377964473 |
| 10 - 100 | 2 | 6.5E-10 | 3 | 3.1E+09 | 9.8E-10 | 5.6E-10 | 0.577350269 |
| 100 - 1,000 | 0 | 0.0E+00 | 1 | 3.1E+09 | 3.3E-10 | 3.3E-10 | 1 |
| 1,000 - 10,000 | 0 | 0.0E+00 | | | | | |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because study well systems are similar to those in data base.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data for the largest spill size category since there have been no occurrences for this spill size on the fixed production systems in the database and its frequency on floating production systems is uncertain.

Exposure for Study System:

**Platform Well Production (bbl)** **4.13E+08**

**Spills from Well and Header Systems in the GoM**
**(Source: MMS - TIMS Database)**

| | | | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Total Production (bbl) | Barrels Spilled per 1E6 Bbl Produced | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1980 | 2 | 7 | | | 2 | 7 | 3.4 | | | | | | |
| 1981 | 3 | 12 | | | 3 | 12 | 4.0 | | | | | | |
| 1982 | 5 | 14 | | | 5 | 14 | 2.7 | | | | | | |
| 1983 | 2 | 31 | | | | | | 2 | 31 | 15.5 | | | |
| 1984 | 1 | 3 | | | 1 | 3 | 3.0 | | | | | | |
| 1985 | 2 | 43 | 351133870 | 0.12 | 1 | 3 | 3.0 | 1 | 40 | 40.0 | | | |
| 1986 | 2 | 5 | 356398376 | 0.01 | 2 | 5 | 2.5 | | | | | | |
| 1987 | 3 | 6 | 328243087 | 0.02 | 3 | 6 | 2.0 | | | | | | |
| 1988 | 5 | 73 | 301704812 | 0.24 | 4 | 18 | 4.5 | 1 | 55 | 55.0 | | | |
| 1989 | 2 | 18 | 281160011 | 0.06 | 1 | 6 | 6.0 | 1 | 12 | 12.0 | | | |
| 1990 | 0 | 0 | 274955773 | 0.00 | | | | | | | | | |
| 1991 | 0 | 0 | 295129769 | 0.00 | | | | | | | | | |
| 1992 | 3 | 74 | 305282682 | 0.24 | 1 | 8 | 8.0 | 2 | 66 | 33.0 | | | |
| 1993 | 0 | 0 | 309229380 | 0.00 | | | | | | | | | |
| 1994 | 2 | 6 | 314743342 | 0.02 | 2 | 6 | 3.0 | | | | | | |
| 1995 | 1 | 1 | 345525211 | 0.00 | 1 | 1 | 1.0 | | | | | | |
| 1996 | 2 | 3 | 369309647 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1997 | 0 | 0 | 411795024 | 0.00 | | | | | | | | | |
| 1998 | 0 | 0 | 444466377 | 0.00 | | | | | | | | | |
| 1999 | 0 | 0 | | | | | | | | | | | |
| **TOTAL** | **35** | **295** | **4.69E+09** | **4.88E-02** | **28** | **91** | **3** | **7** | **204** | **29** | **0** | **0** | **0** |

**TLP - Well Systems (Subsea)**

| | |
|---|---|
| **Exposure (bbl produced)** | **2.73E+08** |

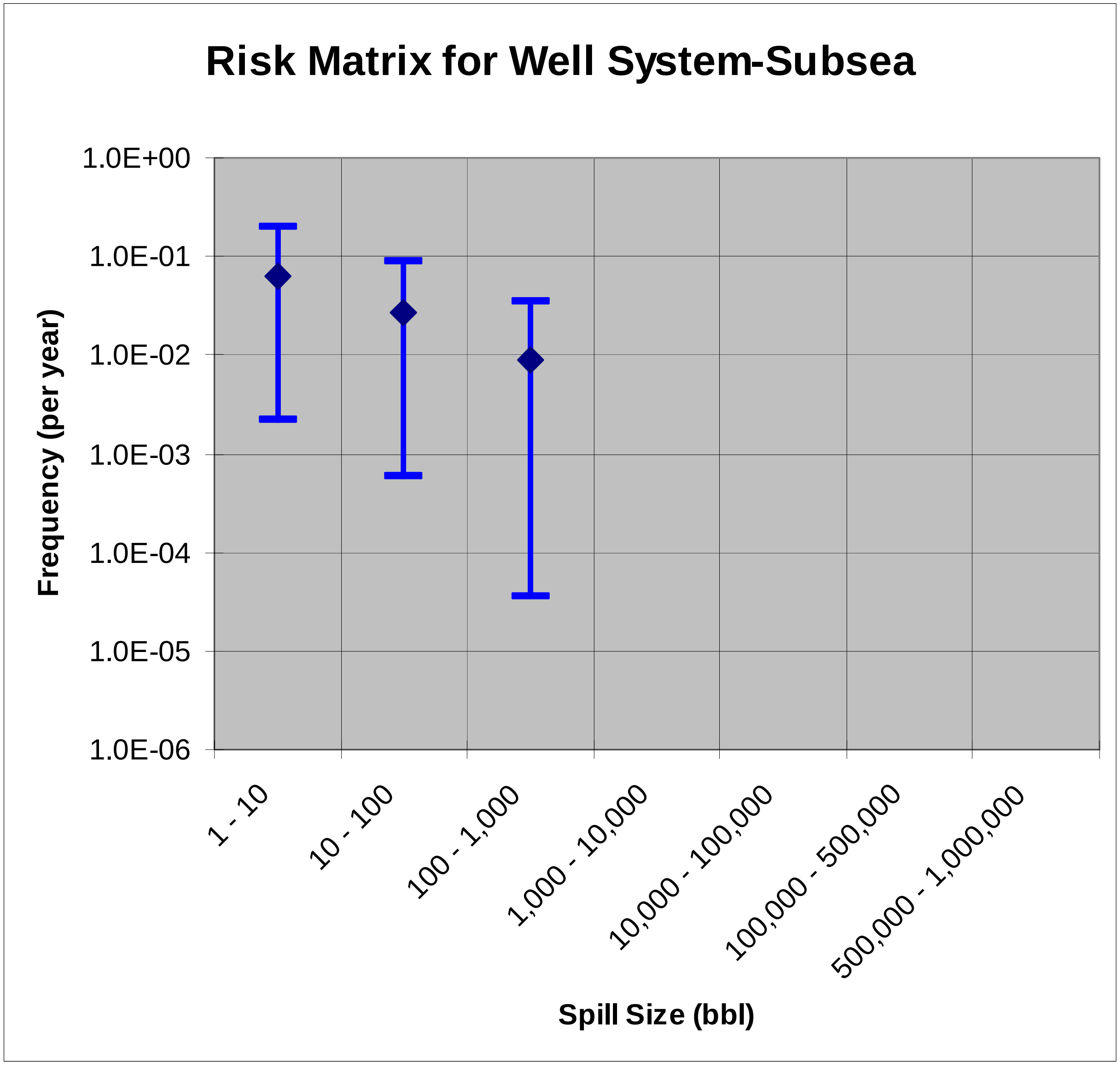
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 4.6E-09 | 1.07 | 2.0E+00 | 1.00 | 2.3E-09 | 0.38 |
| 10 - 100 | 32 | 2.0E-09 | 1.15 | 2.0E+00 | 1.00 | 9.8E-10 | 0.58 |
| 100 - 1,000 | 320 | 6.5E-10 | 1.41 | 2.0E+00 | 1.00 | 3.3E-10 | 1.00 |
| 1,000 - 10,000 | 3200 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **7.8E+01** |
| **Std. Dev. in Total (bbl)** | **8.3E+01** |

| | |
|---|---|
| **Expected Max (bbl)** | **6.4E+01** |
| **Std. Dev. in Max (bbl)** | **6.8E+01** |


Risk Matrix for Well System-Subsea
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
Frequency (per year)
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Reported incidents of oil spills from "well and header systems" in the Gulf of Mexico were taken from the MMS pipeline and platform spill database (provided by Cheryl Anderson of MMS) for the years 1980 to 1999. The data are summarized below. Use only data from 1990 to present to account for changes in operating

Equipment includes subsurface safety valves, wellhead assemblies, chokes, jumpers and injection lines, pressure sensors, surface safety valves, header valves and check valves.

Assume risk is proportional to the volume of production - total production data are available for GOM from 1985-1998.

Total Production bbls in GOM Data:

| | |
|---|---|
| Expected Value (bbl) | 3.1E+09 |
| Coefficient of Uncertainty | 0 |
| Standard Deviation (bbl) | 0 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per bbl) | k" | n" (bbl) | Expected Value (/bbl) | Std. Dev. (/bbl) | Coefficient of Uncertainty |
| 1 - 10 | 6 | 2.0E-09 | 7 | 3.1E+09 | 2.3E-09 | 8.6E-10 | 0.377964473 |
| 10 - 100 | 2 | 6.5E-10 | 3 | 3.1E+09 | 9.8E-10 | 5.6E-10 | 0.577350269 |
| 100 - 1,000 | 0 | 0.0E+00 | 1 | 3.1E+09 | 3.3E-10 | 3.3E-10 | 1 |
| 1,000 - 10,000 | 0 | 0.0E+00 | | | | | |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Double expected frequency for leaks to account for greater potential for sand erosion and cutouts due to high flow rates and detection difficulties for sand.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since wells in database are mostly platform wells and not subsea wells.

Exposure for Study System:

**Subsea Well Production (bbl)** **2.73E+08**

| Spills from Well and Header Systems in the GoM (Source: MMS - TIMS Database) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | |
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Total Production (bbl) | Barrels Spilled per 1E6 Bbl Produced | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1980 | 2 | 7 | | | 2 | 7 | 3.4 | | | | | | |
| 1981 | 3 | 12 | | | 3 | 12 | 4.0 | | | | | | |
| 1982 | 5 | 14 | | | 5 | 14 | 2.7 | | | | | | |
| 1983 | 2 | 31 | | | | | | 2 | 31 | 15.5 | | | |
| 1984 | 1 | 3 | | | 1 | 3 | 3.0 | | | | | | |
| 1985 | 2 | 43 | 351133870 | 0.12 | 1 | 3 | 3.0 | 1 | 40 | 40.0 | | | |
| 1986 | 2 | 5 | 356398376 | 0.01 | 2 | 5 | 2.5 | | | | | | |
| 1987 | 3 | 6 | 328243087 | 0.02 | 3 | 6 | 2.0 | | | | | | |
| 1988 | 5 | 73 | 301704812 | 0.24 | 4 | 18 | 4.5 | 1 | 55 | 55.0 | | | |
| 1989 | 2 | 18 | 281160011 | 0.06 | 1 | 6 | 6.0 | 1 | 12 | 12.0 | | | |
| 1990 | 0 | 0 | 274955773 | 0.00 | | | | | | | | | |
| 1991 | 0 | 0 | 295129769 | 0.00 | | | | | | | | | |
| 1992 | 3 | 74 | 305282682 | 0.24 | 1 | 8 | 8.0 | 2 | 66 | 33.0 | | | |
| 1993 | 0 | 0 | 309229380 | 0.00 | | | | | | | | | |
| 1994 | 2 | 6 | 314743342 | 0.02 | 2 | 6 | 3.0 | | | | | | |
| 1995 | 1 | 1 | 345525211 | 0.00 | 1 | 1 | 1.0 | | | | | | |
| 1996 | 2 | 3 | 369309647 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1997 | 0 | 0 | 411795024 | 0.00 | | | | | | | | | |
| 1998 | 0 | 0 | 444466377 | 0.00 | | | | | | | | | |
| 1999 | 0 | 0 | | | | | | | | | | | |
| **TOTAL** | **35** | **295** | **4.69E+09** | **4.88E-02** | **28** | **91** | **3** | **7** | **204** | **29** | **0** | **0** | **0** |

**TLP - Dry Tree Risers**

| | |
|---|---|
| **Exposure (riser-years)** | **120** |

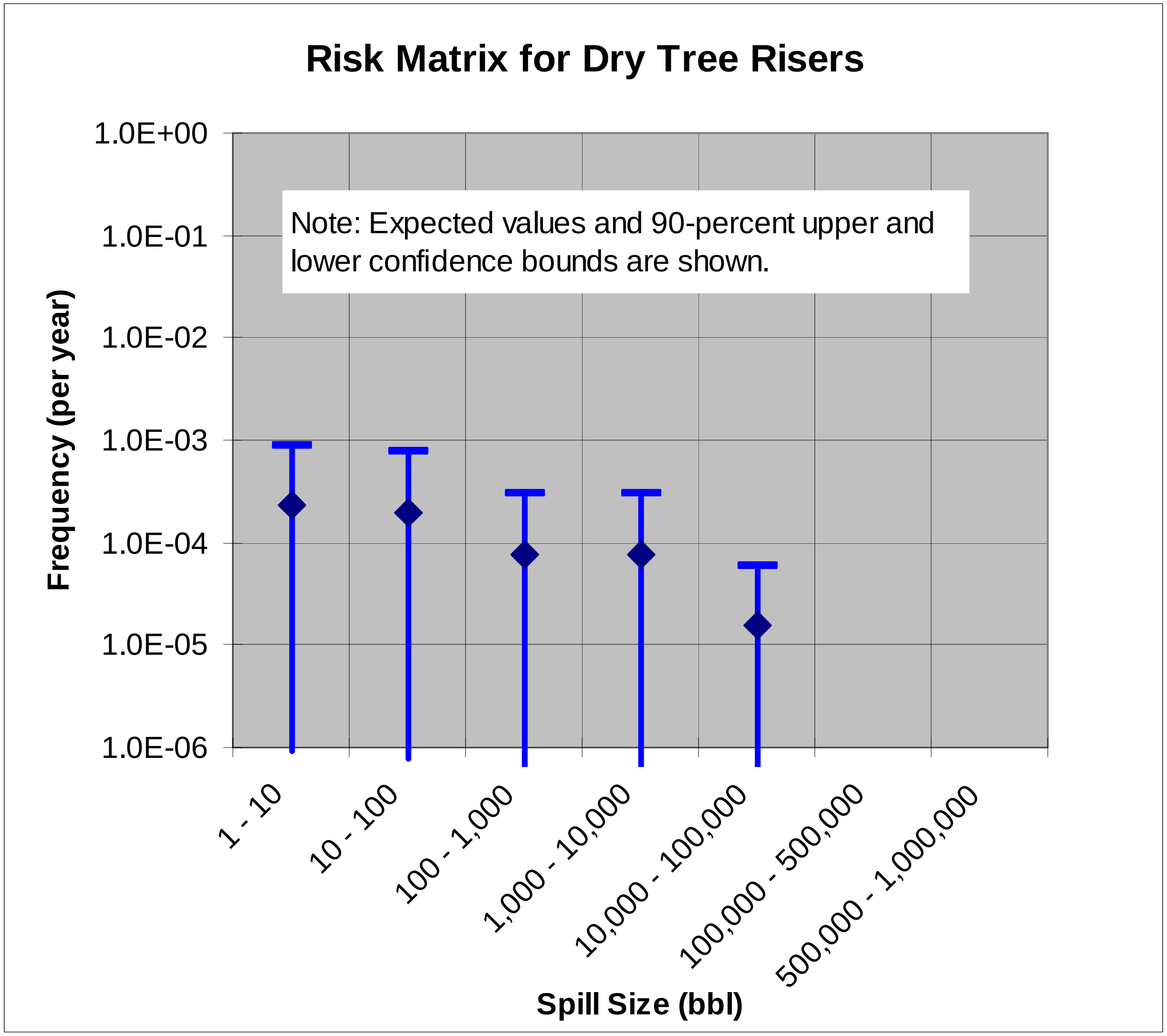
**Input Information**

| Spill Size Range (bbl) | Spill Size (bbl) | Combined (Expert+Data) Estimate: Expected Frequency (per riser-year) | Combined (Expert+Data) Estimate: Coefficient of Uncertainty for Frequency | Expert-Based Extrapolation Bias: Expected Bias | Expert-Based Extrapolation Bias: Coefficient of Uncertainty for Bias | Data-Based Estimate: Expected Frequency (per riser-year) | Data-Based Estimate: Coefficient of Uncertainty for Frequency |
|---|---|---|---|---|---|---|---|
| 1 - 10 | 3 | 3.8E-05 | 1.41 | 1.0E+00 | 1.00 | 3.8E-05 | 1.00 |
| 10 - 100 | 32 | 3.3E-05 | 1.41 | 1.0E+00 | 1.00 | 3.3E-05 | 1.00 |
| 100 - 1,000 | 320 | 1.3E-05 | 1.41 | 1.0E+00 | 1.00 | 1.3E-05 | 1.00 |
| 1,000 - 10,000 | 3200 | 1.3E-05 | 1.41 | 1.0E+00 | 1.00 | 1.3E-05 | 1.00 |
| 10,000 - 100,000 | 32000 | 2.6E-06 | 1.41 | 1.0E+00 | 1.00 | 2.6E-06 | 1.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **1.5E+01** |
| **Std. Dev. in Total (bbl)** | **1.6E+01** |

| | |
|---|---|
| **Expected Max (bbl)** | **1.5E+01** |
| **Std. Dev. in Max (bbl)** | **1.6E+01** |




F.72 – Oil Spill Risk Assessment for TLP

**Basis:**

Use OTC 8518 (Wolford et al. 1997) information for leak frequency from dual-cased production risers: $6.0 \times 10^{-5}$ loss-of-well control events (including during production and well intervention) per riser-year based on fault tree analysis - use $1 \times 10^{-4}$ leaks per riser-year as an approximation for the study system.

Leak Frequency for riser (per riser year):

| | |
|---|---|
| Expected Value (OTC Paper) | 1.00E-04 |
| Coefficient of Uncertainty (Few data to support | 1.00 |
| Standard Deviation | 0.0001 |

Distribute spill sizes from risers using the pipeline spill-size distribution for spills less than 100,000 bbl in size (see Pipeline worksheet for details).

| Spill Size Range (bbl) | Expected Pipeline Frequency (per mile-year) | Leak Distribution for no SSV Failure | Expected Riser Frequency (per riser year) | Coefficient of Uncertainty in Frequency |
|---|---|---|---|---|
| 1 - 10 | 3.72E-04 | 38% | 3.85E-05 | 1.00 |
| 10 - 100 | 3.22E-04 | 33% | 3.33E-05 | 1.00 |
| 100 - 1,000 | 1.24E-04 | 13% | 1.28E-05 | 1.00 |
| 1,000 - 10,000 | 1.24E-04 | 13% | 1.28E-05 | 1.00 |
| 10,000 - 100,000 | 2.48E-05 | 3% | 2.56E-06 | 1.00 |
| 100,000 - 500,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |
| 500,000 - 1,000,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |
| | | Total: | 1.00E-04 | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because estimated frequency was for similar types of risers.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the data because there are no actual occurrences of these types of events from dual risers for deepwater floating production systems.
- While a large spill (>100,000 bbl spill) could occur if there is a leak from the riser system and a failure of the subsea safety valve (SSV), this possibility is considered to be so remote as to be negligible. For example, the probability of failure for an SSV is estimated to be about 0.001 giving approximately a 0.0001x0.001 or 1x10-7 frequency per riser year for this type of an event, which would contribute very little to the expected oil spill volume. Therefore, the frequencies for spills greater than 100,000 bbl are assumed to be zero.

Exposure for Study System:

| | |
|---|---|
| Number of Dry Tree Risers | 6 |
| Service Life (years) | 20 |
| **Exposure (riser-years)** | **120** |

**TLP - Flowlines**

| **Exposure (mile-years)** | **240** |
|---|---|

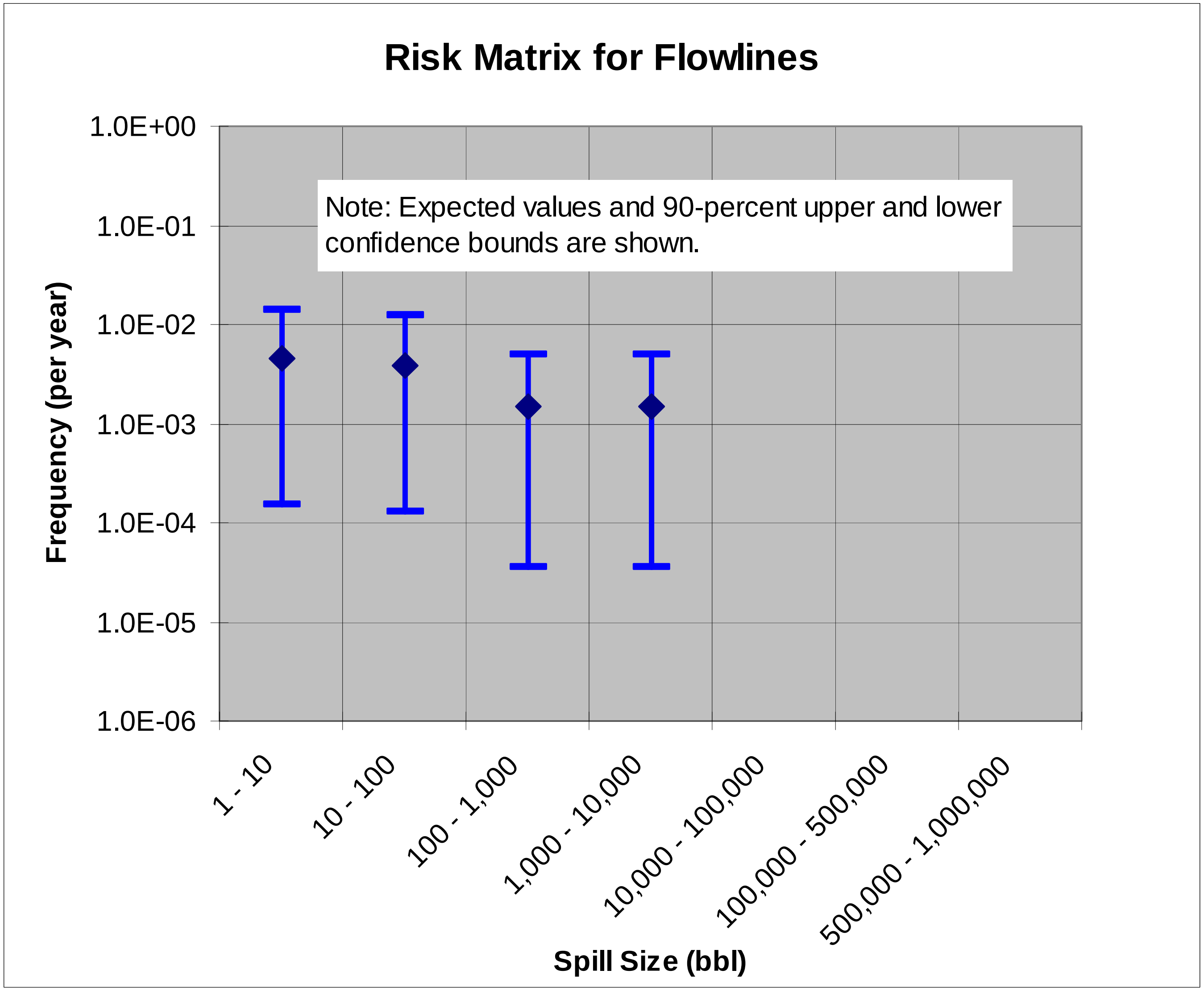
**Input Information**

| | | **Combined (Expert+Data) Estimate** | | **Expert-Based Extrapolation Bias** | | **Data-Based Estimate** | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per mile-year)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per mile-year)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 3.7E-04 | 1.08 | 1.0E+00 | 1.00 | 3.7E-04 | 4.0E-01 |
| 10 - 100 | 32 | 3.2E-04 | 1.08 | 1.0E+00 | 1.00 | 3.2E-04 | 4.1E-01 |
| 100 - 1,000 | 320 | 1.2E-04 | 1.14 | 1.0E+00 | 1.00 | 1.2E-04 | 5.5E-01 |
| 1,000 - 10,000 | 3200 | 1.2E-04 | 1.14 | 1.0E+00 | 1.00 | 1.2E-04 | 5.5E-01 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 2.5E-05 | 1.1E+00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.0E+00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.0E+00 |

**Results for 20-year Life:**

| **Expected Total (bbl)** | **1.1E+02** |
|---|---|
| **Std. Dev. in Total (bbl)** | **1.1E+02** |

| **Expected Max (bbl)** | **1.1E+02** |
|---|---|
| **Std. Dev. in Max (bbl)** | **1.1E+02** |




F.75 – Oil Spill Risk Assessment for TLP

**Basis:**

Reported incidents of oil pipeline leaks in the Gulf of Mexico were taken from the USCG spill database for the years 1992 to 1998. The data are summarized below.

Total Pipeline Miles in GOM federal and state waters estimated from MMS and Lousiana data making the following assumptions:
Federal Waters Sum: Include "unknown" mileage in all years
State Waters Sum: Start with 2,500 miles from Mariano Hinojosa (Louisiana) in 2000; Maintain constant State/Federal Percentage for Earlier Years
Percent Inactive: Assume 17 percent today, 0 percent in 1948 and increase it linearly with time
Total Active: Reduce both federal and state together with same percentage inactive
Total Active Liquid: Assume 30 percent of pipeline length is liquid versus gas (NRC Marine Board Study 1994)
Result - 44,715 mile-years from 1992 to 1998
As a check, Marine Board Study in 1994 reported 17,000 total miles with 30 % oil/condensate, giving 5,100 miles for 7 years or 35,700 mile-years.

Total Mile Years in Data:

| | |
|---|---|
| Expected Value | 44715 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 14756 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per mile-yr) | k" | n" (mile-yr) | Expected Value (per mile-yr) | Std. Dev. (per mile-yr) | c.o.v. |
| 1 - 10 | 14 | 3.1E-04 | 15 | 44715 | 3.7E-04 | 1.5E-04 | 0.40 |
| 10 - 100 | 12 | 2.7E-04 | 13 | 44715 | 3.2E-04 | 1.3E-04 | 0.41 |
| 100 - 1,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 1,000 - 10,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 10,000 - 100,000 | 0 | 0.0E+00 | 1 | 44715 | 2.5E-05 | 2.7E-05 | 1.08 |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because flowliness for study systems will be similar to pipelines in database, although they will be in deeper water than average pipelines in database.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since most of the pipelines in the historical database are in shallower water than the flowlines for the study system. The deepwater effect may lead to a reduction in the frequency of spills (fewer anchor drags and dropped objects), but the difference was not considered to be significant enough (an EQE 1998 study estimated the frequency of spills for deepwater segments of pipeline would be approximately 70-percent of that for shallow water pipeline segments) to be reflected in the expected bias.
- Limit maximum possible spill size per incident to 10,000 bbl because (1) flowline inventory is small (< 10,000 bbl total in parallel lines) and (2) safety systems should shut production in within 45 minutes of a leak occurring (5 hours at 2,000 bbl/hr total in both lines gives 10,000 bbl).

Study System Exposure:

| | |
|---|---|
| Length per Line (miles) | 10 |
| Number of Lines | 2 |
| Service Life (yrs) | 12 |
| **Exposure (mile-years)** | **240** |

**Spills from Pipelines in the GoM and its Waterways**
**(Source: USCG - Marine Casuality and Pollution Database with input from MMS)**

| | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1992 | 10 | 3055 | 3 | 10 | 3.3 | 4 | 123 | 30.8 | 2 | 922 | 461.0 | 1 | 2000 | 2000.0 |
| 1993 | 2 | 5 | 2 | 5 | 2.5 | | | | | | | | | |
| 1994 | 2 | 4554 | | | | 1 | 10 | 10.0 | | | | 1 | 4544 | 4544.0 |
| 1995 | 5 | 32 | 3 | 8 | 2.7 | 2 | 24 | 12.0 | | | | | | |
| 1996 | 2 | 28 | 1 | 2 | 2.0 | 1 | 26 | 26.0 | | | | | | |
| 1997 | 5 | 223 | 2 | 9 | 4.5 | 2 | 51 | 25.5 | 1 | 163 | 163.0 | | | |
| 1998 | 8 | 10214 | 3 | 9 | 3.0 | 2 | 39 | 19.5 | 1 | 743 | 743.0 | 2 | 9423 | 4711.5 |
| **TOTAL** | **34** | **18111** | **14** | **43** | **3.1** | **12** | **273** | **22.8** | **4** | **1828** | **457.0** | **4** | **15967** | **3991.8** |

**TLP - Import Flowline Risers**

| | |
|---|---|
| **Exposure (riser-years)** | **24** |

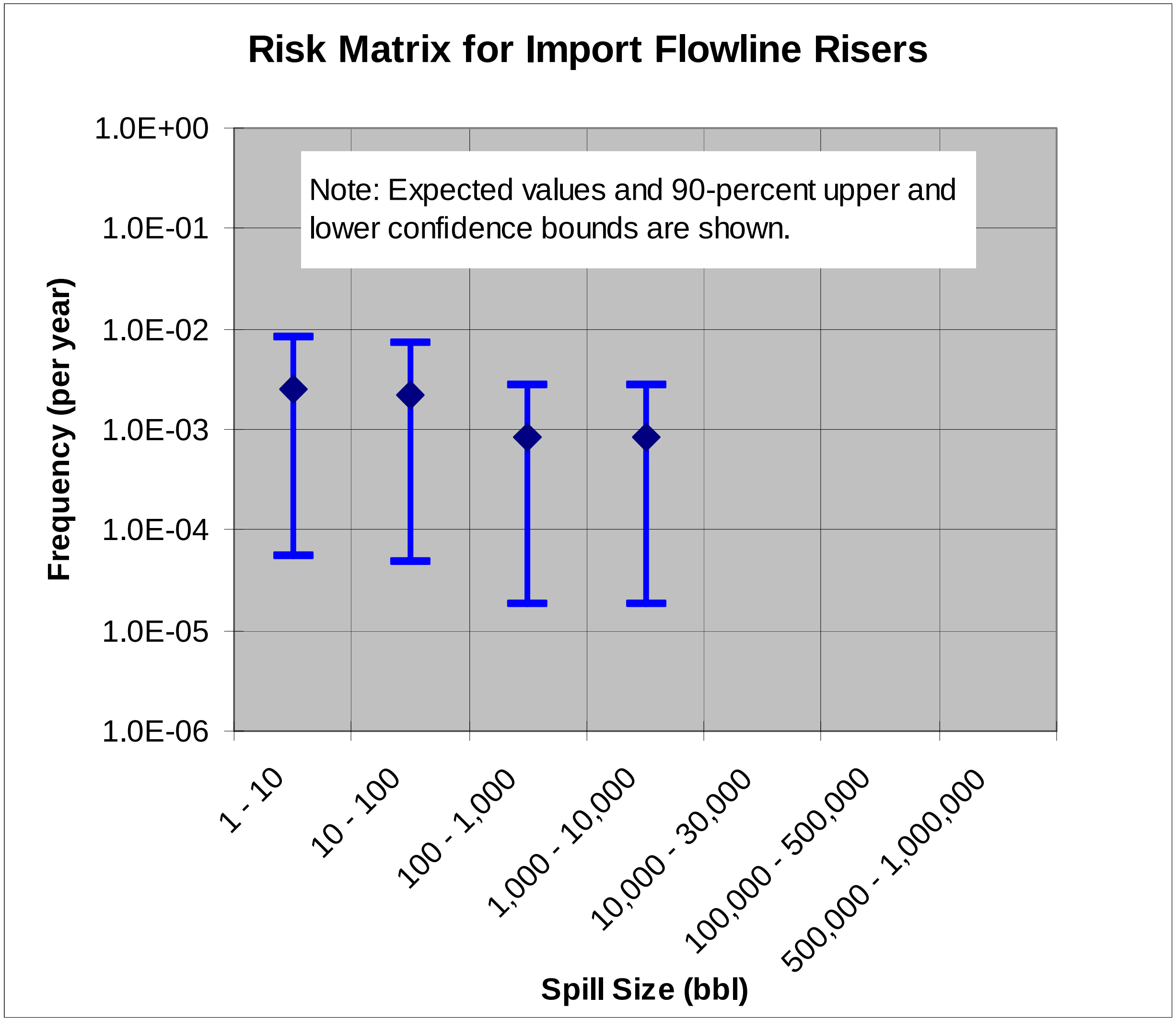
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per riser-year)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per riser-year)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 2.1E-03 | 1.15 | 1.0E+00 | 1.00 | 2.1E-03 | 0.58 |
| 10 - 100 | 32 | 1.8E-03 | 1.15 | 1.0E+00 | 1.00 | 1.8E-03 | 0.58 |
| 100 - 1,000 | 320 | 7.0E-04 | 1.15 | 1.0E+00 | 1.00 | 7.0E-04 | 0.58 |
| 1,000 - 10,000 | 3200 | 7.0E-04 | 1.15 | 1.0E+00 | 1.00 | 7.0E-04 | 0.58 |
| 10,000 - 30,000 | 32000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **6.1E+01** |
| **Std. Dev. in Total (bbl)** | **6.2E+01** |

| | |
|---|---|
| **Expected Max (bbl)** | **6.0E+01** |
| **Std. Dev. in Max (bbl)** | **6.1E+01** |




F.79 – Oil Spill Risk Assessment for TLP

**Basis:**

Use Parloc 93 information for leak frequency from risers, normalized by riser-years: 2 leaks in 565 riser-years for risers with a diameter greater than 8 inches.

Statistical Analysis:

| | |
|---|---|
| Exposure (riser-years) | 565 |
| Leaks | 2 |
| k" | 3 |
| n" (riser-years) | 565 |
| Expected Rate (per riser-year) | 5.31E-03 |
| Coefficient of Uncertainty in Rate | 0.577 |

Distribute spill sizes from risers using the flowline spill-size distribution (see Flowline worksheet for details).

| Spill Size Range (bbl) | Expected Flowline Frequency (per mile-year) | Flowline Leak Distribution | Expected Riser Frequency (per riser year) | Coefficient of Uncertainty in Frequency |
|---|---|---|---|---|
| 1 - 10 | 3.72E-04 | 39% | 2.10E-03 | 0.58 |
| 10 - 100 | 3.22E-04 | 34% | 1.82E-03 | 0.58 |
| 100 - 1,000 | 1.24E-04 | 13% | 6.99E-04 | 0.58 |
| 1,000 - 10,000 | 1.24E-04 | 13% | 6.99E-04 | 0.58 |
| 10,000 - 100,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |
| 100,000 - 500,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |
| 500,000 - 1,000,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because import risers will be in deeper water (which may increase the frequency) but more modern (which may decrease the frequency) than the risers in the database.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since the risers in the historical database are not very representative of import risers on floating production systems in deepwater.
- Limit maximum possible spill size per incident to 10,000 bbl because (1) flowline inventory is small (< 10,000 bbl total in parallel lines) and (2) safety systems should shut production in within 45 minutes of a leak occurring (5 hours at 2,000 bbl/hr total in both lines gives 10,000 bbl).

Study System Import Risers:

| | |
|---|---|
| 2 Import from Flowlines | 2 |
| Years of Service | 12 |
| **Total Riser-Years:** | **24** |

**TLP - Topsides**

| | |
|---|---|
| **Exposure (bbl produced)** | **6.86E+08** |

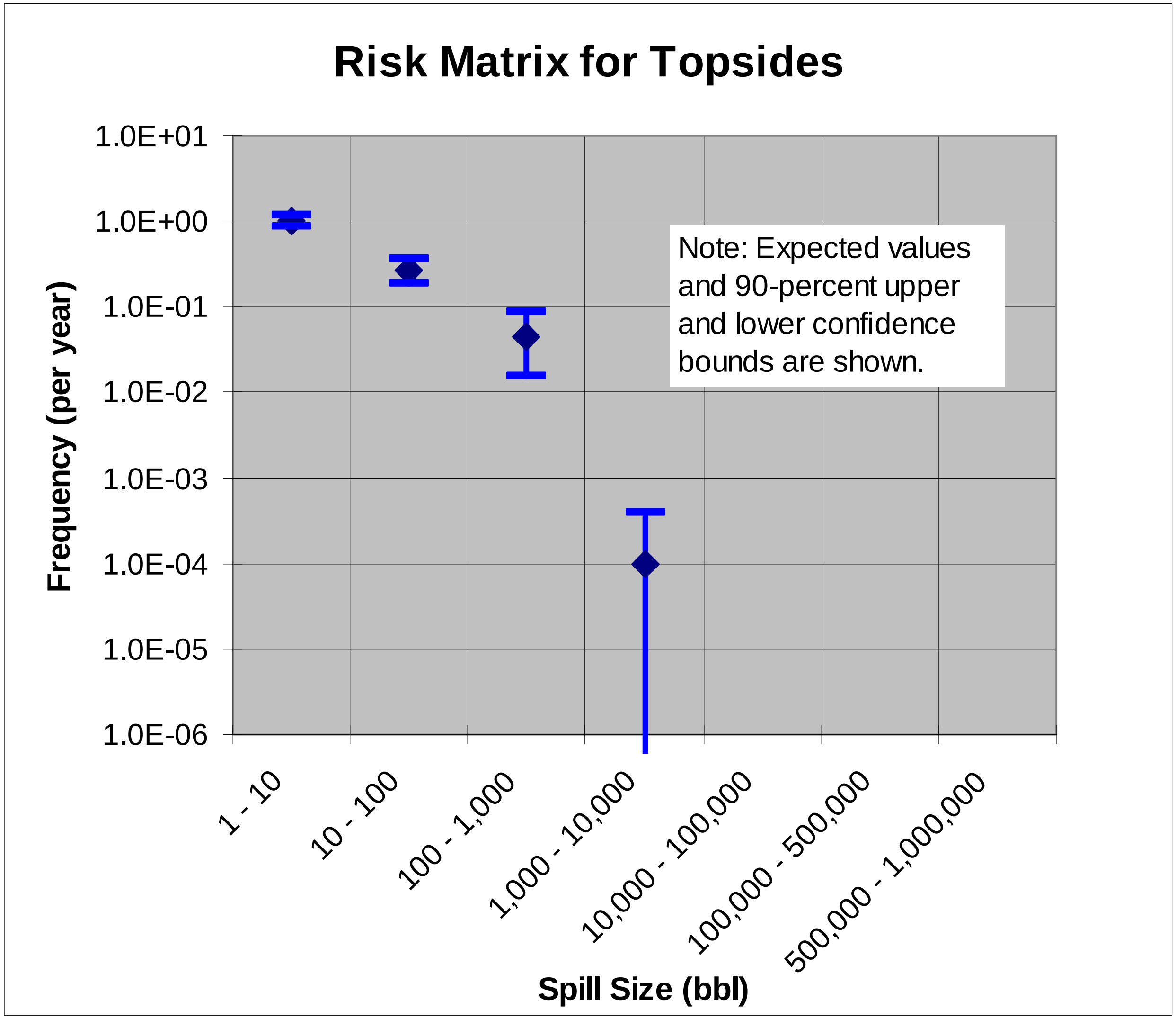
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 3.0E-08 | 0.10 | 1.0E+00 | 0.00 | 3.0E-08 | 0.10 |
| 10 - 100 | 32 | 7.8E-09 | 0.20 | 1.0E+00 | 0.00 | 7.8E-09 | 0.20 |
| 100 - 1,000 | 320 | 1.3E-09 | 0.50 | 1.0E+00 | 0.00 | 1.3E-09 | 0.50 |
| 1,000 - 10,000 | 3200 | 2.9E-12 | 1.41 | 9.0E-03 | 1.00 | 3.3E-10 | 1.00 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **5.2E+02** |
| **Std. Dev. in Total (bbl)** | **1.5E+02** |

| | |
|---|---|
| **Expected Max (bbl)** | **2.1E+02** |
| **Std. Dev. in Max (bbl)** | **5.9E+01** |




F.82 – Oil Spill Risk Assessment for TLP

**Basis:**

Reported incidents of oil spills from "platforms" in the Gulf of Mexico were taken from the MMS pipeline and platform spill database (provided by Cheryl Anderson of MMS) for the years 1980 to 1999. The data are summarized below. Use only data from 1990 to present to account for changes in operating procedures due to implementation of API RP14C.

Process equipment included in data: separators, flare line systems, heaters/treaters, sump systems, pumps, storage tanks, compressors, pig launchers, valves and piping.

Substances included in spill data: oil, condensate, fuel, glycol.

Incidents involving supply vessels and barges (e.g., transfer of fluids to/from a vessel) have been filtered out and are not included in this analysis. The USCG data base is considered to be a more comprehensive source of information about these incidents and activities (included in Supply Vessels worksheet).

Assume risk is proportional to the volume of production - total production data are available for GOM from 1985-1998.

Total GOM Production bbls in Data:

| | |
|---|---|
| Expected Value (bbl) | 3.1E+09 |
| Coefficient of Uncertainty | 0 |
| Standard Deviation (bbl) | 0 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per bbl) | k" | n" (bbl) | Expected Value (/bbl) | Std. Dev. (/bbl) | Coefficient of Uncertainty |
| 1 - 10 | 90 | 2.9E-08 | 91 | 3.1E+09 | 3.0E-08 | 3.1E-09 | 0.105 |
| 10 - 100 | 23 | 7.5E-09 | 24 | 3.1E+09 | 7.8E-09 | 1.6E-09 | 0.204 |
| 100 - 1,000 | 3 | 9.8E-10 | 4 | 3.1E+09 | 1.3E-09 | 6.5E-10 | 0.500 |
| 1,000 - 10,000 | 0 | 0.0E+00 | 1 | 3.1E+09 | 3.3E-10 | 3.3E-10 | 1.000 |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias for spills less than 1,000 bbl because estimated frequencies are for similar types of process systems. Reduce spill frequency for the 1,000 to 10,000 bbl category to $1.0 \times 10^{-4}$ per year to account for the inventory spilled in a total structural failure.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the data for the 1,000 to 10,000 bbl category because there are no actual occurrences of this type of an event in the data record for any platforms including deepwater floating production systems.

Exposure for Study System:

| | |
|---|---|
| Production from Platform Wells (bbl) | 4.13E+08 |
| Production from Subsea Wells (bbl) | 2.73E+08 |
| **Total Production (bbl)** | **6.86E+08** |

| Spills from Oil/Gas Process Activities in the GoM (Source: MMS - TIMS Database) | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | | 10,000 - 100,000 bbl | | |
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Total Production (bbl) | Barrels Spilled per 1E6 bbl Produced | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1980 | 27 | 1678 | | | 23 | 73 | 3.2 | 3 | 149 | 49.7 | | | | 1 | 1456 | 1456.0 | | | |
| 1981 | 21 | 135 | | | 19 | 62 | 3.3 | 2 | 73 | 36.5 | | | | | | | | | |
| 1982 | 26 | 79 | | | 25 | 67 | 2.7 | 1 | 12 | 12.0 | | | | | | | | | |
| 1983 | 48 | 280 | | | 43 | 127 | 3.0 | 5 | 153 | 30.6 | | | | | | | | | |
| 1984 | 39 | 172 | | | 38 | 122 | 3.2 | 1 | 50 | 50.0 | | | | | | | | | |
| 1985 | 34 | 141 | 351133870 | 0.40 | 32 | 100 | 3.1 | 2 | 41 | 20.5 | | | | | | | | | |
| 1986 | 24 | 75 | 356398376 | 0.21 | 24 | 75 | 3.1 | | | | | | | | | | | | |
| 1987 | 19 | 84 | 328243087 | 0.26 | 17 | 49 | 2.9 | 2 | 35 | 17.5 | | | | | | | | | |
| 1988 | 12 | 103 | 301704812 | 0.34 | 10 | 33 | 3.3 | 2 | 70 | 35.0 | | | | | | | | | |
| 1989 | 12 | 355 | 281160011 | 1.26 | 10 | 44 | 4.4 | 1 | 11 | 11.0 | 1 | 300 | 300.0 | | | | | | |
| 1990 | 15 | 91 | 274955773 | 0.33 | 13 | 47 | 3.6 | 2 | 44 | 22.0 | | | | | | | | | |
| 1991 | 11 | 477 | 295129769 | 1.62 | 7 | 33 | 4.7 | 3 | 94 | 31.3 | 1 | 350 | 350.0 | | | | | | |
| 1992 | 9 | 32 | 305282682 | 0.10 | 9 | 32 | 3.6 | | | | | | | | | | | | |
| 1993 | 9 | 42 | 309229380 | 0.14 | 8 | 23 | 2.9 | 1 | 19 | 19.0 | | | | | | | | | |
| 1994 | 6 | 16 | 314743342 | 0.05 | 6 | 16 | 2.7 | | | | | | | | | | | | |
| 1995 | 16 | 594 | 345525211 | 1.72 | 11 | 41 | 3.7 | 4 | 118 | 29.5 | 1 | 435 | 435.0 | | | | | | |
| 1996 | 21 | 271 | 369309647 | 0.73 | 15 | 52 | 3.5 | 6 | 219 | 36.5 | | | | | | | | | |
| 1997 | 13 | 260 | 411795024 | 0.63 | 10 | 33 | 3.3 | 2 | 57 | 28.5 | 1 | 170 | 170.0 | | | | | | |
| 1998 | 16 | 314 | 444466377 | 0.71 | 11 | 35 | 3.2 | 5 | 279 | 55.8 | | | | | | | | | |
| 1999 | 10 | 78 | | | 7 | 25 | 3.6 | 3 | 53 | 17.7 | | | | | | | | | |
| **TOTAL** | **388** | **5277** | **4.69E+09** | **6.09E-01** | **338** | **1089** | **3** | **45** | **1477** | **33** | **4** | **1255** | **314** | **1** | **1456** | **1456** | **0** | **0** | **0** |

**TLP - Export Pipeline Risers**

| | |
|---|---|
| **Exposure (riser-years)** | **20** |

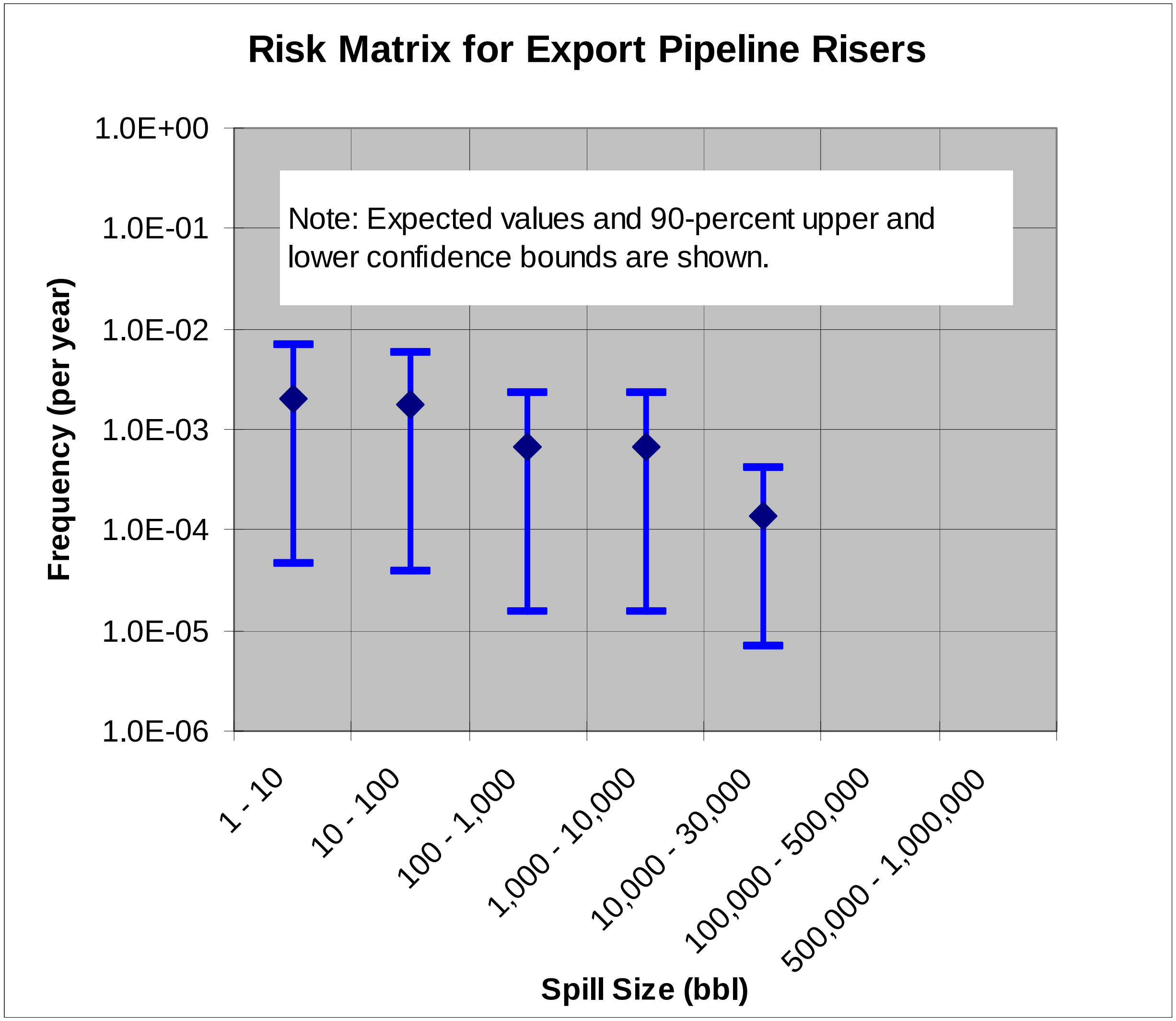
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per riser-year)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per riser-year)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 2.0E-03 | 1.15 | 1.0E+00 | 1.00 | 2.0E-03 | 0.58 |
| 10 - 100 | 32 | 1.8E-03 | 1.15 | 1.0E+00 | 1.00 | 1.8E-03 | 0.58 |
| 100 - 1,000 | 320 | 6.8E-04 | 1.15 | 1.0E+00 | 1.00 | 6.8E-04 | 0.58 |
| 1,000 - 10,000 | 3200 | 6.8E-04 | 1.15 | 1.0E+00 | 1.00 | 6.8E-04 | 0.58 |
| 10,000 - 30,000 | 21000 | 1.4E-04 | 1.00 | 1.0E+00 | 1.00 | 1.4E-04 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **1.1E+02** |
| **Std. Dev. in Total (bbl)** | **7.6E+01** |

| | |
|---|---|
| **Expected Max (bbl)** | **1.1E+02** |
| **Std. Dev. in Max (bbl)** | **7.6E+01** |


Risk Matrix for Export Pipeline Risers
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
Frequency (per year)
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 30,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Use Parloc (1993) information for leak frequency from risers, normalized by riser-years: 2 leaks in 565 riser-years for risers with a diameter greater than 8 inches.

Statistical Analysis:

| | |
|---|---|
| Exposure (riser-years) | 565 |
| Leaks | 2 |
| k" | 3 |
| n" (riser-years) | 565 |
| Expected Rate (per riser-year) | 5.31E-03 |
| Coefficient of Uncertainty in Rate | 0.577 |

Distribute spill sizes from risers using the pipeline spill-size distribution (see Pipeline worksheet for details).

| Spill Size Range (bbl) | Expected Pipeline Frequency (per mile-year) | Pipeline Leak Distribution | Expected Riser Frequency (per riser year) | Coefficient of Uncertainty in Frequency |
|---|---|---|---|---|
| 1 - 10 | 3.72E-04 | 38% | 2.04E-03 | 0.58 |
| 10 - 100 | 3.22E-04 | 33% | 1.77E-03 | 0.58 |
| 100 - 1,000 | 1.24E-04 | 13% | 6.81E-04 | 0.58 |
| 1,000 - 10,000 | 1.24E-04 | 13% | 6.81E-04 | 0.58 |
| 10,000 - 100,000 | 2.48E-05 | 3% | 1.36E-04 | 0.00 |
| 100,000 - 500,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |
| 500,000 - 1,000,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because import risers will be in deeper water (which may increase the frequency) but more modern (which may decrease the frequency) than the risers in the database.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since the risers in the historical database are not very representative of export risers on floating production systems in deepwater.
- Limit maximum possible spill size to 100,000 bbl and use a triangular probability distribution (decreasing with increasing size) in the 10,000 to 100,000 bbl category because (1) hydrostatic pressures in deeper water and “P-traps” due to bottom contours limit the volume of inventory that can leak and (2) it is not credible that pumping from the TLP would continue for more than several hours after a leak occurs (6,200 bbl/hr production rate) due to detection systems and operational requirements. Therefore, the representative spill-size for the largest category (10,000 to 100,000 bbls) is obtained by assuming that the logarithm of the spill size has a triangular distribution (versus a uniform distribution) with the maximum likelihood at 10,000 bbls and the minimum likelihood at 100,000 bbls, giving a representative value of 21,000 bbls. (Note that this same approach is used for the largest spill-size category for FPSO shuttle tankers.)

Exposure for Study System:

| | |
|---|---|
| 1 Export Riser | 1 |
| Years of Service | 20 |
| **Total Riser-Years:** | **20** |

**TLP - Pipelines**

| | |
|---|---|
| **Exposure (mile-years)** | **2900** |

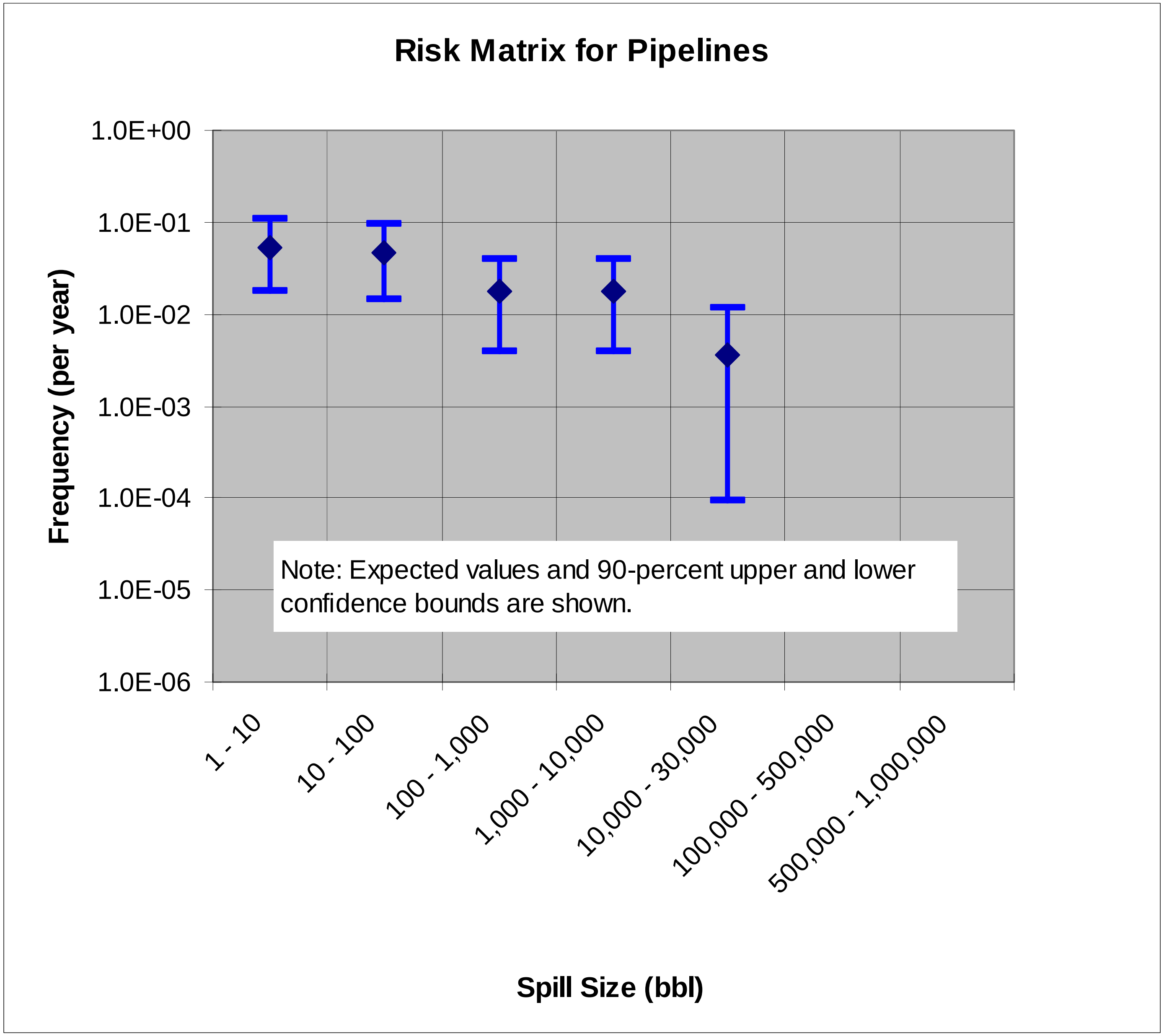
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per mile-year)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per mile-year)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 3.7E-04 | 0.52 | 1.0E+00 | 0.33 | 3.7E-04 | 0.40 |
| 10 - 100 | 32 | 3.2E-04 | 0.53 | 1.0E+00 | 0.33 | 3.2E-04 | 0.41 |
| 100 - 1,000 | 320 | 1.2E-04 | 0.64 | 1.0E+00 | 0.33 | 1.2E-04 | 0.55 |
| 1,000 - 10,000 | 3200 | 1.2E-04 | 0.64 | 1.0E+00 | 0.33 | 1.2E-04 | 0.55 |
| 10,000 - 100,000 | 21000 | 2.5E-05 | 1.13 | 1.0E+00 | 0.33 | 2.5E-05 | 1.08 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **2.8E+03** |
| **Std. Dev. in Total (bbl)** | **1.9E+03** |

| | |
|---|---|
| **Expected Max (bbl)** | **2.4E+03** |
| **Std. Dev. in Max (bbl)** | **1.7E+03** |


Risk Matrix for Pipelines
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
Frequency (per year)
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 30,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Reported incidents of oil pipeline leaks in the Gulf of Mexico were taken from the USCG spill database for the years 1992 to 1998. The data are summarized below.

Total Pipeline Miles in GOM federal and state waters estimated from MMS and Lousiana data making the following assumptions:
Federal Waters Sum: Include "unknown" mileage in all years
State Waters Sum: Start with 2,500 miles from Mariano Hinojosa (Louisiana) in 2000; Maintain constant State/Federal Percentage for Earlier Years
Percent Inactive: Assume 17 percent today, 0 percent in 1948 and increase it linearly with time
Total Active: Reduce both federal and state together with same percentage inactive
Total Active Liquid: Assume 30 percent of pipeline length is liquid versus gas (NRC Marine Board Study 1994)
Result - 44,715 mile-years from 1992 to 1998
As a check, Marine Board Study in 1994 reported 17,000 total miles with 30 % oil/condensate, giving 5,100 miles for 7 years or 35,700 mile-years.

| Total Mile Years in Data: | |
|---|---|
| Expected Value | 44715 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 14756 |

| Spill Size Range (bbl) | Count | Frequency (per mile-yr) | Statistically Estimated Frequency (no prior information): k" | n" (mile-yr) | Expected Value (per mile-yr) | Std. Dev. (per mile-yr) | c.o.v. |
|---|---|---|---|---|---|---|---|
| 1 - 10 | 14 | 3.1E-04 | 15 | 44715 | 3.7E-04 | 1.5E-04 | 0.40 |
| 10 - 100 | 12 | 2.7E-04 | 13 | 44715 | 3.2E-04 | 1.3E-04 | 0.41 |
| 100 - 1,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 1,000 - 10,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 10,000 - 100,000 | 0 | 0.0E+00 | 1 | 44715 | 2.5E-05 | 2.7E-05 | 1.08 |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because pipelines for study systems will be similar to pipelines in database, although they will be in deeper water on average.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data since most of the pipelines in the historical database are in shallower water on average than the pipeline for the study system. The deepwater effect may lead to a reduction in the frequency of spills (fewer anchor drags and dropped objects), but the difference was not considered to be significant enough (an EQE 1998 study estimated the frequency of spills for deepwater segments of pipeline would be approximately 70-percent of that for shallow water pipeline segments) to be reflected in the expected bias.

- Limit maximum possible spill size to 100,000 bbl and use a triangular probability distribution (decreasing with increasing size) in the 10,000 to 100,000 bbl category because (1) hydrostatic pressures in deeper water and “P-traps” due to bottom contours limit the volume of inventory that can leak and (2) it is not credible that pumping from the TLP would continue for more than several hours after a leak occurs (6,200 bbl/hr production rate) due to detection systems and operational requirements. Therefore, the representative spill-size for the largest category (10,000 to 100,000 bbls) is obtained by assuming that the logarithm of the spill size has a triangular distribution (versus a uniform distribution) with the maximum likelihood at 10,000 bbls and the minimum likelihood at 100,000 bbls, giving a representative value of 21,000 bbls. (Note that this same approach is used for the largest spill-size category for FPSO shuttle tankers.)

| Exposure for Study System (mile-years): | |
|---|---|
| to Hub (miles) | 45 |
| to Shore from Hub (miles) | 80 |
| to Terminal from Shore (miles) | 20 |
| Total Length (miles) | 145 |
| **Mile Years (20 years)** | **2900** |

**Spills from Pipelines in the GoM and its Waterways**
**(Source: USCG - Marine Casuality and Pollution Database with input from MMS)**

| | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1992 | 10 | 3055 | 3 | 10 | 3.3 | 4 | 123 | 30.8 | 2 | 922 | 461.0 | 1 | 2000 | 2000.0 |
| 1993 | 2 | 5 | 2 | 5 | 2.5 | | | | | | | | | |
| 1994 | 2 | 4554 | | | | 1 | 10 | 10.0 | | | | 1 | 4544 | 4544.0 |
| 1995 | 5 | 32 | 3 | 8 | 2.7 | 2 | 24 | 12.0 | | | | | | |
| 1996 | 2 | 28 | 1 | 2 | 2.0 | 1 | 26 | 26.0 | | | | | | |
| 1997 | 5 | 223 | 2 | 9 | 4.5 | 2 | 51 | 25.5 | 1 | 163 | 163.0 | | | |
| 1998 | 8 | 10214 | 3 | 9 | 3.0 | 2 | 39 | 19.5 | 1 | 743 | 743.0 | 2 | 9423 | 4711.5 |
| **TOTAL** | **34** | **18111** | **14** | **43** | **3.1** | **12** | **273** | **22.8** | **4** | **1828** | **457.0** | **4** | **15967** | **3991.8** |

**TLP - Supply Vessels**

| Exposure (docking calls) | 12287 |
|---|---|

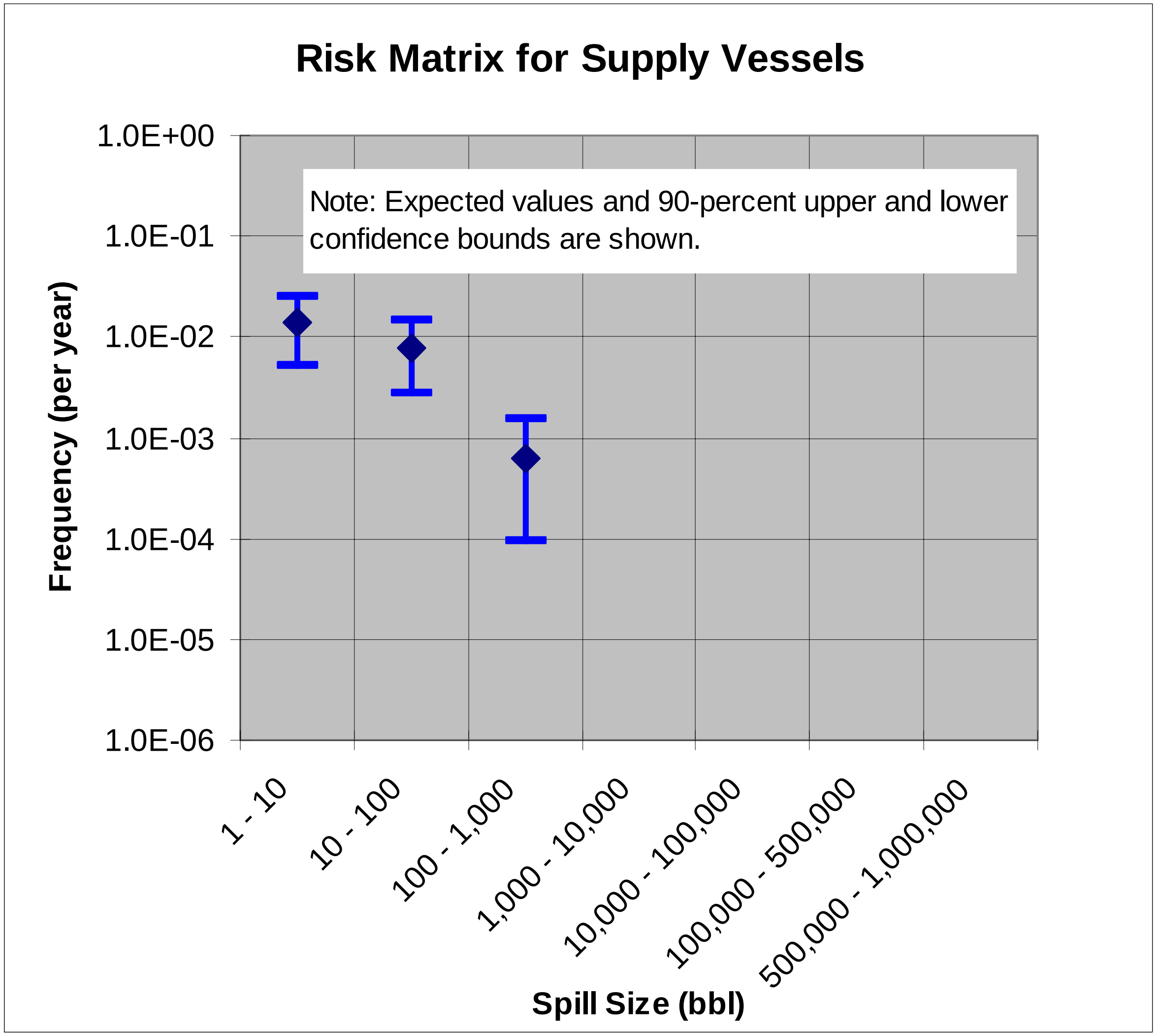
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Spill Size (bbl) | Expected Frequency (per call) | Coefficient of Uncertainty for Frequency | Expected Bias | Coefficient of Uncertainty for Bias | Expected Frequency (per call) | Coefficient of Uncertainty for Frequency |
| 1 - 10 | 3 | 2.2E-05 | 0.46 | 1.0E+00 | 0.33 | 2.2E-05 | 0.32 |
| 10 - 100 | 32 | 1.2E-05 | 0.48 | 1.0E+00 | 0.33 | 1.2E-05 | 0.34 |
| 100 - 1,000 | 320 | 1.0E-06 | 0.75 | 1.0E+00 | 0.33 | 1.0E-06 | 0.67 |
| 1,000 - 10,000 | 3200 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 3.4E-07 | 1.08 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **9.7E+00** |
| **Std. Dev. in Total (bbl)** | **3.8E+00** |

| | |
|---|---|
| **Expected Max (bbl)** | **9.1E+00** |
| **Std. Dev. in Max (bbl)** | **3.5E+00** |




F.93 – Oil Spill Risk Assessment for TLP

**Basis:**

Risk of a spill from a supply vessel is assumed to be proportional to the number of docking or port calls (in field and at the terminal) because this is where most spills occur due to the number of operations (including offloading) and difficulties in navigation (traffic and shore).

The USCG database of spills from offshore supply vessels (OSVs) was used to estimate the frequency of different spill sizes. Data from the years 1985-1999 were used in this analysis.

The data base was searched for petroleum spills from supply vessels. Substances considered included crude, fuel, diesel, lubricating oil and drilling mud.

Incidents were included from the following locations to represent the "Gulf of Mexico": Gulf of Mexico, Sabine/Neches River, Corpus Christi Ship Channel and Harbor, Galveston Bay, Houston Ship Channel, Lower and Upper Mississippi River, and Intercoastal Waterway - Gulf.

The database includes incidents related to vessel transit and docking calls at platorms and ports. A rough picture of supply vessel activity in the GOM (based on discussions with Edison Chouest): 300 boats making an average of 2 dock calls per day = 300x2x365 = 219,000 docking calls per year.

| Total Docking Calls in Data (15 yrs): | |
|---|---|
| Expected Value | 3285000 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 1084050 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per call) | k" | n" (calls) | Expected Value (/call) | Std. Dev. (/call) | c.o.v. |
| 1 - 10 | 65 | 2.0E-05 | 66 | 3285000 | 2.2E-05 | 7.2E-06 | 0.32 |
| 10 - 100 | 36 | 1.1E-05 | 37 | 3285000 | 1.2E-05 | 4.3E-06 | 0.34 |
| 100 - 1,000 | 2 | 6.1E-07 | 3 | 3285000 | 1.0E-06 | 6.8E-07 | 0.67 |
| 1,000 - 10,000 | 0 | 0.0E+00 | 1 | 3285000 | 3.4E-07 | 3.6E-07 | 1.08 |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data because supply vessels for these systems will be larger and more modern (dynamically-positioned) than the typical vessels that comprise the historical data.
- Limit maximum possible spill size to 1,000 bbl to be consistent with cargo capacity for typical supply vessels (less than 1,000 bbl).

Exposure for Study System:

| | |
|---|---|
| 1 trip per 3 days during production | 0.333333333 |
| Days of Production (20 years) | 7300 |
| Trips | 2433.333333 |
| | |
| 1 trip per 3 days during drilling/workover | 0.333333333 |
| 6 Platform Wells (20 years) | |
| Drilling & Completion (5*90 + 6*20 days) | 570 |
| Slickline (3 per well-year @ 5 days) | 1800 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 |
| Change out (1/3 per well-yr @ 50 days) | 2000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 |
| Trips | 3230 |
| | |
| 3 Subsea Wells (12 years) | |
| Drilling & Completion (3*90 + 90 days) | 360 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 |
| Change out (1/8 per well-yr @ 50 days) | 225 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 |
| Trips | 480 |
| | |
| **Docking calls (trips*2)** | **12287** |

**Spills from OSV Activities in the GoM and its Waterways**
**(Source: USCG - Marine Casuality and Pollution Database)**

| | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | | 10,000 - 100,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1985 | 0 | 0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1986 | 7 | 34 | 6 | 17 | 2.8 | 1 | 17 | 17.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1987 | 4 | 42 | 3 | 6 | 2.0 | 1 | 36 | 36.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1988 | 3 | 40 | 2 | 10 | 5.0 | 1 | 30 | 30.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1989 | 5 | 30 | 4 | 9 | 2.3 | 1 | 21 | 21.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1990 | 10 | 78 | 7 | 24 | 3.4 | 3 | 54 | 18.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1991 | 11 | 78 | 9 | 37 | 4.1 | 2 | 41 | 20.5 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1992 | 3 | 39 | 2 | 7 | 3.5 | 1 | 32 | 32.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1993 | 8 | 191 | 3 | 9 | 3.0 | 5 | 182 | 36.4 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1994 | 10 | 21 | 10 | 21 | 2.1 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1995 | 10 | 534 | 3 | 9 | 3.0 | 6 | 211 | 35.2 | 1 | 314 | 314.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1996 | 9 | 161 | 5 | 18 | 3.6 | 4 | 143 | 35.8 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1997 | 10 | 103 | 6 | 26 | 4.3 | 4 | 77 | 19.3 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1998 | 9 | 257 | 4 | 11 | 2.8 | 4 | 116 | 29.0 | 1 | 130 | 130.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1999 | 4 | 193 | 1 | 3 | 3.0 | 3 | 190 | 63.3 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| **TOTAL** | **103** | **1801** | **65** | **207** | **3** | **36** | **1150** | **32** | **2** | **444** | **222** | **0** | **0** | **0** | **0** | **0** | **0** |

**TLP - Drilling and Intervention**

| | |
|---|---|
| **Exposure (man-days)** | **246912** |

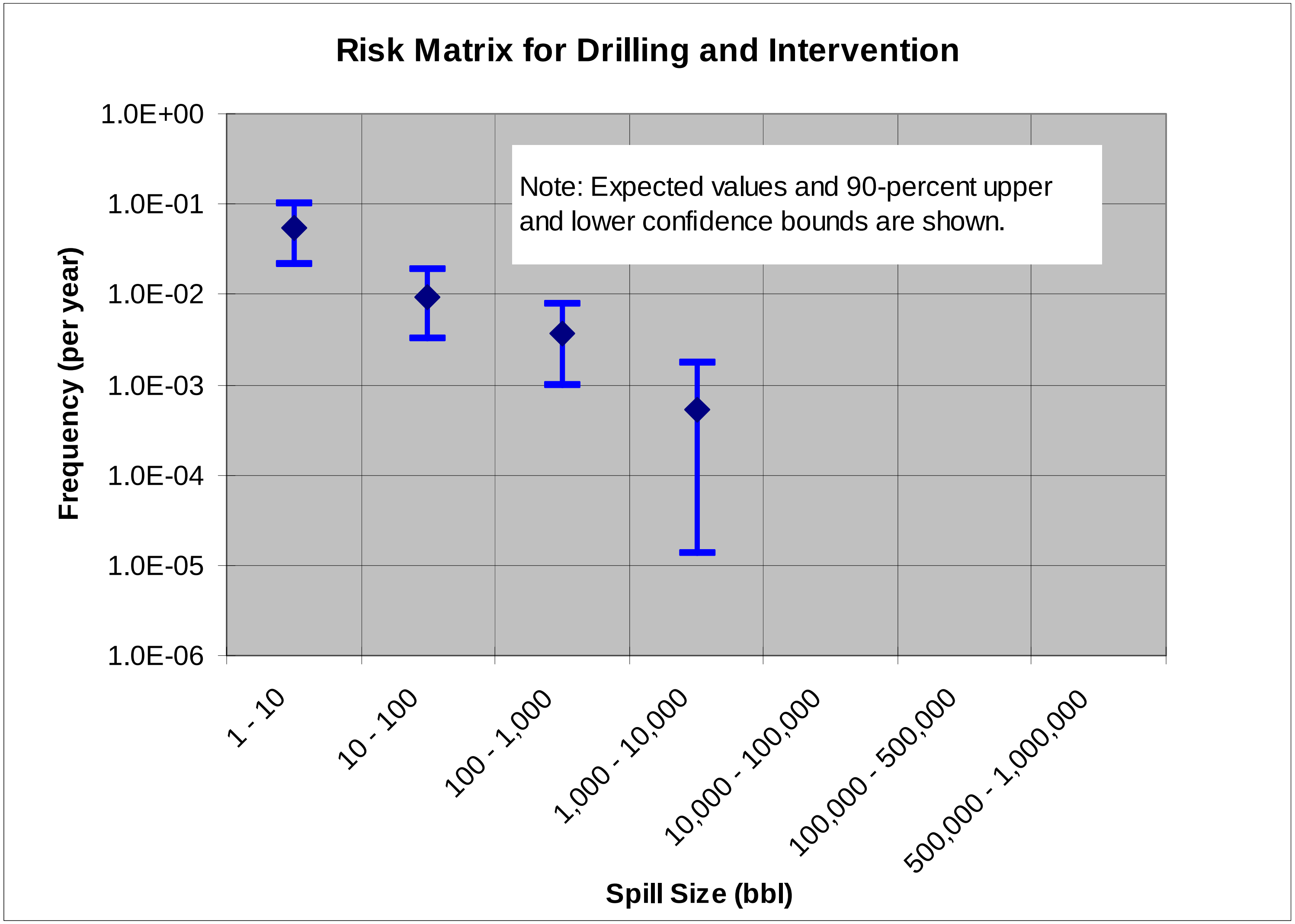
**Input Information**

| Spill Size Range (bbl) | Spill Size (bbl) | Combined (Expert+Data) Estimate: Expected Frequency (per man-day) | Combined (Expert+Data) Estimate: Coefficient of Uncertainty for Frequency | Expert-Based Extrapolation Bias: Expected Bias | Expert-Based Extrapolation Bias: Coefficient of Uncertainty for Bias | Data-Based Estimate: Expected Frequency (per man-day) | Data-Based Estimate: Coefficient of Uncertainty for Frequency |
|---|---|---|---|---|---|---|---|
| 1 - 10 | 3 | 4.4E-06 | 0.46 | 1.0E+00 | 0.33 | 4.4E-06 | 0.31 |
| 10 - 100 | 32 | 7.7E-07 | 0.51 | 1.0E+00 | 0.33 | 7.7E-07 | 0.39 |
| 100 - 1,000 | 320 | 3.0E-07 | 0.59 | 1.0E+00 | 0.33 | 3.0E-07 | 0.49 |
| 1,000 - 10,000 | 3200 | 4.3E-08 | 1.13 | 1.0E+00 | 0.33 | 4.3E-08 | 1.08 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **6.7E+01** |
| **Std. Dev. in Total (bbl)** | **4.1E+01** |

| | |
|---|---|
| **Expected Max (bbl)** | **6.3E+01** |
| **Std. Dev. in Max (bbl)** | **4.0E+01** |




F.98 – Oil Spill Risk Assessment for TLP

**Basis:**

Risk of a spill from drilling and well intervention is assumed to be proportional to the number of man-days of operations. This approach means that operations that require a larger crew will have a greater risk of oil spill because more activities and difficulties are involved. It is also used here because information about man-days of drill crew operations in the GOM is available from IADC, an average of 1.3 million man-days per year in the 1990's. One concern is that the IADC information includes activities in state waters while the MMS data may only include OCS waters, therefore the denominator may be overestimated slightly.

The MMS platform data base (1980-1999) was used to identify drilling activity-related incidents. These incidents include exploratory drilling, development drilling and well workovers and completions. Substances reported in the data base include crude, fuel, diesel, drilling fluids and drilling mud. Rig types include both platform and MODU rigs.

| Total man-days in Data (20 yrs): | |
|---|---|
| Expected Value | 26000000 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 8580000 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per man-day) | k" | n" (man-day) | Expected Value (per man-day) | Std. Dev. (per man-day) | c.o.v. |
| 1 - 10 | 103 | 4.0E-06 | 104 | 26000000 | 4.4E-06 | 1.4E-06 | 0.31 |
| 10 - 100 | 17 | 6.5E-07 | 18 | 26000000 | 7.7E-07 | 3.0E-07 | 0.39 |
| 100 - 1,000 | 6 | 2.3E-07 | 7 | 26000000 | 3.0E-07 | 1.5E-07 | 0.49 |
| 1,000 - 10,000 | 0 | 0.0E+00 | 1 | 26000000 | 4.3E-08 | 4.6E-08 | 1.08 |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data because there are relatively few historical data available for deep-water drilling in the Gulf of Mexico (compared to shallow-water drilling).
- Although they have not occurred in the data record, the possiblity for spills larger than 10,000 bbl was evaluated. The estimated frequency was considered to be negligibly small because the reservoir characteristics will be relatively well known since significant exploration and development drilling will have taken place before the production life begins.

Exposure for Study System:

| 6 Platform Wells (20 years) | days | crew | man-days |
|---|---|---|---|
| Drilling & Completion (5*90 + 6*20 days) | 570 | 40 | 22800 |
| Slickline (3 per well-year @ 5 days) | 1800 | 4 | 7200 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Change out (1/3 per well-yr @ 50 days) | 2000 | 40 | 80000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 | 40 | 48000 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 | 520 | 40 | 20800 |
| | | | |
| 3 Subsea Wells (12 years) | | | |
| Drilling & Completion (3*90 + 90 days) | 360 | 40 | 14400 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 | 4 | 720 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 | 8 | 1152 |
| Change out (1/8 per well-yr @ 50 days) | 225 | 8 | 1800 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 | 40 | 7200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 | 156 | 40 | 6240 |
| Replace Wellhead (1/12 per well-yr @ 65 da | 195 | 40 | 7800 |
| | | | |
| | | **Total (man-days):** | **246912** |

| Spills from Drilling Activities in the GoM (Source: MMS - TIMS Database) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | <= 10 bbl | | | > 10 bbl & <= 100 bbl | | | 100 - 1,000 bbl | | |
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Total Production | Barrels Spilled per 1E6 bbl Produced | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1980 | 8 | 353 | | | 6 | 17 | 2.8 | 1 | 50 | 50.0 | 1 | 286 | 286.0 |
| 1981 | 4 | 253 | | | 1 | 4 | 4.0 | 2 | 39 | 19.5 | 1 | 210 | 210.0 |
| 1982 | 13 | 50 | | | 13 | 50 | 3.8 | | | | | | |
| 1983 | 14 | 77 | | | 13 | 52 | 4.0 | 1 | 25 | 25.0 | | | |
| 1984 | 2 | 6 | | | 2 | 6 | 3.0 | | | | | | |
| 1985 | 13 | 98 | 351133870 | 0.28 | 12 | 48 | 4.0 | 1 | 50 | 50.0 | | | |
| 1986 | 7 | 31 | 356398376 | 0.09 | 7 | 31 | 4.4 | | | | | | |
| 1987 | 10 | 106 | 328243087 | 0.32 | 7 | 18 | 2.6 | 3 | 88 | 29.3 | | | |
| 1988 | 0 | 0 | 301704812 | 0.00 | | | | | | | | | |
| 1989 | 7 | 184 | 281160011 | 0.65 | 4 | 11 | 2.8 | 2 | 56 | 28.0 | 1 | 117 | 117.0 |
| 1990 | 4 | 127 | 274955773 | 0.46 | 3 | 17 | 5.7 | | | | 1 | 110 | 110.0 |
| 1991 | 4 | 14 | 295129769 | 0.05 | 4 | 14 | 3.5 | | | | | | |
| 1992 | 2 | 102 | 305282682 | 0.33 | 1 | 2 | 2.0 | 1 | 100 | 100.0 | | | |
| 1993 | 1 | 3 | 309229380 | 0.01 | 1 | 3 | 3.0 | | | | | | |
| 1994 | 1 | 3 | 314743342 | 0.01 | 1 | 3 | 3.0 | | | | | | |
| 1995 | 4 | 8 | 345525211 | 0.02 | 4 | 8 | 2.0 | | | | | | |
| 1996 | 4 | 19 | 369309647 | 0.05 | 3 | 7 | 2.3 | 1 | 12 | 12.0 | | | |
| 1997 | 2 | 3 | 411795024 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1998 | 5 | 32 | 444466377 | 0.07 | 4 | 11 | 2.8 | 1 | 21 | 21.0 | | | |
| 1999 | 2 | 7 | | | 2 | 7 | 3.5 | | | | | | |
| **TOTAL** | **107** | **1476** | **4.69E+09** | **1.56E-01** | **90** | **312** | **3** | **13** | **441** | **34** | **4** | **723** | **181** |

**Spills from Completion/Workover Activities in the GoM**

**(Source: MMS - TIMS Database)**

| | | | | | <= 10 bbl | | | > 10 bbl & <= 100 bbl | | | >100 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled** | **Total Production** | **Barrels Spilled per 1E6 bbl Produced** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1980 | 0 | 0 | | | | | | | | | | | |
| 1981 | 3 | 68 | | | 2 | 4 | 2.0 | 1 | 64 | 64.0 | | | |
| 1982 | 1 | 3 | | | 1 | 3 | 3.0 | | | | | | |
| 1983 | 1 | 2 | | | 1 | 2 | 2.0 | | | | | | |
| 1984 | 0 | 0 | | | | | | | | | | | |
| 1985 | 1 | 5 | 351133870 | 0.01 | 1 | 5 | 5.0 | | | | | | |
| 1986 | 0 | 0 | 356398376 | 0.00 | | | | | | | | | |
| 1987 | 1 | 3 | 328243087 | 0.01 | 1 | 3 | 3.0 | | | | | | |
| 1988 | 0 | 0 | 301704812 | 0.00 | | | | | | | | | |
| 1989 | 1 | 6 | 281160011 | 0.02 | 1 | 6 | 6.0 | | | | | | |
| 1990 | 1 | 8 | 274955773 | 0.03 | 1 | 8 | 8.0 | | | | | | |
| 1991 | 0 | 0 | 295129769 | 0.00 | | | | | | | | | |
| 1992 | 0 | 0 | 305282682 | 0.00 | | | | | | | | | |
| 1993 | 0 | 0 | 309229380 | 0.00 | | | | | | | | | |
| 1994 | 3 | 172 | 314743342 | 0.55 | 1 | 6 | 6.0 | 1 | 25 | 25.0 | 1 | 141 | 141.0 |
| 1995 | 1 | 4 | 345525211 | 0.01 | 1 | 4 | 4.0 | | | | | | |
| 1996 | 1 | 5 | 369309647 | 0.01 | 1 | 5 | 5.0 | | | | | | |
| 1997 | 2 | 3 | 411795024 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1998 | 3 | 276 | 444466377 | 0.62 | | | | 2 | 106 | 53.0 | 1 | 170 | 170.0 |
| 1999 | 0 | 0 | | | | | | | | | | | |
| **TOTAL** | **19** | **555** | **4.69E+09** | **1.03E-01** | **13** | **49** | **4** | **4** | **195** | **49** | **2** | **311** | **156** |

Appendix F.3

Oil Spill Risk Assessment for Hub/Host Jacket

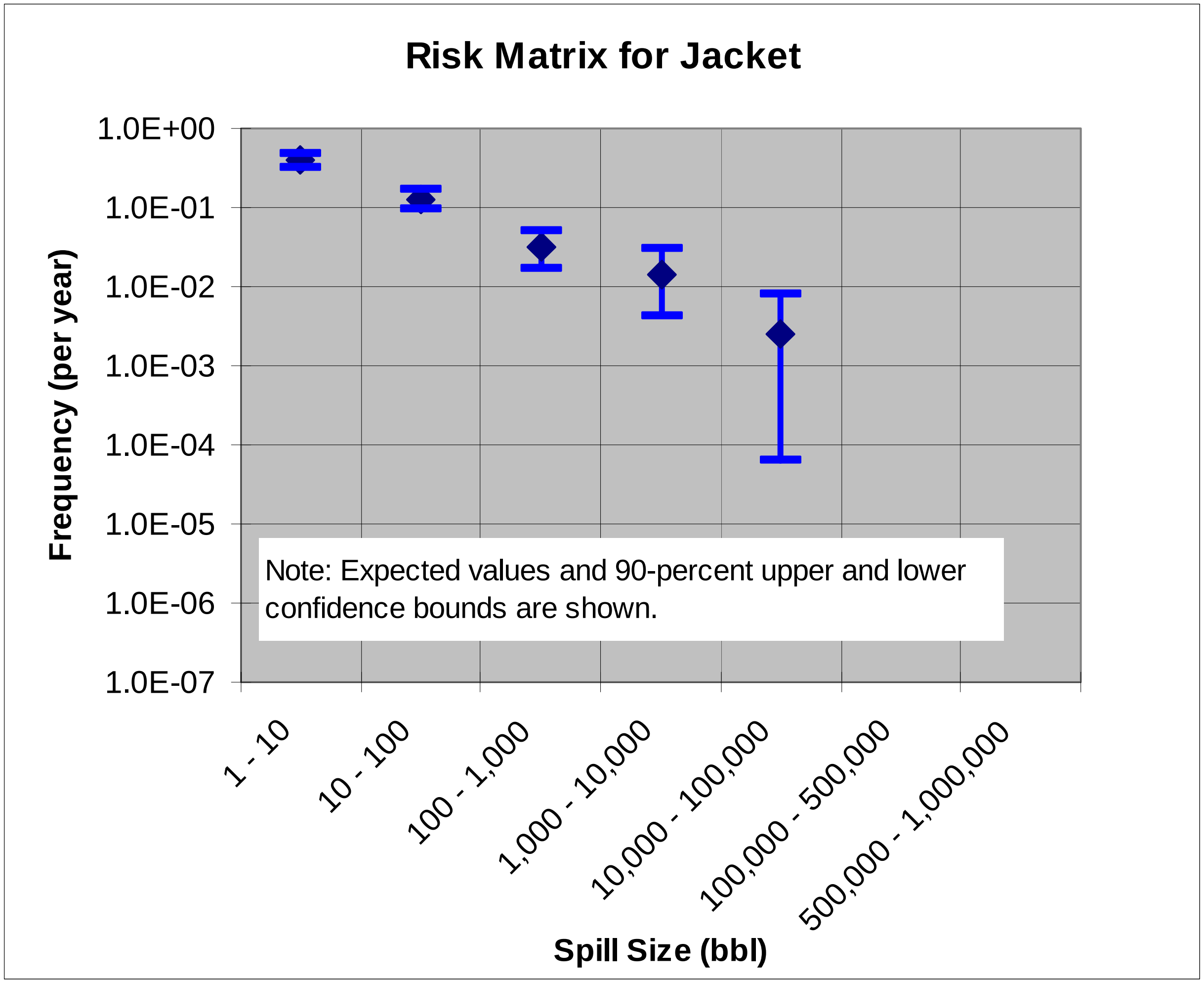
**Jacket - Risk Summary**

**Overall System Risk Results for 20-year Life:**

| | |
|---|---|
| Expected Total (bbl) | 2.3E+03 |
| Std. Dev. in Total (bbl) | 1.3E+03 |

| | |
|---|---|
| Expected Max (bbl) | 1.9E+03 |
| Std. Dev. in Max (bbl) | 1.2E+03 |

| | Sub-system Risk Results for 20-year Life | | | |
|---|---|---|---|---|
| | Expected Total (bbl) | Std. Dev. in Total (bbl) | Expected Maximum (bbl) | Std Dev. in Maximum (bbl) |
| Well Systems - Platform | 9 | 6 | 8 | 6 |
| Well Systems - Subsea | 25 | 27 | 24 | 25 |
| Flowlines | 107 | 109 | 105 | 106 |
| Topsides | 147 | 41 | 95 | 32 |
| Pipelines | 1937 | 1284 | 1746 | 1183 |
| Supply Vessels | 10 | 4 | 9 | 4 |
| Drilling and Intervention | 67 | 41 | 63 | 40 |




F.105 – Oil Spill Risk Assessment for Hub/Host Jacket

**Jacket - Frequency Summary**

**Summary Information for Frequencies**

| | Total System Frequency | | | | | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Expected Value (per year) | Coefficient of Uncertainty | k for Gamma Distribution | n for Gamma Distribution | Lower 90% (per year) | Upper 90% (per year) |
| 1 - 10 | 3.9E-01 | 1.1E-01 | 8.1E+01 | 2.1E+02 | 3.2E-01 | 4.7E-01 |
| 10 - 100 | 1.3E-01 | 1.8E-01 | 2.9E+01 | 2.3E+02 | 9.2E-02 | 1.7E-01 |
| 100 - 1,000 | 3.1E-02 | 3.3E-01 | 9.0E+00 | 2.9E+02 | 1.6E-02 | 5.0E-02 |
| 1,000 - 10,000 | 1.5E-02 | 5.6E-01 | 3.2E+00 | 2.2E+02 | 4.1E-03 | 3.0E-02 |
| 10,000 - 100,000 | 2.5E-03 | 1.1E+00 | 7.8E-01 | 3.2E+02 | 6.3E-05 | 8.1E-03 |
| 100,000 - 500,000 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0.0E+00 | | | | | |

| | Expected Frequency by Sub-system (per year) | | | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Well Systems - Platform | Well Systems - Subsea | Flowlines | Topsides | Pipelines | Supply Vessels | Drilling and Intervention |
| 1 - 10 | 6.9E-03 | 0.0E+00 | 4.5E-03 | 2.8E-01 | 3.7E-02 | 1.4E-02 | 5.5E-02 |
| 10 - 100 | 3.0E-03 | 0.0E+00 | 3.9E-03 | 7.3E-02 | 3.2E-02 | 7.7E-03 | 9.5E-03 |
| 100 - 1,000 | 9.9E-04 | 0.0E+00 | 1.5E-03 | 1.2E-02 | 1.2E-02 | 6.2E-04 | 3.7E-03 |
| 1,000 - 10,000 | 0.0E+00 | 0.0E+00 | 1.5E-03 | 1.0E-04 | 1.2E-02 | 0.0E+00 | 5.3E-04 |
| 10,000 - 100,000 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 2.5E-03 | 0.0E+00 | 0.0E+00 |
| 100,000 - 500,000 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |
| 500,000 - 1,000,000 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |

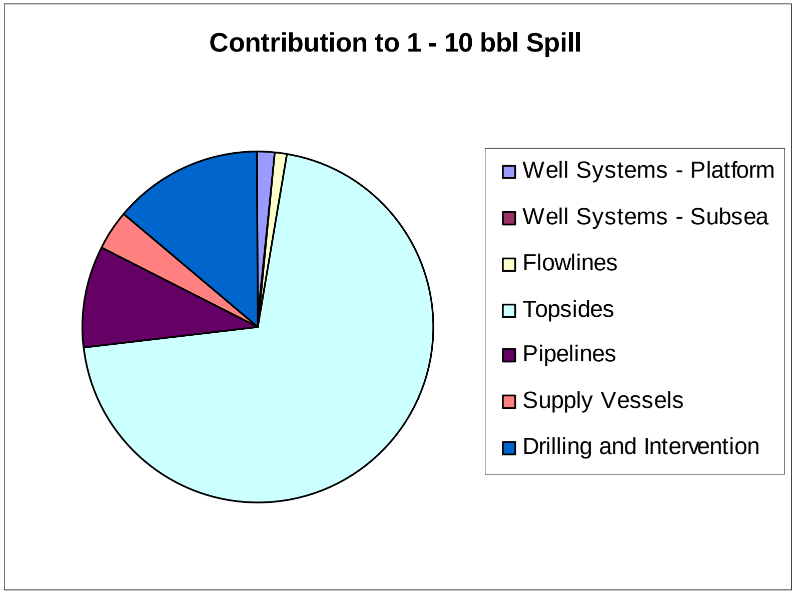
**Summary Information for Jacket Production Frequencies**

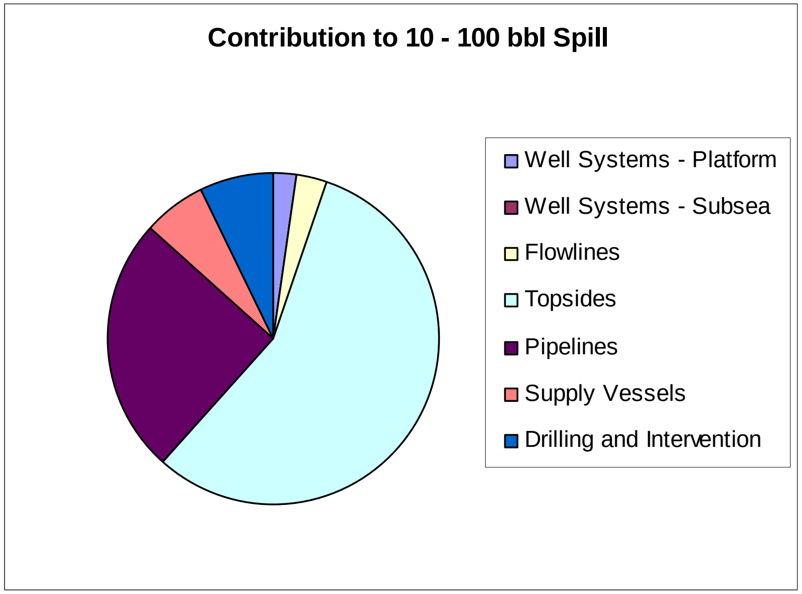
| | Production System Frequency | | | | | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Expected Value (per year) | Coefficient of Uncertainty | k for Gamma Distribution | n for Gamma Distribution | Lower 90% (per year) | Upper 90% (per year) |
| 1 - 10 | 3.6E-01 | 1.1E-01 | 8.3E+01 | 2.3E+02 | 2.9E-01 | 4.2E-01 |
| 10 - 100 | 9.7E-02 | 1.7E-01 | 3.4E+01 | 3.5E+02 | 7.1E-02 | 1.3E-01 |
| 100 - 1,000 | 1.9E-02 | 3.6E-01 | 7.8E+00 | 4.1E+02 | 9.3E-03 | 3.1E-02 |
| 1,000 - 10,000 | 2.1E-03 | 8.5E-01 | 1.4E+00 | 6.5E+02 | 2.1E-04 | 5.7E-03 |
| 10,000 - 100,000 | | | | | | |
| 100,000 - 500,000 | | | | | | |
| 500,000 - 1,000,000 | | | | | | |

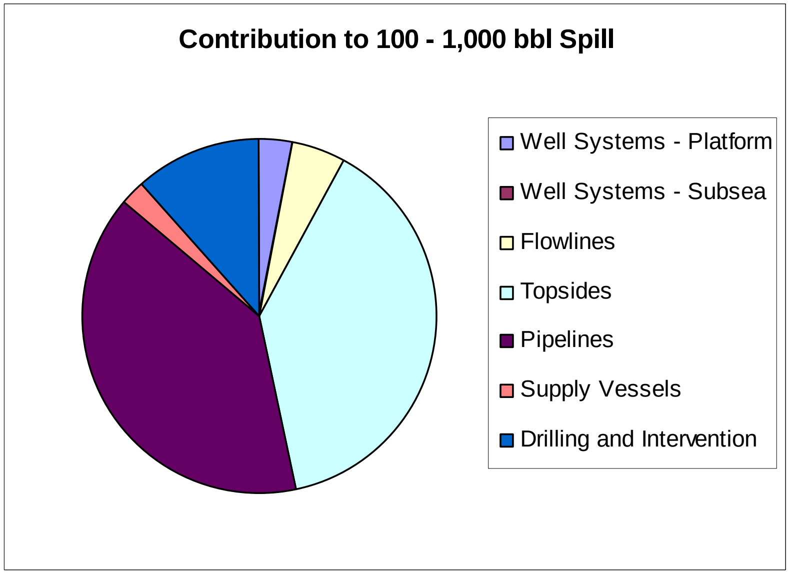
**Summary Information for Jacket Transportation Frequencies**

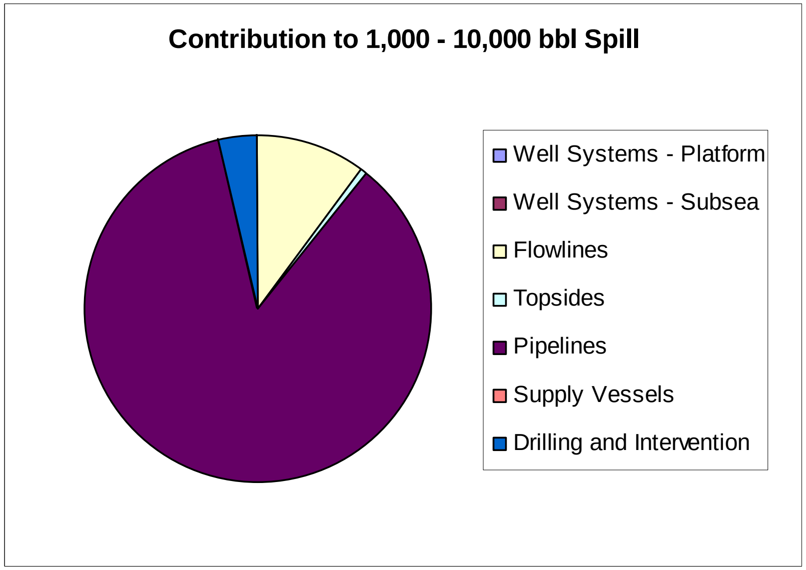
| | Transportation System Frequency | | | | | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Expected Value (per year) | Coefficient of Uncertainty | k for Gamma Distribution | n for Gamma Distribution | Lower 90% (per year) | Upper 90% (per year) |
| 1 - 10 | 3.7E-02 | 4.9E-02 | 4.1E+02 | 1.1E+04 | 3.4E-02 | 4.0E-02 |
| 10 - 100 | 3.2E-02 | 1.3E-01 | 5.7E+01 | 1.8E+03 | 2.6E-02 | 4.0E-02 |
| 100 - 1,000 | 1.2E-02 | 2.5E-01 | 1.5E+01 | 1.2E+03 | 7.7E-03 | 1.8E-02 |
| 1,000 - 10,000 | 1.2E-02 | 5.5E-01 | 3.3E+00 | 2.7E+02 | 3.7E-03 | 2.5E-02 |
| 10,000 - 100,000 | 2.5E-03 | 1.1E+00 | 7.8E-01 | 3.2E+02 | 6.3E-05 | 8.1E-03 |
| 100,000 - 500,000 | | | | | | |
| 500,000 - 1,000,000 | | | | | | |

Hub/Host Jacket - Contribution to Total Frequency for Different Spill Sizes



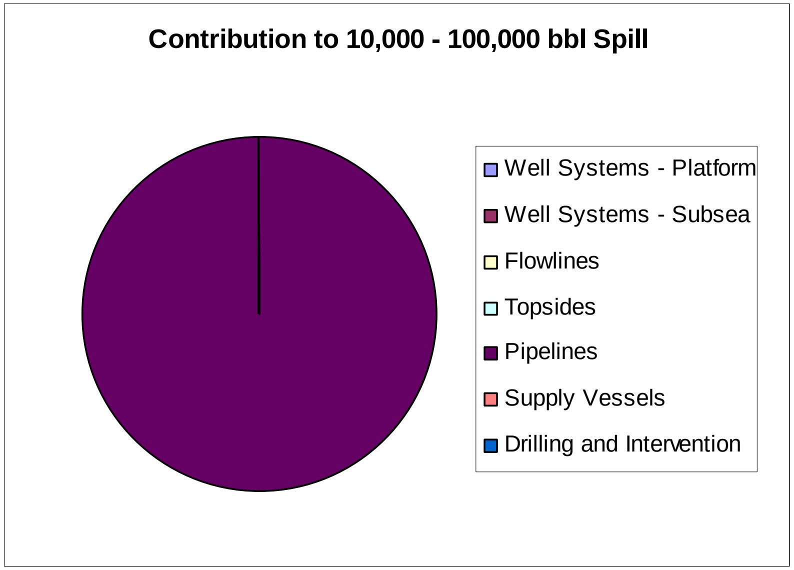



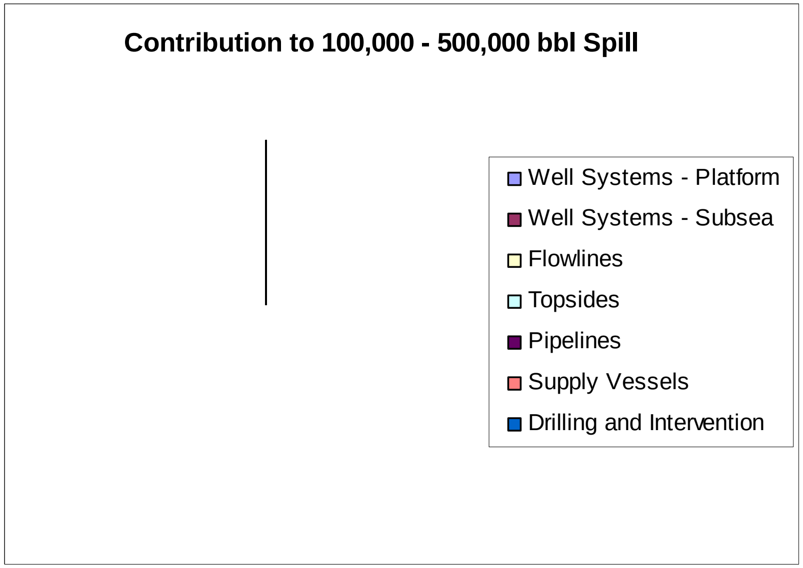



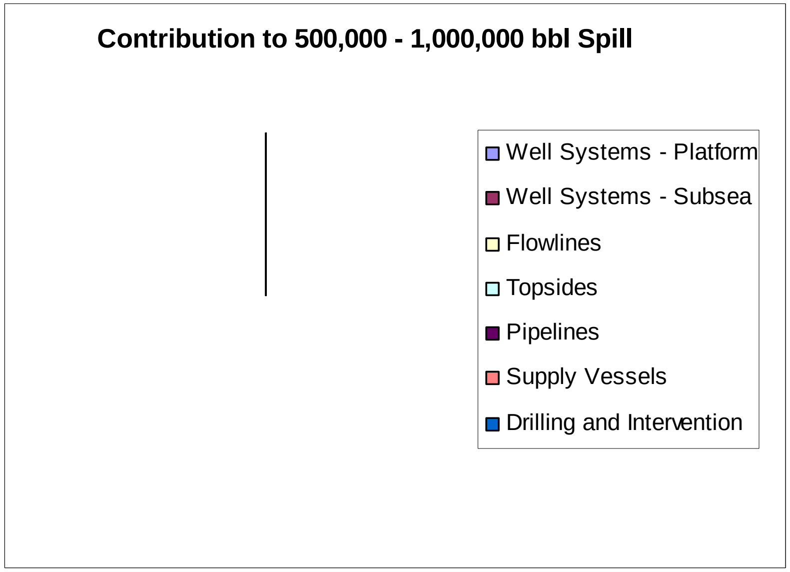




F.108 – Oil Spill Risk Assessment for Hub/Host Jacket

Hub/Host Jacket - Contribution to Total Frequency for Different Spill Sizes




F.109 – Oil Spill Risk Assessment for Hub/Host Jacket

**Jacket - Well Systems (Platform)**

| | |
|---|---|
| **Exposure (bbl produced)** | **6.09E+07** |

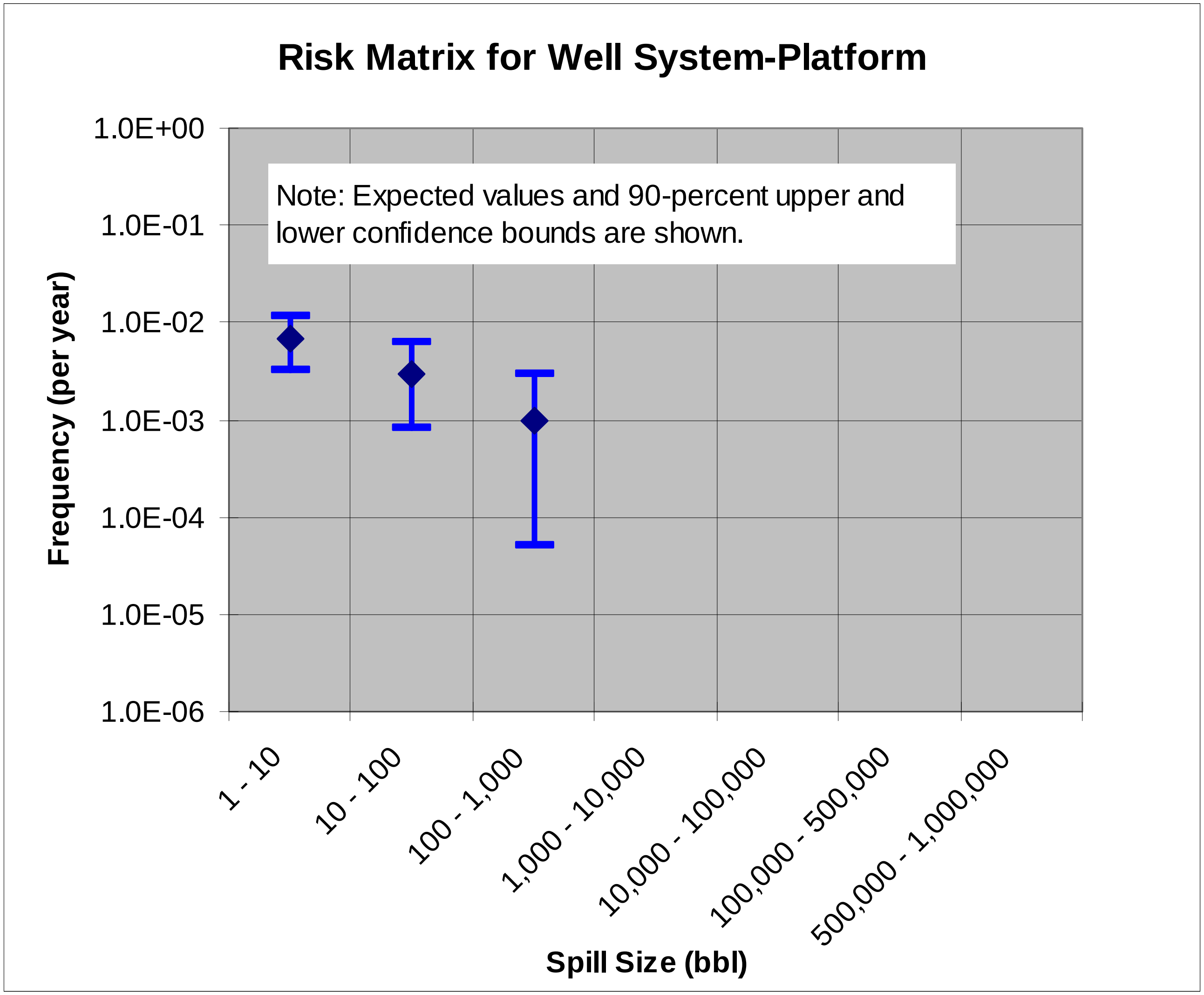
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 2.3E-09 | 0.38 | 1.0E+00 | 0.00 | 2.3E-09 | 0.38 |
| 10 - 100 | 32 | 9.8E-10 | 0.58 | 1.0E+00 | 0.00 | 9.8E-10 | 0.58 |
| 100 - 1,000 | 320 | 3.3E-10 | 1.00 | 1.0E+00 | 0.00 | 3.3E-10 | 1.00 |
| 1,000 - 10,000 | 3200 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **8.7E+00** |
| **Std. Dev. in Total (bbl)** | **6.4E+00** |

| | |
|---|---|
| **Expected Max (bbl)** | **8.5E+00** |
| **Std. Dev. in Max (bbl)** | **6.3E+00** |




F.111 – Oil Spill Risk Assessment for Hub/Host Jacket

**Basis:**

Reported incidents of oil spills from "well and header systems" in the Gulf of Mexico were taken from the MMS pipeline and platform spill database (provided by Cheryl Anderson of MMS) for the years 1980 to 1999. The data are summarized below. Use only data from 1990 to present to account for changes in operating procedures due to implementation of API RP14C.

Equipment includes subsurface safety valves, wellhead assemblies, chokes, jumpers and injection lines, pressure sensors, surface safety valves, header valves and check valves.

Assume risk is proportional to the volume of production - total production data are available for GOM from 1985-1998.

| Total Production bbls in GOM Data: | |
|---|---|
| Expected Value (bbl) | 3.1E+09 |
| Coefficient of Uncertainty | 0 |
| Standard Deviation (bbl) | 0 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per bbl) | k" | n" (bbl) | Expected Value (/bbl) | Std. Dev. (/bbl) | Coefficient of Uncertainty |
| 1 - 10 | 6 | 2.0E-09 | 7 | 3.1E+09 | 2.3E-09 | 8.6E-10 | 0.377964473 |
| 10 - 100 | 2 | 6.5E-10 | 3 | 3.1E+09 | 9.8E-10 | 5.6E-10 | 0.577350269 |
| 100 - 1,000 | 0 | 0.0E+00 | 1 | 3.1E+09 | 3.3E-10 | 3.3E-10 | 1 |
| 1,000 - 10,000 | 0 | 0.0E+00 | | | | | |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:
- Assume no extrapolation bias because study well systems are similar to those in data base.

Exposure for Study System:

**Platform Well Production (bbl)** **6.09E+07**

**Spills from Well and Header Systems in the GoM**
**(Source: MMS - TIMS Database)**

| | | | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Total Production (bbl)** | **Barrels Spilled per 1E6 Bbl Produced** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1980 | 2 | 7 | | | 2 | 7 | 3.4 | | | | | | |
| 1981 | 3 | 12 | | | 3 | 12 | 4.0 | | | | | | |
| 1982 | 5 | 14 | | | 5 | 14 | 2.7 | | | | | | |
| 1983 | 2 | 31 | | | | | | 2 | 31 | 15.5 | | | |
| 1984 | 1 | 3 | | | 1 | 3 | 3.0 | | | | | | |
| 1985 | 2 | 43 | 351133870 | 0.12 | 1 | 3 | 3.0 | 1 | 40 | 40.0 | | | |
| 1986 | 2 | 5 | 356398376 | 0.01 | 2 | 5 | 2.5 | | | | | | |
| 1987 | 3 | 6 | 328243087 | 0.02 | 3 | 6 | 2.0 | | | | | | |
| 1988 | 5 | 73 | 301704812 | 0.24 | 4 | 18 | 4.5 | 1 | 55 | 55.0 | | | |
| 1989 | 2 | 18 | 281160011 | 0.06 | 1 | 6 | 6.0 | 1 | 12 | 12.0 | | | |
| 1990 | 0 | 0 | 274955773 | 0.00 | | | | | | | | | |
| 1991 | 0 | 0 | 295129769 | 0.00 | | | | | | | | | |
| 1992 | 3 | 74 | 305282682 | 0.24 | 1 | 8 | 8.0 | 2 | 66 | 33.0 | | | |
| 1993 | 0 | 0 | 309229380 | 0.00 | | | | | | | | | |
| 1994 | 2 | 6 | 314743342 | 0.02 | 2 | 6 | 3.0 | | | | | | |
| 1995 | 1 | 1 | 345525211 | 0.00 | 1 | 1 | 1.0 | | | | | | |
| 1996 | 2 | 3 | 369309647 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1997 | 0 | 0 | 411795024 | 0.00 | | | | | | | | | |
| 1998 | 0 | 0 | 444466377 | 0.00 | | | | | | | | | |
| 1999 | 0 | 0 | | | | | | | | | | | |
| **TOTAL** | **35** | **295** | **4.69E+09** | **4.88E-02** | **28** | **91** | **3** | **7** | **204** | **29** | **0** | **0** | **0** |

**Jacket - Well Systems (Subsea)**

| | |
|---|---|
| **Exposure (bbl produced)** | **8.89E+07** |

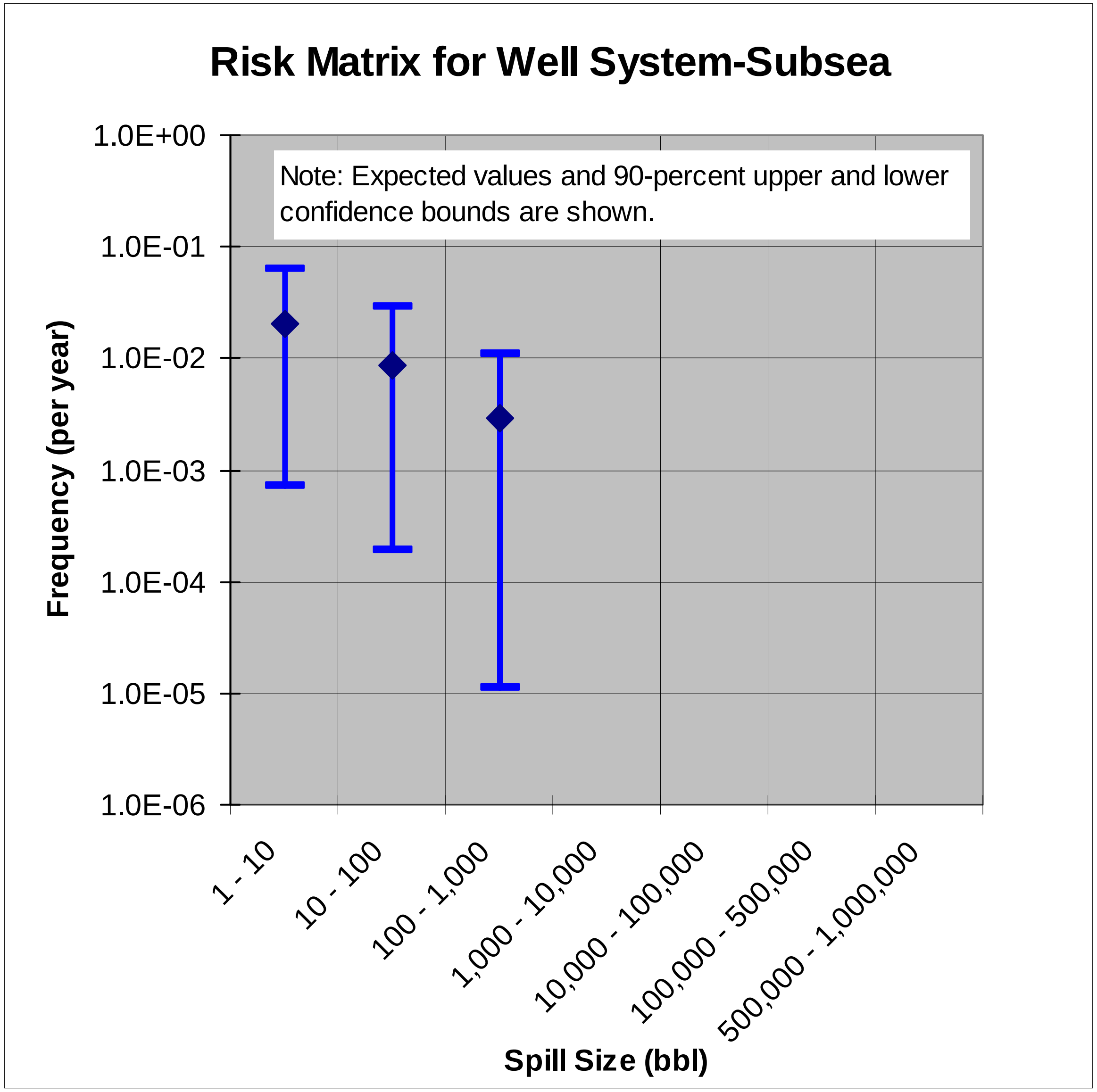
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 4.6E-09 | 1.07 | 2.0E+00 | 1.00 | 2.3E-09 | 0.38 |
| 10 - 100 | 32 | 2.0E-09 | 1.15 | 2.0E+00 | 1.00 | 9.8E-10 | 0.58 |
| 100 - 1,000 | 320 | 6.5E-10 | 1.41 | 2.0E+00 | 1.00 | 3.3E-10 | 1.00 |
| 1,000 - 10,000 | 3200 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **2.5E+01** |
| **Std. Dev. in Total (bbl)** | **2.7E+01** |

| | |
|---|---|
| **Expected Max (bbl)** | **2.4E+01** |
| **Std. Dev. in Max (bbl)** | **2.5E+01** |




F.115 – Oil Spill Risk Assessment for Hub/Host Jacket

**Basis:**

Reported incidents of oil spills from "well and header systems" in the Gulf of Mexico were taken from the MMS pipeline and platform spill database (provided by Cheryl Anderson of MMS) for the years 1980 to 1999. The data are summarized below. Use only data from 1990 to present to account for changes in operating procedures due to implementation of API RP14C.

Equipment includes subsurface safety valves, wellhead assemblies, chokes, jumpers and injection lines, pressure sensors, surface safety valves, header valves and check valves.

Assume risk is proportional to the volume of production - total production data are available for GOM from 1985-1998.

| Total Production bbls in GOM Data: | |
|---|---|
| Expected Value (bbl) | 3.1E+09 |
| Coefficient of Uncertainty | 0 |
| Standard Deviation (bbl) | 0 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per bbl) | k" | n" (bbl) | Expected Value (/bbl) | Std. Dev. (/bbl) | Coefficient of Uncertainty |
| 1 - 10 | 6 | 2.0E-09 | 7 | 3.1E+09 | 2.3E-09 | 8.6E-10 | 0.377964473 |
| 10 - 100 | 2 | 6.5E-10 | 3 | 3.1E+09 | 9.8E-10 | 5.6E-10 | 0.577350269 |
| 100 - 1,000 | 0 | 0.0E+00 | 1 | 3.1E+09 | 3.3E-10 | 3.3E-10 | 1 |
| 1,000 - 10,000 | 0 | 0.0E+00 | | | | | |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Double expected frequency for leaks to account for greater potential for sand erosion and cutouts due to high flow rates and detection difficulties for sand.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since wells in database are mostly platform wells and not subsea wells.

Exposure for Study System:

**Subsea Well Production (bbl)** **8.89E+07**

**Spills from Well and Header Systems in the GoM**
**(Source: MMS - TIMS Database)**

| | | | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Total Production (bbl)** | **Barrels Spilled per 1E6 Bbl Produced** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1980 | 2 | 7 | | | 2 | 7 | 3.4 | | | | | | |
| 1981 | 3 | 12 | | | 3 | 12 | 4.0 | | | | | | |
| 1982 | 5 | 14 | | | 5 | 14 | 2.7 | | | | | | |
| 1983 | 2 | 31 | | | | | | 2 | 31 | 15.5 | | | |
| 1984 | 1 | 3 | | | 1 | 3 | 3.0 | | | | | | |
| 1985 | 2 | 43 | 351133870 | 0.12 | 1 | 3 | 3.0 | 1 | 40 | 40.0 | | | |
| 1986 | 2 | 5 | 356398376 | 0.01 | 2 | 5 | 2.5 | | | | | | |
| 1987 | 3 | 6 | 328243087 | 0.02 | 3 | 6 | 2.0 | | | | | | |
| 1988 | 5 | 73 | 301704812 | 0.24 | 4 | 18 | 4.5 | 1 | 55 | 55.0 | | | |
| 1989 | 2 | 18 | 281160011 | 0.06 | 1 | 6 | 6.0 | 1 | 12 | 12.0 | | | |
| 1990 | 0 | 0 | 274955773 | 0.00 | | | | | | | | | |
| 1991 | 0 | 0 | 295129769 | 0.00 | | | | | | | | | |
| 1992 | 3 | 74 | 305282682 | 0.24 | 1 | 8 | 8.0 | 2 | 66 | 33.0 | | | |
| 1993 | 0 | 0 | 309229380 | 0.00 | | | | | | | | | |
| 1994 | 2 | 6 | 314743342 | 0.02 | 2 | 6 | 3.0 | | | | | | |
| 1995 | 1 | 1 | 345525211 | 0.00 | 1 | 1 | 1.0 | | | | | | |
| 1996 | 2 | 3 | 369309647 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1997 | 0 | 0 | 411795024 | 0.00 | | | | | | | | | |
| 1998 | 0 | 0 | 444466377 | 0.00 | | | | | | | | | |
| 1999 | 0 | 0 | | | | | | | | | | | |
| **TOTAL** | **35** | **295** | **4.69E+09** | **4.88E-02** | **28** | **91** | **3** | **7** | **204** | **29** | **0** | **0** | **0** |

**Jacket - Flowlines**

| | |
|---|---|
| **Exposure (mile-years)** | **240** |

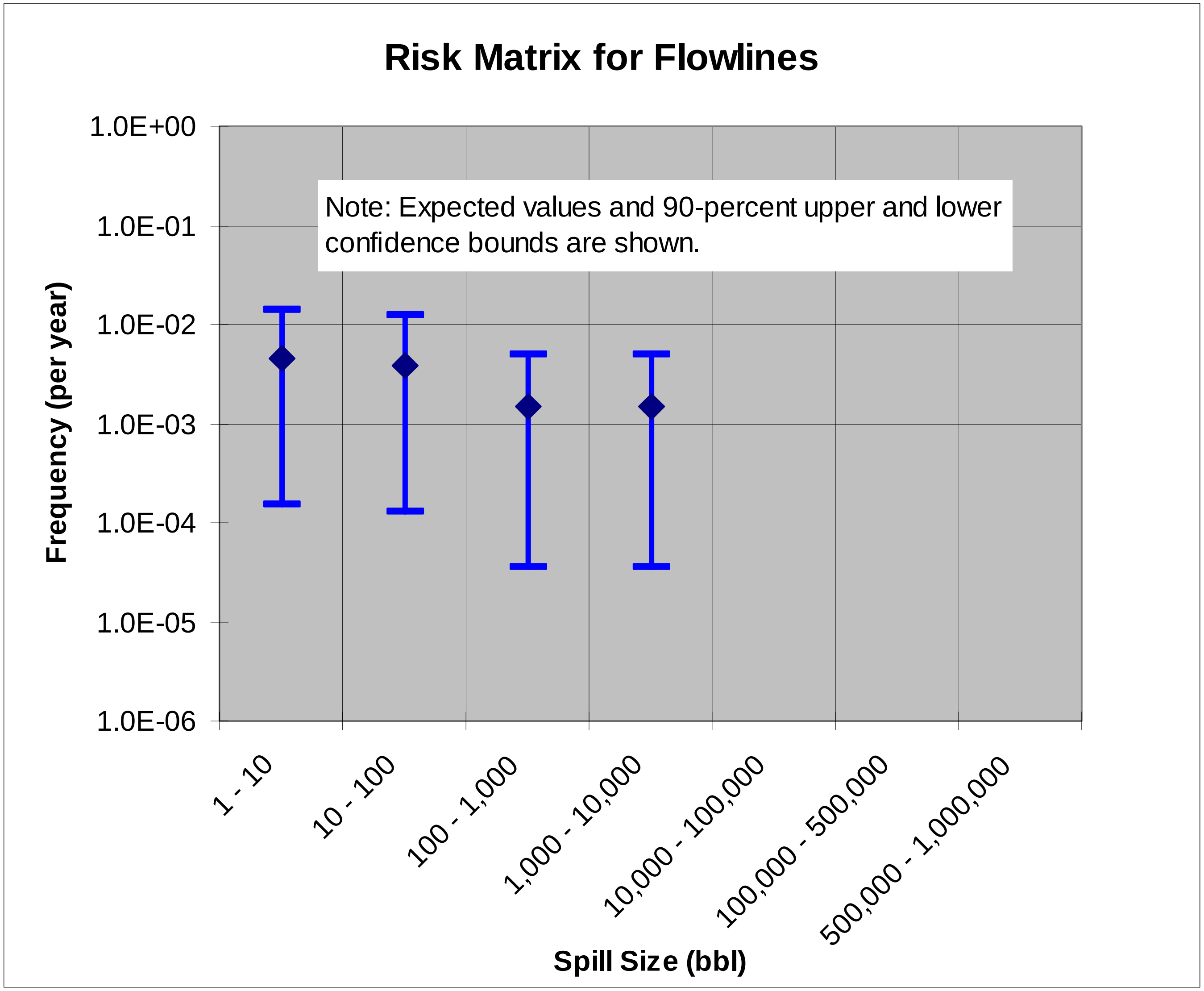
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per mile-year)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per mile-year)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 3.7E-04 | 1.08 | 1.0E+00 | 1.00 | 3.7E-04 | 4.0E-01 |
| 10 - 100 | 32 | 3.2E-04 | 1.08 | 1.0E+00 | 1.00 | 3.2E-04 | 4.1E-01 |
| 100 - 1,000 | 320 | 1.2E-04 | 1.14 | 1.0E+00 | 1.00 | 1.2E-04 | 5.5E-01 |
| 1,000 - 10,000 | 3200 | 1.2E-04 | 1.14 | 1.0E+00 | 1.00 | 1.2E-04 | 5.5E-01 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 2.5E-05 | 1.1E+00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.0E+00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.0E+00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **1.1E+02** |
| **Std. Dev. in Total (bbl)** | **1.1E+02** |

| | |
|---|---|
| **Expected Max (bbl)** | **1.1E+02** |
| **Std. Dev. in Max (bbl)** | **1.1E+02** |




F.119 – Oil Spill Risk Assessment for Hub/Host Jacket

**Basis:**

Reported incidents of oil pipeline leaks in the Gulf of Mexico were taken from the USCG spill database for the years 1992 to 1998. The data are summarized below.

Total Pipeline Miles in GOM federal and state waters estimated from MMS and Lousiana data making the following assumptions:
Federal Waters Sum: Include "unknown" mileage in all years
State Waters Sum: Start with 2,500 miles from Mariano Hinojosa (Louisiana) in 2000; Maintain constant State/Federal Percentage for Earlier Years
Percent Inactive: Assume 17 percent today, 0 percent in 1948 and increase it linearly with time
Total Active: Reduce both federal and state together with same percentage inactive
Total Active Liquid: Assume 30 percent of pipeline length is liquid versus gas (NRC Marine Board Study 1994)
Result - 44,715 mile-years from 1992 to 1998
As a check, Marine Board Study in 1994 reported 17,000 total miles with 30 % oil/condensate, giving 5,100 miles for 7 years or 35,700 mile-years.

Total Mile Years in Data:

| | |
|---|---|
| Expected Value | 44715 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 14756 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per mile-yr) | k" | n" (mile-yr) | Expected Value (per mile-yr) | Std. Dev. (per mile-yr) | c.o.v. |
| 1 - 10 | 14 | 3.1E-04 | 15 | 44715 | 3.7E-04 | 1.5E-04 | 0.40 |
| 10 - 100 | 12 | 2.7E-04 | 13 | 44715 | 3.2E-04 | 1.3E-04 | 0.41 |
| 100 - 1,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 1,000 - 10,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 10,000 - 100,000 | 0 | 0.0E+00 | 1 | 44715 | 2.5E-05 | 2.7E-05 | 1.08 |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because flowliness for study systems will be similar to pipelines in database, although they will be in deeper water than average pipelines in database.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since most of the pipelines in the historical database are in shallower water than the flowlines for the study system. The deepwater effect may lead to a reduction in the frequency of spills (fewer anchor drags and dropped objects), but the difference was not considered to be significant enough (an EQE 1998 study estimated the frequency of spills for deepwater segments of pipeline would be approximately 70-percent of that for shallow water pipeline segments) to be reflected in the expected bias.
- Limit maximum possible spill size per incident to 10,000 bbl because (1) flowline inventory is small (< 10,000 bbl total in parallel lines) and (2) safety systems should shut production in within 45 minutes of a leak occurring (5 hours at 2,000 bbl/hr total in both lines gives 10,000 bbl).

Study System Exposure:

| | |
|---|---|
| Length per Line (miles) | 10 |
| Number of Lines | 2 |
| Service Life (yrs) | 12 |
| **Exposure (mile-years)** | **240** |

## Spills from Pipelines in the GoM and its Waterways
## (Source: USCG - Marine Casuality and Pollution Database with input from MMS)

| | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1992 | 10 | 3055 | 3 | 10 | 3.3 | 4 | 123 | 30.8 | 2 | 922 | 461.0 | 1 | 2000 | 2000.0 |
| 1993 | 2 | 5 | 2 | 5 | 2.5 | | | | | | | | | |
| 1994 | 2 | 4554 | | | | 1 | 10 | 10.0 | | | | 1 | 4544 | 4544.0 |
| 1995 | 5 | 32 | 3 | 8 | 2.7 | 2 | 24 | 12.0 | | | | | | |
| 1996 | 2 | 28 | 1 | 2 | 2.0 | 1 | 26 | 26.0 | | | | | | |
| 1997 | 5 | 223 | 2 | 9 | 4.5 | 2 | 51 | 25.5 | 1 | 163 | 163.0 | | | |
| 1998 | 8 | 10214 | 3 | 9 | 3.0 | 2 | 39 | 19.5 | 1 | 743 | 743.0 | 2 | 9423 | 4711.5 |
| **TOTAL** | **34** | **18111** | **14** | **43** | **3.1** | **12** | **273** | **22.8** | **4** | **1828** | **457.0** | **4** | **15967** | **3991.8** |

**Jacket - Topsides**

| | |
|---|---|
| **Exposure (bbl produced)** | **1.86E+08** |

**Input Information**

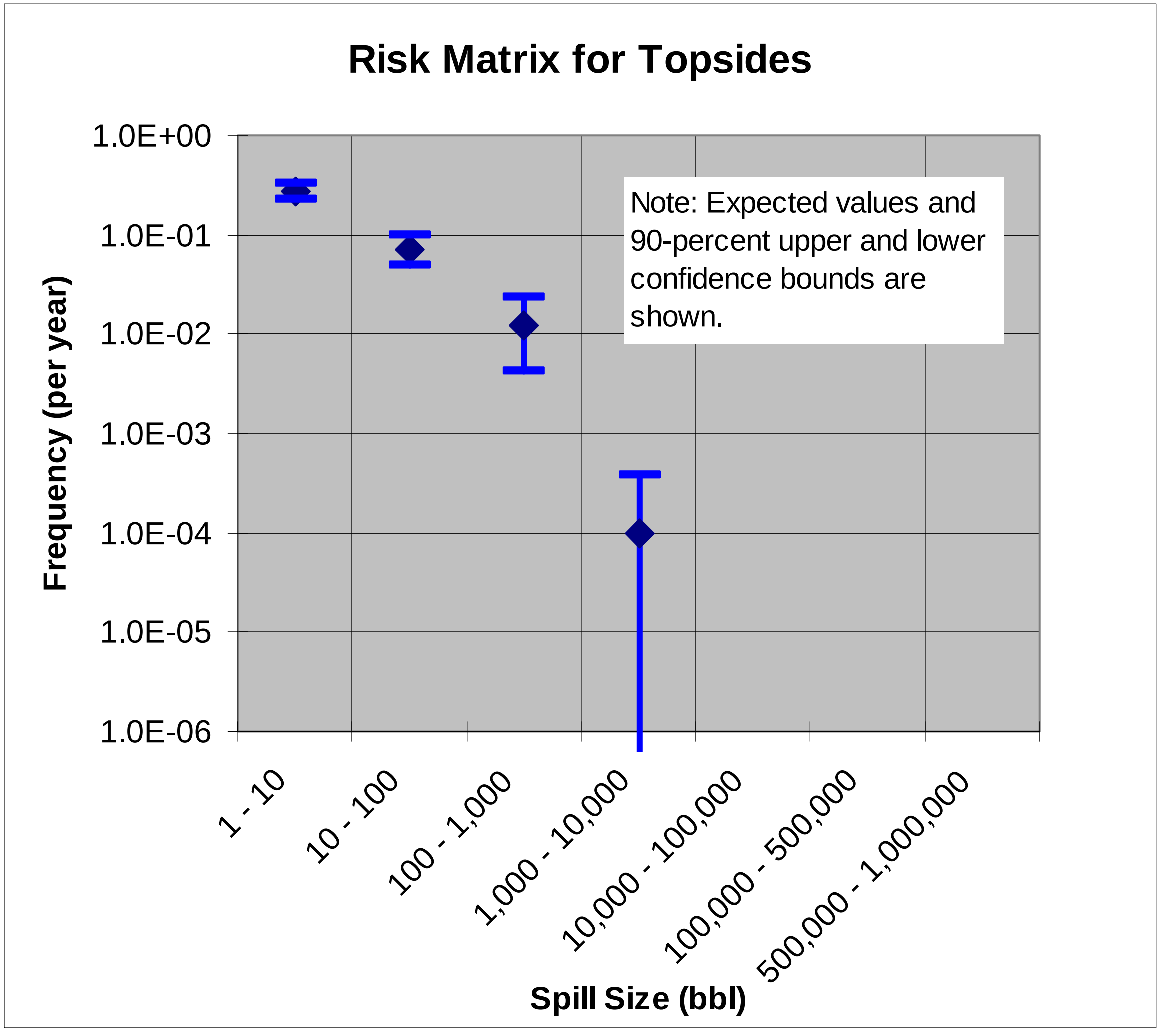
| Spill Size Range (bbl) | Spill Size (bbl) | Combined (Expert+Data) Estimate: Expected Frequency (per bbl) | Combined (Expert+Data) Estimate: Coefficient of Uncertainty for Frequency | Expert-Based Extrapolation Bias: Expected Bias | Expert-Based Extrapolation Bias: Coefficient of Uncertainty for Bias | Data-Based Estimate: Expected Frequency (per bbl) | Data-Based Estimate: Coefficient of Uncertainty for Frequency |
|---|---|---|---|---|---|---|---|
| 1 - 10 | 3 | 3.0E-08 | 0.10 | 1.0E+00 | 0.00 | 3.0E-08 | 0.10 |
| 10 - 100 | 32 | 7.8E-09 | 0.20 | 1.0E+00 | 0.00 | 7.8E-09 | 0.20 |
| 100 - 1,000 | 320 | 1.3E-09 | 0.50 | 1.0E+00 | 0.00 | 1.3E-09 | 0.50 |
| 1,000 - 10,000 | 3200 | 1.1E-11 | 1.41 | 3.3E-02 | 1.00 | 3.3E-10 | 1.00 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **1.5E+02** |
| **Std. Dev. in Total (bbl)** | **4.1E+01** |

| | |
|---|---|
| **Expected Max (bbl)** | **9.5E+01** |
| **Std. Dev. in Max (bbl)** | **3.2E+01** |

F.122 – Oil Spill Risk Assessment for Hub/Host Jacket




F.123 – Oil Spill Risk Assessment for Hub/Host Jacket

**Basis:**

Reported incidents of oil spills from "platforms" in the Gulf of Mexico were taken from the MMS pipeline and platform spill database (provided by Cheryl Anderson of MMS) for the years 1980 to 1999. The data are summarized below. Use only data from 1990 to present to account for changes in operating procedures due to implementation of API RP14C.

Process equipment included in data: separators, flare line systems, heaters/treaters, sump systems, pumps, storage tanks, compressors, pig launchers, valves and piping.

Substances included in spill data: oil, condensate, fuel, glycol.

Incidents involving supply vessels and barges (e.g., transfer of fluids to/from a vessel) have been filtered out and are not included in this analysis. The USCG data base is considered to be a more comprehensive source of information about these incidents and activities (included in Supply Vessels worksheet).

Assume risk is proportional to the volume of production - total production data are available for GOM from 1985-1998.

| Total GOM Production bbls in Data: | |
|---|---|
| Expected Value (bbl) | 3.1E+09 |
| Coefficient of Uncertainty | 0 |
| Standard Deviation (bbl) | 0 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per bbl) | k" | n" (bbl) | Expected Value (/bbl) | Std. Dev. (/bbl) | Coefficient of Uncertainty |
| 1 - 10 | 90 | 2.9E-08 | 91 | 3.1E+09 | 3.0E-08 | 3.1E-09 | 0.105 |
| 10 - 100 | 23 | 7.5E-09 | 24 | 3.1E+09 | 7.8E-09 | 1.6E-09 | 0.204 |
| 100 - 1,000 | 3 | 9.8E-10 | 4 | 3.1E+09 | 1.3E-09 | 6.5E-10 | 0.500 |
| 1,000 - 10,000 | 0 | 0.0E+00 | 1 | 3.1E+09 | 3.3E-10 | 3.3E-10 | 1.000 |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias for spills less than 1,000 bbl because estimated frequencies are for similar types of process systems. Reduce spill frequency for the 1,000 to 10,000 bbl category to $1.0\text{x}10^{-4}$ per year to account for the inventory spilled in a total structural failure.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the data for the 1,000 to 10,000 bbl category because there are no actual occurrences of this type of an event in the data record for any platforms including deepwater floating production systems.

| Exposure for Study System: | |
|---|---|
| Production from Platform Wells (bbl) | 6.09E+07 |
| Production from Subsea Wells (bbl) | 8.89E+07 |
| 2.5% Transhipped Volume (bbl) | 3.65E+07 |
| **Total Production (bbl)** | **1.86E+08** |

**Spills from Oil/Gas Process Activities in the GoM**
**(Source: MMS - TIMS Database)**

| | | | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | | 10,000 - 100,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Total Production (bbl) | Barrels Spilled per 1E6 bbl Produced | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1980 | 27 | 1678 | | | 23 | 73 | 3.2 | 3 | 149 | 49.7 | | | | 1 | 1456 | 1456.0 | | | |
| 1981 | 21 | 135 | | | 19 | 62 | 3.3 | 2 | 73 | 36.5 | | | | | | | | | |
| 1982 | 26 | 79 | | | 25 | 67 | 2.7 | 1 | 12 | 12.0 | | | | | | | | | |
| 1983 | 48 | 280 | | | 43 | 127 | 3.0 | 5 | 153 | 30.6 | | | | | | | | | |
| 1984 | 39 | 172 | | | 38 | 122 | 3.2 | 1 | 50 | 50.0 | | | | | | | | | |
| 1985 | 34 | 141 | 351133870 | 0.40 | 32 | 100 | 3.1 | 2 | 41 | 20.5 | | | | | | | | | |
| 1986 | 24 | 75 | 356398376 | 0.21 | 24 | 75 | 3.1 | | | | | | | | | | | | |
| 1987 | 19 | 84 | 328243087 | 0.26 | 17 | 49 | 2.9 | 2 | 35 | 17.5 | | | | | | | | | |
| 1988 | 12 | 103 | 301704812 | 0.34 | 10 | 33 | 3.3 | 2 | 70 | 35.0 | | | | | | | | | |
| 1989 | 12 | 355 | 281160011 | 1.26 | 10 | 44 | 4.4 | 1 | 11 | 11.0 | 1 | 300 | 300.0 | | | | | | |
| 1990 | 15 | 91 | 274955773 | 0.33 | 13 | 47 | 3.6 | 2 | 44 | 22.0 | | | | | | | | | |
| 1991 | 11 | 477 | 295129769 | 1.62 | 7 | 33 | 4.7 | 3 | 94 | 31.3 | 1 | 350 | 350.0 | | | | | | |
| 1992 | 9 | 32 | 305282682 | 0.10 | 9 | 32 | 3.6 | | | | | | | | | | | | |
| 1993 | 9 | 42 | 309229380 | 0.14 | 8 | 23 | 2.9 | 1 | 19 | 19.0 | | | | | | | | | |
| 1994 | 6 | 16 | 314743342 | 0.05 | 6 | 16 | 2.7 | | | | | | | | | | | | |
| 1995 | 16 | 594 | 345525211 | 1.72 | 11 | 41 | 3.7 | 4 | 118 | 29.5 | 1 | 435 | 435.0 | | | | | | |
| 1996 | 21 | 271 | 369309647 | 0.73 | 15 | 52 | 3.5 | 6 | 219 | 36.5 | | | | | | | | | |
| 1997 | 13 | 260 | 411795024 | 0.63 | 10 | 33 | 3.3 | 2 | 57 | 28.5 | 1 | 170 | 170.0 | | | | | | |
| 1998 | 16 | 314 | 444466377 | 0.71 | 11 | 35 | 3.2 | 5 | 279 | 55.8 | | | | | | | | | |
| 1999 | 10 | 78 | | | 7 | 25 | 3.6 | 3 | 53 | 17.7 | | | | | | | | | |
| **TOTAL** | **388** | **5277** | **4.69E+09** | **6.09E-01** | **338** | **1089** | **3** | **45** | **1477** | **33** | **4** | **1255** | **314** | **1** | **1456** | **1456** | **0** | **0** | **0** |

**Jacket - Pipelines**

| Exposure (mile-years) | 2000 |
|---|---|

**Input Information**

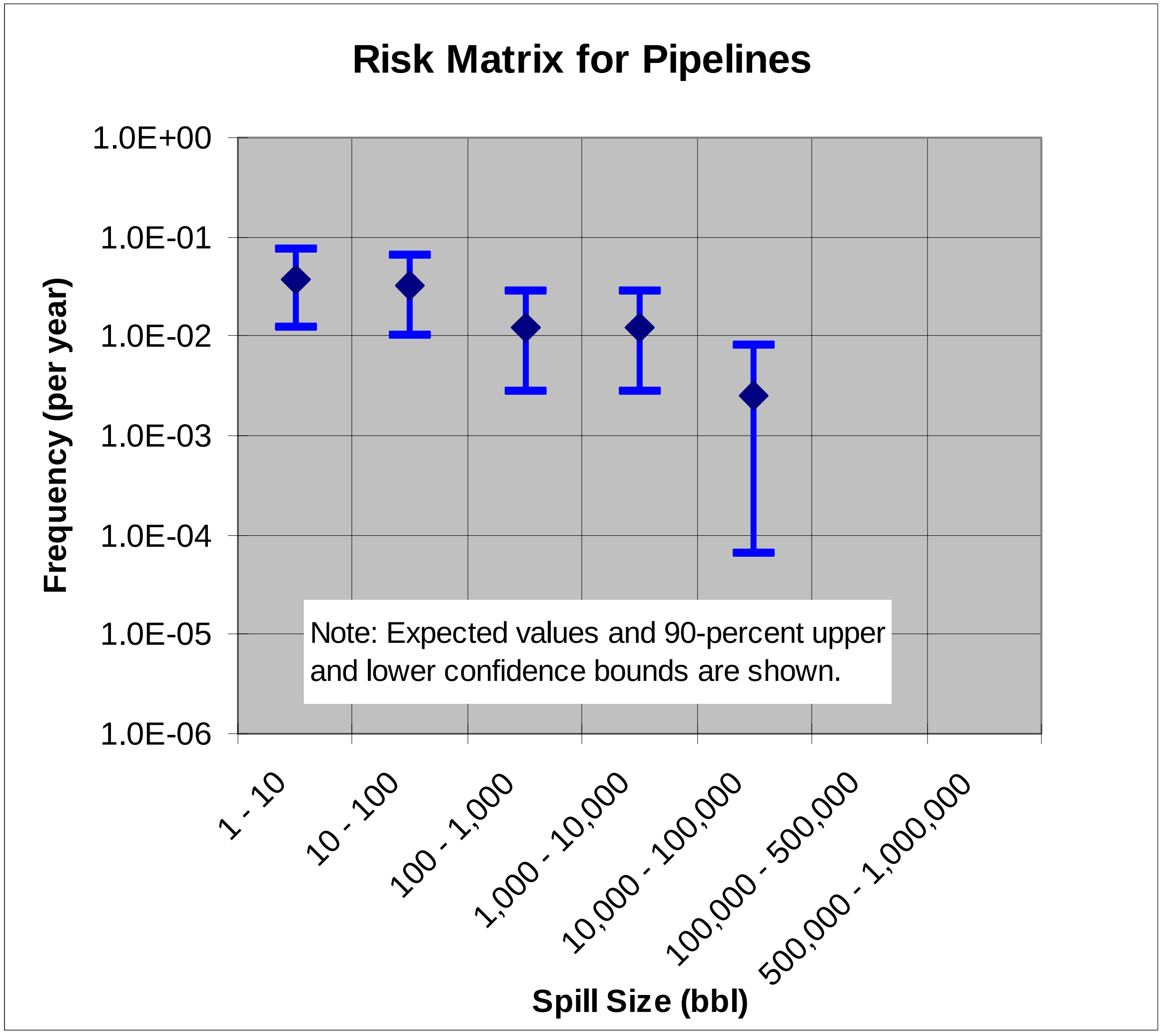
| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Spill Size (bbl) | Expected Frequency (per mile-year) | Coefficient of Uncertainty for Frequency | Expected Bias | Coefficient of Uncertainty for Bias | Expected Frequency (per mile-year) | Coefficient of Uncertainty for Frequency |
| 1 - 10 | 3 | 3.7E-04 | 0.52 | 1.0E+00 | 0.33 | 3.7E-04 | 0.40 |
| 10 - 100 | 32 | 3.2E-04 | 0.53 | 1.0E+00 | 0.33 | 3.2E-04 | 0.41 |
| 100 - 1,000 | 320 | 1.2E-04 | 0.64 | 1.0E+00 | 0.33 | 1.2E-04 | 0.55 |
| 1,000 - 10,000 | 3200 | 1.2E-04 | 0.64 | 1.0E+00 | 0.33 | 1.2E-04 | 0.55 |
| 10,000 - 100,000 | 21000 | 2.5E-05 | 1.13 | 1.0E+00 | 0.33 | 2.5E-05 | 1.08 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| Expected Total (bbl) | 1.9E+03 |
|---|---|
| Std. Dev. in Total (bbl) | 1.3E+03 |

| Expected Max (bbl) | 1.7E+03 |
|---|---|
| Std. Dev. in Max (bbl) | 1.2E+03 |

F.126 – Oil Spill Risk Assessment for Hub/Host Jacket




F.127 – Oil Spill Risk Assessment for Hub/Host Jacket

**Basis:**

Reported incidents of oil pipeline leaks in the Gulf of Mexico were taken from the USCG spill database for the years 1992 to 1998. The data are summarized below.

Total Pipeline Miles in GOM federal and state waters estimated from MMS and Lousiana data making the following assumptions:
Federal Waters Sum: Include "unknown" mileage in all years
State Waters Sum: Start with 2,500 miles from Mariano Hinojosa (Louisiana) in 2000; Maintain constant State/Federal Percentage for Earlier Years
Percent Inactive: Assume 17 percent today, 0 percent in 1948 and increase it linearly with time
Total Active: Reduce both federal and state together with same percentage inactive
Total Active Liquid: Assume 30 percent of pipeline length is liquid versus gas (NRC Marine Board Study 1994)
Result - 44,715 mile-years from 1992 to 1998
As a check, Marine Board Study in 1994 reported 17,000 total miles with 30 % oil/condensate, giving 5,100 miles for 7 years or 35,700 mile-years.

Total Mile Years in Data:

| | |
|---|---|
| Expected Value | 44715 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 14756 |

| Spill Size Range (bbl) | Count | Frequency (per mile-yr) | Statistically Estimated Frequency (no prior information) k" | n" (mile-yr) | Expected Value (per mile-yr) | Std. Dev. (per mile-yr) | c.o.v. |
|---|---|---|---|---|---|---|---|
| 1 - 10 | 14 | 3.1E-04 | 15 | 44715 | 3.7E-04 | 1.5E-04 | 0.40 |
| 10 - 100 | 12 | 2.7E-04 | 13 | 44715 | 3.2E-04 | 1.3E-04 | 0.41 |
| 100 - 1,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 1,000 - 10,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 10,000 - 100,000 | 0 | 0.0E+00 | 1 | 44715 | 2.5E-05 | 2.7E-05 | 1.08 |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because pipelines for study systems will be similar to pipelines in database, although they will be in deeper water on average.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data since most of the pipelines in the historical database are in shallower water on average than the pipeline for the study system. The deepwater effect may lead to a reduction in the frequency of spills (fewer anchor drags and dropped objects), but the difference was not considered to be significant enough (an EQE 1998 study estimated the frequency of spills for deepwater segments of pipeline would be approximately 70-percent of that for shallow water pipeline segments) to be reflected in the expected bias.
- Limit maximum possible spill size to 100,000 bbl and use a triangular probability distribution (decreasing with increasing size) in the 10,000 to 100,000 bbl category because (1) hydrostatic pressures in deeper water and “P-traps” due to bottom contours limit the volume of inventory that can leak and (2) it is not credible that pumping from the jacket would continue for more than several hours after a leak occurs (6,200 bbl/hr production rate) due to detection systems and operational requirements. Therefore, the representative spill-size for the largest category (10,000 to 100,000 bbls) is obtained by assuming that the logarithm of the spill size has a triangular distribution (versus a uniform distribution) with the maximum likelihood at 10,000 bbls and the minimum likelihood at 100,000 bbls, giving a representative value of 21,000 bbls. (Note that this same approach is used for the largest spill-size category for FPSO shuttle tankers.)

Exposure for Study System (mile-years):

| | |
|---|---|
| to Shore from Hub (miles) | 80 |
| to Terminal from Shore (miles) | 20 |
| Total Length (miles) | 100 |
| **Mile Years (20 years)** | **2000** |

| Spills from Pipelines in the GoM and its Waterways<br>(Source: USCG - Marine Casuality and Pollution Database with input from MMS) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | |
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1992 | 10 | 3055 | 3 | 10 | 3.3 | 4 | 123 | 30.8 | 2 | 922 | 461.0 | 1 | 2000 | 2000.0 |
| 1993 | 2 | 5 | 2 | 5 | 2.5 | | | | | | | | | |
| 1994 | 2 | 4554 | | | | 1 | 10 | 10.0 | | | | 1 | 4544 | 4544.0 |
| 1995 | 5 | 32 | 3 | 8 | 2.7 | 2 | 24 | 12.0 | | | | | | |
| 1996 | 2 | 28 | 1 | 2 | 2.0 | 1 | 26 | 26.0 | | | | | | |
| 1997 | 5 | 223 | 2 | 9 | 4.5 | 2 | 51 | 25.5 | 1 | 163 | 163.0 | | | |
| 1998 | 8 | 10214 | 3 | 9 | 3.0 | 2 | 39 | 19.5 | 1 | 743 | 743.0 | 2 | 9423 | 4711.5 |
| **TOTAL** | **34** | **18111** | **14** | **43** | **3.1** | **12** | **273** | **22.8** | **4** | **1828** | **457.0** | **4** | **15967** | **3991.8** |

**Jacket - Supply Vessels**

| Exposure (docking calls) | 12287 |
|---|---|

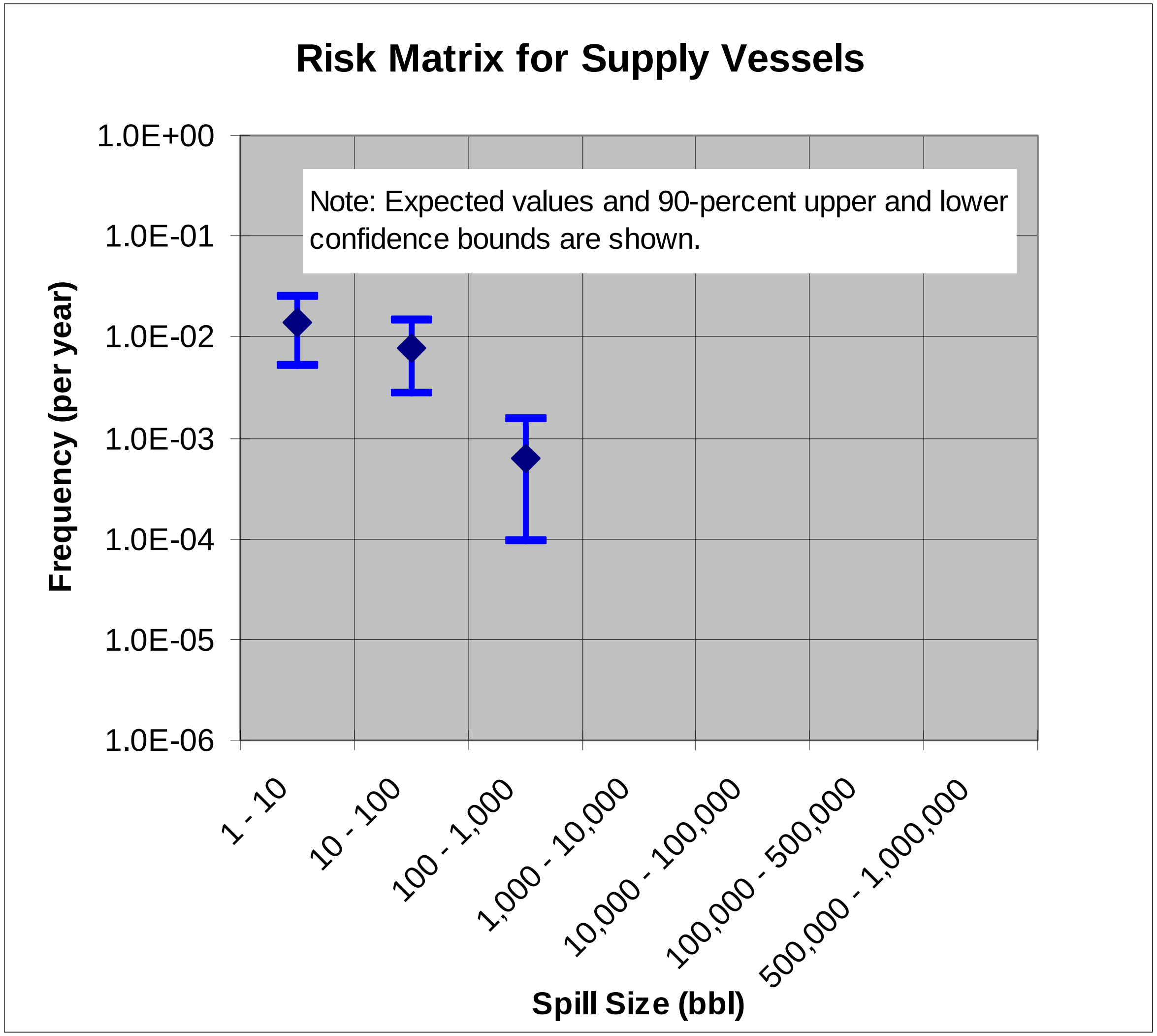
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Spill Size (bbl) | Expected Frequency (per call) | Coefficient of Uncertainty for Frequency | Expected Bias | Coefficient of Uncertainty for Bias | Expected Frequency (per call) | Coefficient of Uncertainty for Frequency |
| 1 - 10 | 3 | 2.2E-05 | 0.46 | 1.0E+00 | 0.33 | 2.2E-05 | 0.32 |
| 10 - 100 | 32 | 1.2E-05 | 0.48 | 1.0E+00 | 0.33 | 1.2E-05 | 0.34 |
| 100 - 1,000 | 320 | 1.0E-06 | 0.75 | 1.0E+00 | 0.33 | 1.0E-06 | 0.67 |
| 1,000 - 10,000 | 3200 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 3.4E-07 | 1.08 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| Expected Total (bbl) | 9.7E+00 |
|---|---|
| Std. Dev. in Total (bbl) | 3.8E+00 |

| Expected Max (bbl) | 9.1E+00 |
|---|---|
| Std. Dev. in Max (bbl) | 3.5E+00 |




F.131 – Oil Spill Risk Assessment for Hub/Host Jacket

**Basis:**

Risk of a spill from a supply vessel is assumed to be proportional to the number of docking or port calls (in field and at the terminal) because this is where most spills occur due to the number of operations (including offloading) and difficulties in navigation (traffic and shore).

The USCG database of spills from offshore supply vessels (OSVs) was used to estimate the frequency of different spill sizes. Data from the years 1985-1999 were used in this analysis.

The data base was searched for petroleum spills from supply vessels. Substances considered included crude, fuel, diesel, lubricating oil and drilling mud.

Incidents were included from the following locations to represent the "Gulf of Mexico": Gulf of Mexico, Sabine/Neches River, Corpus Christi Ship Channel and Harbor, Galveston Bay, Houston Ship Channel, Lower and Upper Mississippi River, and Intercoastal Waterway - Gulf.

The database includes incidents related to vessel transit and docking calls at platorms and ports. A rough picture of supply vessel activity in the GOM (based on discussions with Edison Chouest): 300 boats making an average of 2 dock calls per day = 300x2x365 = 219,000 docking calls per year.

| Total Docking Calls in Data (15 yrs): | |
|---|---|
| Expected Value | 3285000 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 1084050 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per call) | k" | n" (calls) | Expected Value (/call) | Std. Dev. (/call) | c.o.v. |
| 1 - 10 | 65 | 2.0E-05 | 66 | 3285000 | 2.2E-05 | 7.2E-06 | 0.32 |
| 10 - 100 | 36 | 1.1E-05 | 37 | 3285000 | 1.2E-05 | 4.3E-06 | 0.34 |
| 100 - 1,000 | 2 | 6.1E-07 | 3 | 3285000 | 1.0E-06 | 6.8E-07 | 0.67 |
| 1,000 - 10,000 | 0 | 0.0E+00 | 1 | 3285000 | 3.4E-07 | 3.6E-07 | 1.08 |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data because supply vessels for these systems will be larger and more modern (dynamically-positioned) than the typical vessels that comprise the historical data.
- Limit maximum possible spill size to 1,000 bbl to be consistent with cargo capacity for typical supply vessels (less than 1,000 bbl).

Exposure for Study System:

| | |
|---|---|
| 1 trip per 3 days during production | 0.333333333 |
| Days of Production (20 years) | 7300 |
| Trips | 2433.333333 |
| | |
| 1 trip per 3 days during drilling/workover | 0.333333333 |
| 6 Platform Wells (20 years) | |
| Drilling & Completion (5*90 + 6*20 days) | 570 |
| Slickline (3 per well-year @ 5 days) | 1800 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 |
| Change out (1/3 per well-yr @ 50 days) | 2000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 |
| Trips | 3230 |
| | |
| 3 Subsea Wells (12 years) | |
| Drilling & Completion (3*90 + 90 days) | 360 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 |
| Change out (1/8 per well-yr @ 50 days) | 225 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 |
| Trips | 480 |
| | |
| **Docking calls (trips*2)** | **12287** |

| Spills from OSV Activities in the GoM and its Waterways (Source: USCG - Marine Casuality and Pollution Database) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | | 10,000 - 100,000 bbl | | |
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1985 | 0 | 0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1986 | 7 | 34 | 6 | 17 | 2.8 | 1 | 17 | 17.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1987 | 4 | 42 | 3 | 6 | 2.0 | 1 | 36 | 36.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1988 | 3 | 40 | 2 | 10 | 5.0 | 1 | 30 | 30.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1989 | 5 | 30 | 4 | 9 | 2.3 | 1 | 21 | 21.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1990 | 10 | 78 | 7 | 24 | 3.4 | 3 | 54 | 18.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1991 | 11 | 78 | 9 | 37 | 4.1 | 2 | 41 | 20.5 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1992 | 3 | 39 | 2 | 7 | 3.5 | 1 | 32 | 32.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1993 | 8 | 191 | 3 | 9 | 3.0 | 5 | 182 | 36.4 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1994 | 10 | 21 | 10 | 21 | 2.1 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1995 | 10 | 534 | 3 | 9 | 3.0 | 6 | 211 | 35.2 | 1 | 314 | 314.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1996 | 9 | 161 | 5 | 18 | 3.6 | 4 | 143 | 35.8 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1997 | 10 | 103 | 6 | 26 | 4.3 | 4 | 77 | 19.3 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1998 | 9 | 257 | 4 | 11 | 2.8 | 4 | 116 | 29.0 | 1 | 130 | 130.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1999 | 4 | 193 | 1 | 3 | 3.0 | 3 | 190 | 63.3 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| **TOTAL** | **103** | **1801** | **65** | **207** | **3** | **36** | **1150** | **32** | **2** | **444** | **222** | **0** | **0** | **0** | **0** | **0** | **0** |

**Jacket - Drilling and Intervention**

| Exposure (man-days) | 246912 |
|---|---|

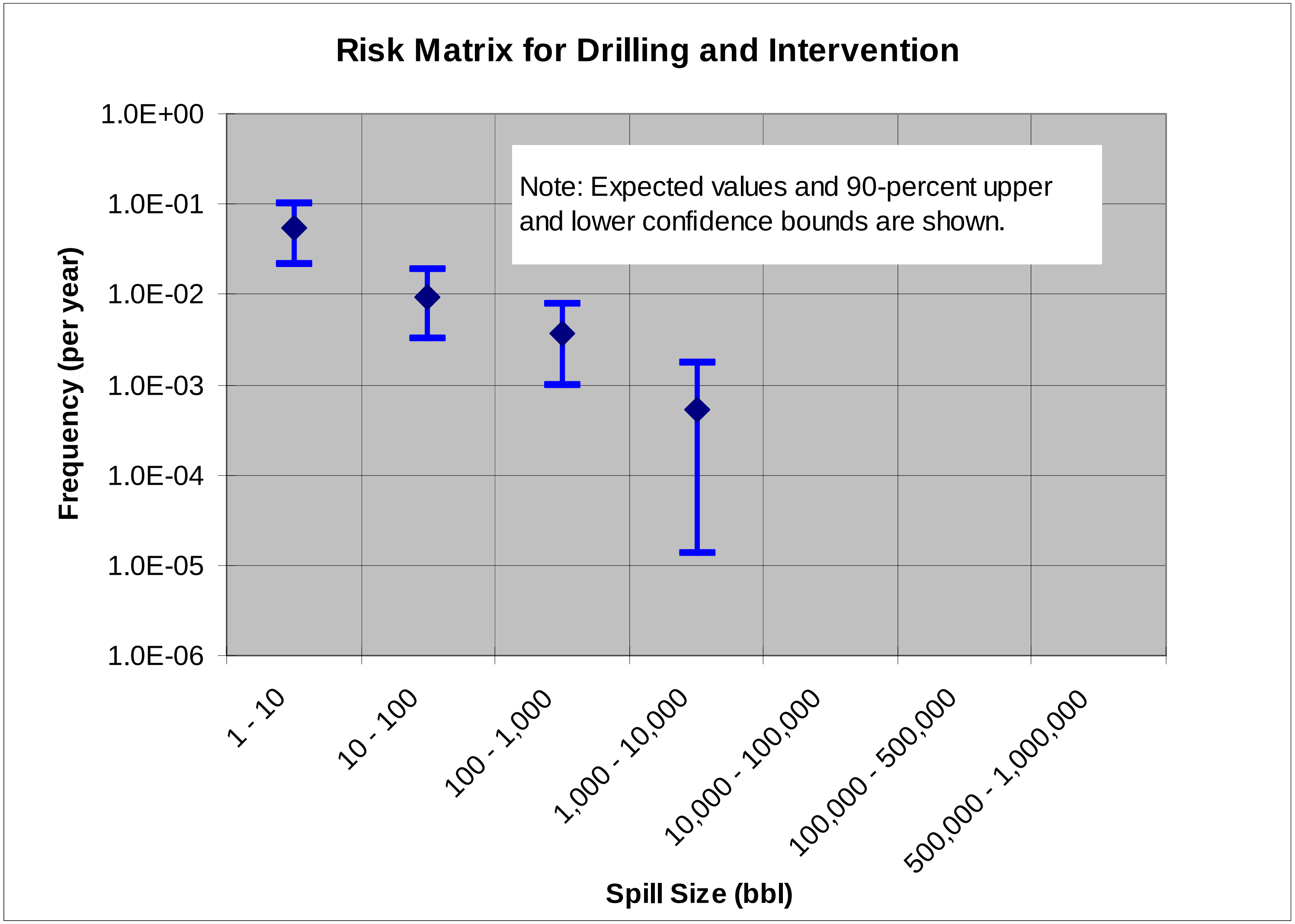
**Input Information**

| Spill Size Range (bbl) | Spill Size (bbl) | Combined (Expert+Data) Estimate: Expected Frequency (per man-day) | Combined (Expert+Data) Estimate: Coefficient of Uncertainty for Frequency | Expert-Based Extrapolation Bias: Expected Bias | Expert-Based Extrapolation Bias: Coefficient of Uncertainty for Bias | Data-Based Estimate: Expected Frequency (per man-day) | Data-Based Estimate: Coefficient of Uncertainty for Frequency |
|---|---|---|---|---|---|---|---|
| 1 - 10 | 3 | 4.4E-06 | 0.46 | 1.0E+00 | 0.33 | 4.4E-06 | 0.31 |
| 10 - 100 | 32 | 7.7E-07 | 0.51 | 1.0E+00 | 0.33 | 7.7E-07 | 0.39 |
| 100 - 1,000 | 320 | 3.0E-07 | 0.59 | 1.0E+00 | 0.33 | 3.0E-07 | 0.49 |
| 1,000 - 10,000 | 3200 | 4.3E-08 | 1.13 | 1.0E+00 | 0.33 | 4.3E-08 | 1.08 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| Expected Total (bbl) | 6.7E+01 |
|---|---|
| Std. Dev. in Total (bbl) | 4.1E+01 |

| Expected Max (bbl) | 6.3E+01 |
|---|---|
| Std. Dev. in Max (bbl) | 4.0E+01 |


Risk Matrix for Drilling and Intervention
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
Frequency (per year)
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Risk of a spill from drilling and well intervention is assumed to be proportional to the number of man-days of operations. This approach means that operations that require a larger crew will have a greater risk of oil spill because more activities and difficulties are involved. It is also used here because information about man-days of drill crew operations in the GOM is available from IADC, an average of 1.3 million man-days per year in the 1990's. One concern is that the IADC information includes activities in state waters while the MMS data may only include OCS waters, therefore the denominator may be overestimated slightly.

The MMS platform data base (1980-1999) was used to identify drilling activity-related incidents. These incidents include exploratory drilling, development drilling and well workovers and completions. Substances reported in the data base include crude, fuel, diesel, drilling fluids and drilling mud. Rig types include both platform and MODU rigs.

| Total man-days in Data (20 yrs): | |
|---|---|
| Expected Value | 26000000 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 8580000 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per man-day) | k" | n" (man-day) | Expected Value (per man-day) | Std. Dev. (per man-day) | c.o.v. |
| 1 - 10 | 103 | 4.0E-06 | 104 | 26000000 | 4.4E-06 | 1.4E-06 | 0.31 |
| 10 - 100 | 17 | 6.5E-07 | 18 | 26000000 | 7.7E-07 | 3.0E-07 | 0.39 |
| 100 - 1,000 | 6 | 2.3E-07 | 7 | 26000000 | 3.0E-07 | 1.5E-07 | 0.49 |
| 1,000 - 10,000 | 0 | 0.0E+00 | 1 | 26000000 | 4.3E-08 | 4.6E-08 | 1.08 |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data because there are relatively few historical data available for deep-water drilling in the Gulf of Mexico (compared to shallow-water drilling).
- Although they have not occurred in the data record, the possiblity for spills larger than 10,000 bbl was evaluated. The estimated frequency was considered to be negligibly small because the reservoir characteristics will be relatively well known since significant exploration and development drilling will have taken place before the production life begins.

Exposure for Study System:

| 6 Platform Wells (20 years) | days | crew | man-days |
|---|---|---|---|
| Drilling & Completion (5*90 + 6*20 days) | 570 | 40 | 22800 |
| Slickline (3 per well-year @ 5 days) | 1800 | 4 | 7200 |
| Coiled Tubing (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Hydraulic (3/4 per well-yr @ 20 days) | 1800 | 8 | 14400 |
| Change out (1/3 per well-yr @ 50 days) | 2000 | 40 | 80000 |
| Recompletion (1/5 per well-yr @ 50 days) | 1200 | 40 | 48000 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 | 40 | 20800 |
| | | | |
| 3 Subsea Wells (12 years) | | | |
| Drilling & Completion (3*90 + 90 days) | 360 | 40 | 14400 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 | 4 | 720 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 | 8 | 1152 |
| Change out (1/8 per well-yr @ 50 days) | 225 | 8 | 1800 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 | 40 | 7200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 | 40 | 6240 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 | 40 | 7800 |
| | | **Total (man-days):** | **246912** |

**Spills from Drilling Activities in the GoM**

**(Source: MMS - TIMS Database)**

| | | | | | <= 10 bbl | | | > 10 bbl & <= 100 bbl | | | 100 - 1,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Total Production** | **Barrels Spilled per 1E6 bbl Produced** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1980 | 8 | 353 | | | 6 | 17 | 2.8 | 1 | 50 | 50.0 | 1 | 286 | 286.0 |
| 1981 | 4 | 253 | | | 1 | 4 | 4.0 | 2 | 39 | 19.5 | 1 | 210 | 210.0 |
| 1982 | 13 | 50 | | | 13 | 50 | 3.8 | | | | | | |
| 1983 | 14 | 77 | | | 13 | 52 | 4.0 | 1 | 25 | 25.0 | | | |
| 1984 | 2 | 6 | | | 2 | 6 | 3.0 | | | | | | |
| 1985 | 13 | 98 | 351133870 | 0.28 | 12 | 48 | 4.0 | 1 | 50 | 50.0 | | | |
| 1986 | 7 | 31 | 356398376 | 0.09 | 7 | 31 | 4.4 | | | | | | |
| 1987 | 10 | 106 | 328243087 | 0.32 | 7 | 18 | 2.6 | 3 | 88 | 29.3 | | | |
| 1988 | 0 | 0 | 301704812 | 0.00 | | | | | | | | | |
| 1989 | 7 | 184 | 281160011 | 0.65 | 4 | 11 | 2.8 | 2 | 56 | 28.0 | 1 | 117 | 117.0 |
| 1990 | 4 | 127 | 274955773 | 0.46 | 3 | 17 | 5.7 | | | | 1 | 110 | 110.0 |
| 1991 | 4 | 14 | 295129769 | 0.05 | 4 | 14 | 3.5 | | | | | | |
| 1992 | 2 | 102 | 305282682 | 0.33 | 1 | 2 | 2.0 | 1 | 100 | 100.0 | | | |
| 1993 | 1 | 3 | 309229380 | 0.01 | 1 | 3 | 3.0 | | | | | | |
| 1994 | 1 | 3 | 314743342 | 0.01 | 1 | 3 | 3.0 | | | | | | |
| 1995 | 4 | 8 | 345525211 | 0.02 | 4 | 8 | 2.0 | | | | | | |
| 1996 | 4 | 19 | 369309647 | 0.05 | 3 | 7 | 2.3 | 1 | 12 | 12.0 | | | |
| 1997 | 2 | 3 | 411795024 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1998 | 5 | 32 | 444466377 | 0.07 | 4 | 11 | 2.8 | 1 | 21 | 21.0 | | | |
| 1999 | 2 | 7 | | | 2 | 7 | 3.5 | | | | | | |
| **TOTAL** | **107** | **1476** | **4.69E+09** | **1.56E-01** | **90** | **312** | **3** | **13** | **441** | **34** | **4** | **723** | **181** |

**Spills from Completion/Workover Activities in the GoM**

**(Source: MMS - TIMS Database)**

| | | | | | <= 10 bbl | | | > 10 bbl & <= 100 bbl | | | >100 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled** | **Total Production** | **Barrels Spilled per 1E6 bbl Produced** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1980 | 0 | 0 | | | | | | | | | | | |
| 1981 | 3 | 68 | | | 2 | 4 | 2.0 | 1 | 64 | 64.0 | | | |
| 1982 | 1 | 3 | | | 1 | 3 | 3.0 | | | | | | |
| 1983 | 1 | 2 | | | 1 | 2 | 2.0 | | | | | | |
| 1984 | 0 | 0 | | | | | | | | | | | |
| 1985 | 1 | 5 | 351133870 | 0.01 | 1 | 5 | 5.0 | | | | | | |
| 1986 | 0 | 0 | 356398376 | 0.00 | | | | | | | | | |
| 1987 | 1 | 3 | 328243087 | 0.01 | 1 | 3 | 3.0 | | | | | | |
| 1988 | 0 | 0 | 301704812 | 0.00 | | | | | | | | | |
| 1989 | 1 | 6 | 281160011 | 0.02 | 1 | 6 | 6.0 | | | | | | |
| 1990 | 1 | 8 | 274955773 | 0.03 | 1 | 8 | 8.0 | | | | | | |
| 1991 | 0 | 0 | 295129769 | 0.00 | | | | | | | | | |
| 1992 | 0 | 0 | 305282682 | 0.00 | | | | | | | | | |
| 1993 | 0 | 0 | 309229380 | 0.00 | | | | | | | | | |
| 1994 | 3 | 172 | 314743342 | 0.55 | 1 | 6 | 6.0 | 1 | 25 | 25.0 | 1 | 141 | 141.0 |
| 1995 | 1 | 4 | 345525211 | 0.01 | 1 | 4 | 4.0 | | | | | | |
| 1996 | 1 | 5 | 369309647 | 0.01 | 1 | 5 | 5.0 | | | | | | |
| 1997 | 2 | 3 | 411795024 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1998 | 3 | 276 | 444466377 | 0.62 | | | | 2 | 106 | 53.0 | 1 | 170 | 170.0 |
| 1999 | 0 | 0 | | | | | | | | | | | |
| **TOTAL** | **19** | **555** | **4.69E+09** | **1.03E-01** | **13** | **49** | **4** | **4** | **195** | **49** | **2** | **311** | **156** |

Appendix F.4

Oil Spill Risk Assessment for FPSO

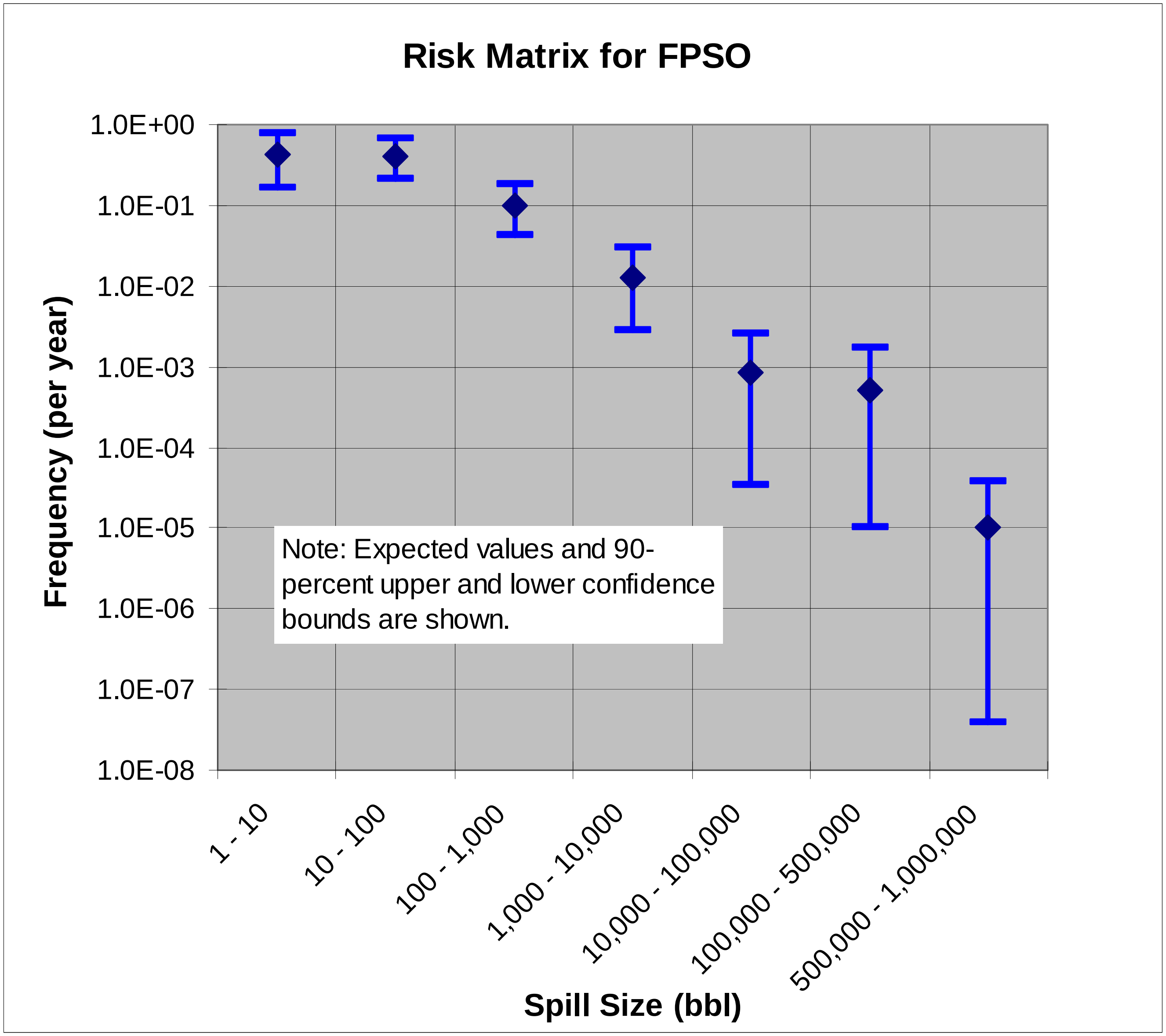
**FPSO - Risk Summary**

**Overall System Risk Results for 20-year Life:**

| | |
|---|---|
| Expected Total (bbl) | 4.2E+03 |
| Std. Dev. in Total (bbl) | 2.2E+03 |

| | |
|---|---|
| Expected Max (bbl) | 3.4E+03 |
| Std. Dev. in Max (bbl) | 2.1E+03 |

| | Sub-system Risk Results for 20-year Life | | | |
|---|---|---|---|---|
| | Expected Total (bbl) | Std. Dev. in Total (bbl) | Expected Maximum (bbl) | Std Dev. in Maximum (bbl) |
| Well Systems - Subsea | 205 | 218 | 135 | 133 |
| Flowlines | 279 | 284 | 266 | 263 |
| Import Flowline Risers | 236 | 241 | 226 | 226 |
| Topsides | 486 | 165 | 207 | 59 |
| Shuttle Tanker | 2692 | 2145 | 2593 | 2113 |
| FPSO Cargo | 275 | 238 | 275 | 238 |
| Supply Vessels | 7 | 2 | 6 | 2 |
| Drilling and Intervention | 37 | 23 | 36 | 22 |




F.143 – Oil Spill Risk Assessment for FPSO

**FPSO - Frequency Summary**

**Summary Information for Frequencies**

| | Total System Frequency | | | | | |
|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Expected Value (per year)** | **Coefficient of Uncertainty** | **k for Gamma Distribution** | **n for Gamma Distribution** | **Lower 90% (per year)** | **Upper 90% (per year)** |
| 1 - 10 | 4.2E-01 | 4.4E-01 | 5.1E+00 | 1.2E+01 | 1.7E-01 | 7.7E-01 |
| 10 - 100 | 4.1E-01 | 3.3E-01 | 9.0E+00 | 2.2E+01 | 2.2E-01 | 6.6E-01 |
| 100 - 1,000 | 1.0E-01 | 4.3E-01 | 5.4E+00 | 5.3E+01 | 4.2E-02 | 1.8E-01 |
| 1,000 - 10,000 | 1.3E-02 | 6.5E-01 | 2.3E+00 | 1.8E+02 | 2.8E-03 | 2.9E-02 |
| 10,000 - 100,000 | 8.3E-04 | 1.0E+00 | 9.2E-01 | 1.1E+03 | 3.4E-05 | 2.6E-03 |
| 100,000 - 500,000 | 5.1E-04 | 1.2E+00 | 7.3E-01 | 1.4E+03 | 1.0E-05 | 1.7E-03 |
| 500,000 - 1,000,000 | 1.0E-05 | 1.4E+00 | 5.0E-01 | 5.0E+04 | 3.9E-08 | 3.8E-05 |

| | Expected Frequency by Sub-system (per year) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Well Systems - Subsea** | **Flowlines** | **Import Flowline Risers** | **Topsides** | **Shuttle Tanker** | **FPSO Cargo** | **Supply Vessels** | **Drilling and Intervention** |
| 1 - 10 | 1.6E-01 | 1.2E-02 | 1.1E-02 | 1.1E-01 | 8.6E-02 | 0.0E+00 | 9.5E-03 | 3.1E-02 |
| 10 - 100 | 7.0E-02 | 1.0E-02 | 9.7E-03 | 2.8E-01 | 3.2E-02 | 0.0E+00 | 5.3E-03 | 5.3E-03 |
| 100 - 1,000 | 2.3E-02 | 3.9E-03 | 3.2E-03 | 4.7E-02 | 2.2E-02 | 0.0E+00 | 4.3E-04 | 2.1E-03 |
| 1,000 - 10,000 | 0.0E+00 | 3.9E-03 | 3.2E-03 | 0.0E+00 | 5.4E-03 | 9.0E-05 | 0.0E+00 | 2.9E-04 |
| 10,000 - 100,000 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 7.4E-04 | 9.0E-05 | 0.0E+00 | 0.0E+00 |
| 100,000 - 500,000 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 5.0E-04 | 1.0E-05 | 0.0E+00 | 0.0E+00 |
| 500,000 - 1,000,000 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 1.0E-05 | 0.0E+00 | 0.0E+00 |

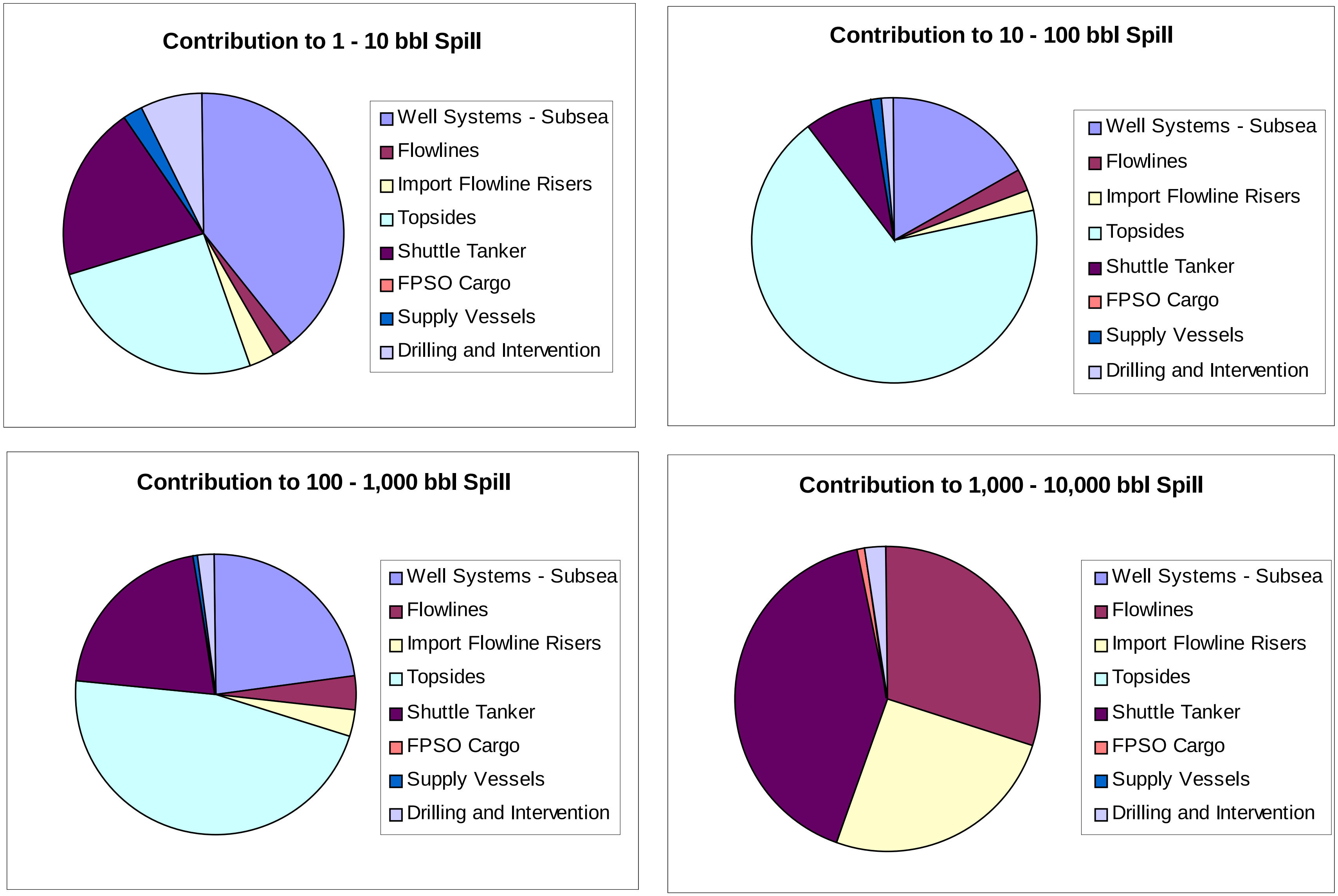
**Summary Information for FPSO Production Frequencies**

| | Production System Frequency | | | | | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Expected Value (per year) | Coefficient of Uncertainty | k for Gamma Distribution | n for Gamma Distribution | Lower 90% (per year) | Upper 90% (per year) |
| 1 - 10 | 3.3E-01 | 5.4E-01 | 3.4E+00 | 1.0E+01 | 1.0E-01 | 6.7E-01 |
| 10 - 100 | 3.8E-01 | 3.6E-01 | 7.8E+00 | 2.0E+01 | 1.9E-01 | 6.3E-01 |
| 100 - 1,000 | 8.0E-02 | 5.1E-01 | 3.8E+00 | 4.8E+01 | 2.6E-02 | 1.6E-01 |
| 1,000 - 10,000 | 7.4E-03 | 7.8E-01 | 1.6E+00 | 2.2E+02 | 9.9E-04 | 1.9E-02 |
| 10,000 - 100,000 | | | | | | |
| 100,000 - 500,000 | | | | | | |
| 500,000 - 1,000,000 | | | | | | |

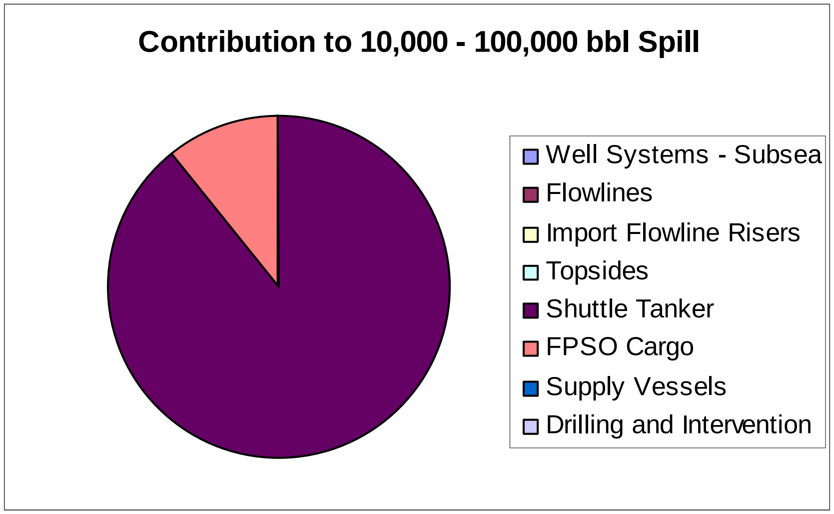
**Summary Information for FPSO Transportation Frequencies**

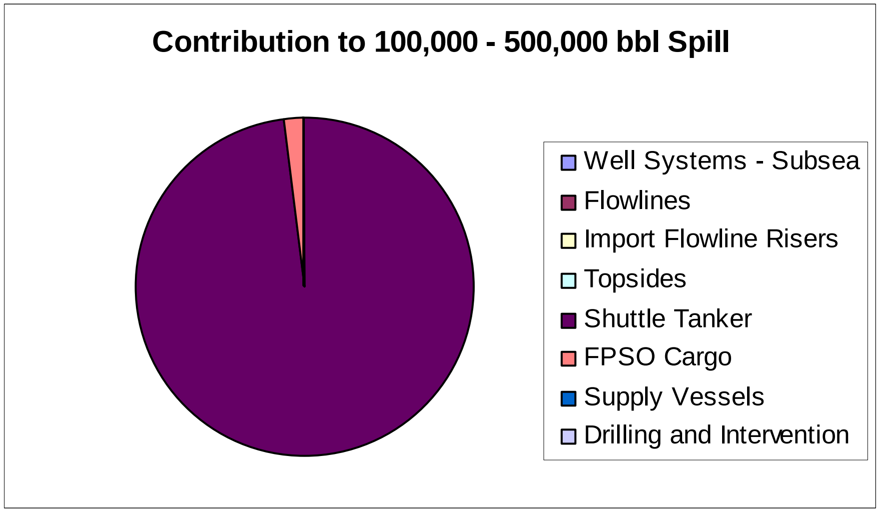
| | Transportation System Frequency | | | | | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Expected Value (per year) | Coefficient of Uncertainty | k for Gamma Distribution | n for Gamma Distribution | Lower 90% (per year) | Upper 90% (per year) |
| 1 - 10 | 8.6E-02 | 5.1E-01 | 3.8E+00 | 4.4E+01 | 2.8E-02 | 1.7E-01 |
| 10 - 100 | 3.2E-02 | 6.1E-01 | 2.7E+00 | 8.2E+01 | 7.9E-03 | 7.1E-02 |
| 100 - 1,000 | 2.2E-02 | 6.8E-01 | 2.1E+00 | 9.9E+01 | 4.2E-03 | 5.0E-02 |
| 1,000 - 10,000 | 5.5E-03 | 1.1E+00 | 8.1E-01 | 1.5E+02 | 1.6E-04 | 1.8E-02 |
| 10,000 - 100,000 | 8.3E-04 | 1.0E+00 | 9.2E-01 | 1.1E+03 | 3.4E-05 | 2.6E-03 |
| 100,000 - 500,000 | 5.1E-04 | 1.2E+00 | 7.3E-01 | 1.4E+03 | 1.0E-05 | 1.7E-03 |
| 500,000 - 1,000,000 | 1.0E-05 | 1.4E+00 | 5.0E-01 | 5.0E+04 | 3.9E-08 | 3.8E-05 |

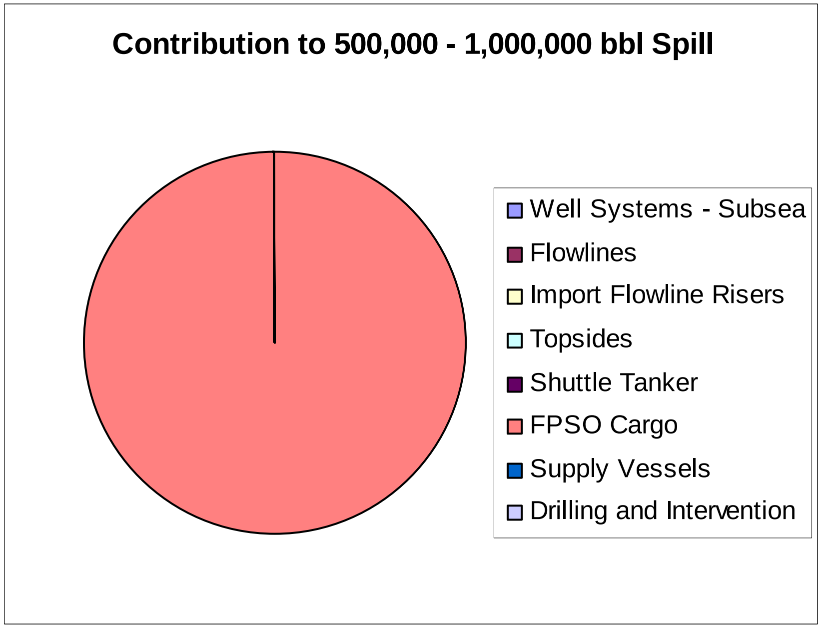
FPSO - Contribution to Total Frequency for Different Spill Sizes



FPSO - Contribution to Total Frequency for Different Spill Sizes



**FPSO - Well Systems (Subsea)**

| | |
|---|---|
| **Exposure (bbl produced)** | **7.19E+08** |

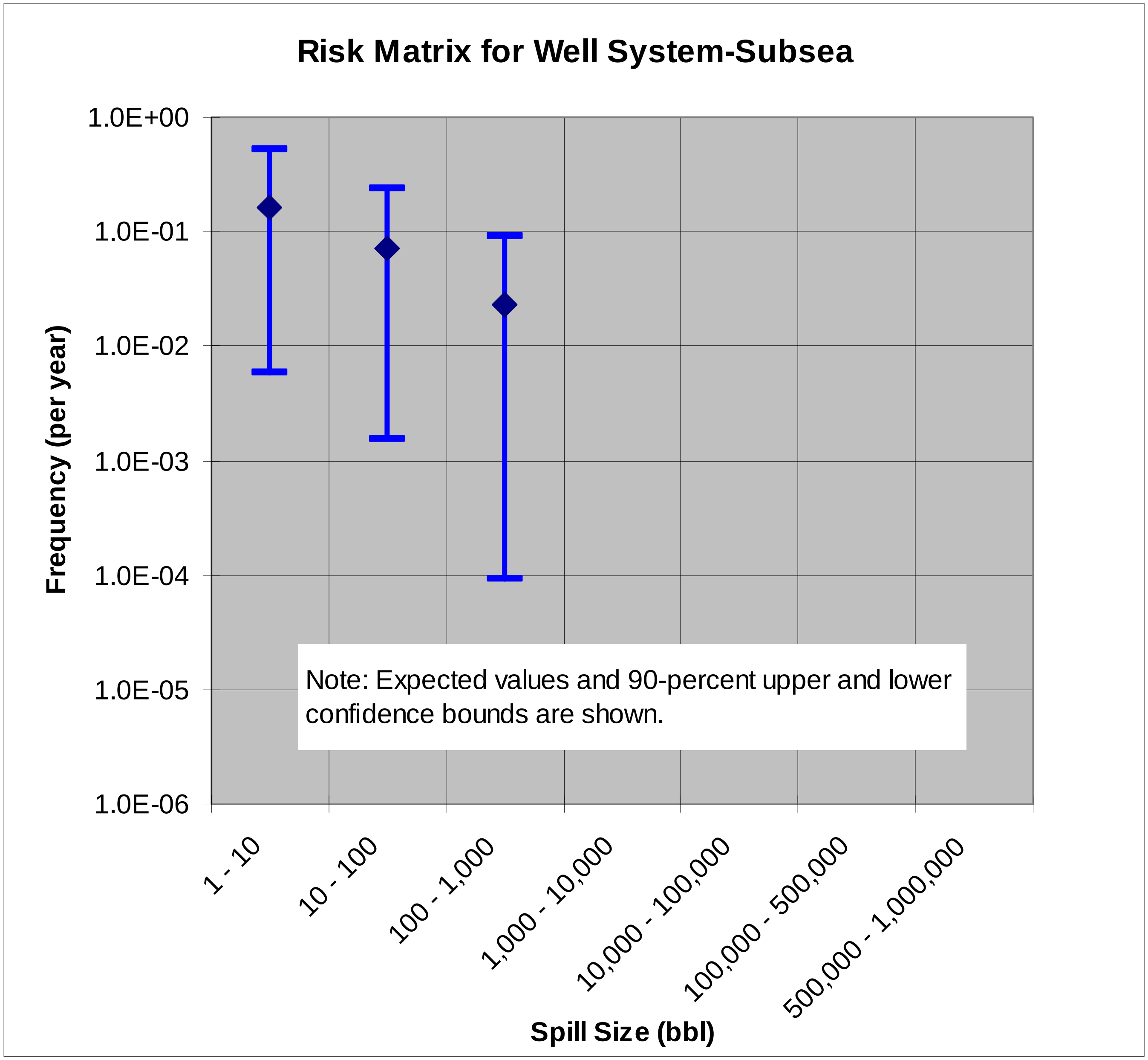
**Input Information**

| | | **Combined (Expert+Data) Estimate** | | **Expert-Based Extrapolation Bias** | | **Data-Based Estimate** | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 4.6E-09 | 1.07 | 2.0E+00 | 1.00 | 2.3E-09 | 0.38 |
| 10 - 100 | 32 | 2.0E-09 | 1.15 | 2.0E+00 | 1.00 | 9.8E-10 | 0.58 |
| 100 - 1,000 | 320 | 6.5E-10 | 1.41 | 2.0E+00 | 1.00 | 3.3E-10 | 1.00 |
| 1,000 - 10,000 | 3200 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **2.0E+02** |
| **Std. Dev. in Total (bbl)** | **2.2E+02** |

| | |
|---|---|
| **Expected Max (bbl)** | **1.4E+02** |
| **Std. Dev. in Max (bbl)** | **1.3E+02** |


Risk Matrix for Well System-Subsea
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
Frequency (per year)
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Reported incidents of oil spills from "well and header systems" in the Gulf of Mexico were taken from the MMS pipeline and platform spill database (provided by Cheryl Anderson of MMS) for the years 1980 to 1999. The data are summarized below. Use only data from 1990 to present to account for changes in operating procedures due to implementation of API RP14C.

Equipment includes subsurface safety valves, wellhead assemblies, chokes, jumpers and injection lines, pressure sensors, surface safety valves, header valves and check valves.

Assume risk is proportional to the volume of production - total production data are available for GOM from 1985-1998.

Total Production bbls in GOM Data:

| | |
|---|---|
| Expected Value (bbl) | 3.1E+09 |
| Coefficient of Uncertainty | 0 |
| Standard Deviation (bbl) | 0 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per bbl) | k" | n" (bbl) | Expected Value (/bbl) | Std. Dev. (/bbl) | Coefficient of Uncertainty |
| 1 - 10 | 6 | 2.0E-09 | 7 | 3.1E+09 | 2.3E-09 | 8.6E-10 | 0.377964473 |
| 10 - 100 | 2 | 6.5E-10 | 3 | 3.1E+09 | 9.8E-10 | 5.6E-10 | 0.577350269 |
| 100 - 1,000 | 0 | 0.0E+00 | 1 | 3.1E+09 | 3.3E-10 | 3.3E-10 | 1 |
| 1,000 - 10,000 | 0 | 0.0E+00 | | | | | |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Double expected frequency for leaks to account for greater potential for sand erosion and cutouts due to high flow rates and detection difficulties for sand.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since wells in database are mostly platform wells and not subsea wells.

Exposure for Study System:

**Subsea Well Production (bbl)** **7.19E+08**

**Spills from Well and Header Systems in the GoM**
**(Source: MMS - TIMS Database)**

| | | | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Total Production (bbl) | Barrels Spilled per 1E6 Bbl Produced | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1980 | 2 | 7 | | | 2 | 7 | 3.4 | | | | | | |
| 1981 | 3 | 12 | | | 3 | 12 | 4.0 | | | | | | |
| 1982 | 5 | 14 | | | 5 | 14 | 2.7 | | | | | | |
| 1983 | 2 | 31 | | | | | | 2 | 31 | 15.5 | | | |
| 1984 | 1 | 3 | | | 1 | 3 | 3.0 | | | | | | |
| 1985 | 2 | 43 | 351133870 | 0.12 | 1 | 3 | 3.0 | 1 | 40 | 40.0 | | | |
| 1986 | 2 | 5 | 356398376 | 0.01 | 2 | 5 | 2.5 | | | | | | |
| 1987 | 3 | 6 | 328243087 | 0.02 | 3 | 6 | 2.0 | | | | | | |
| 1988 | 5 | 73 | 301704812 | 0.24 | 4 | 18 | 4.5 | 1 | 55 | 55.0 | | | |
| 1989 | 2 | 18 | 281160011 | 0.06 | 1 | 6 | 6.0 | 1 | 12 | 12.0 | | | |
| 1990 | 0 | 0 | 274955773 | 0.00 | | | | | | | | | |
| 1991 | 0 | 0 | 295129769 | 0.00 | | | | | | | | | |
| 1992 | 3 | 74 | 305282682 | 0.24 | 1 | 8 | 8.0 | 2 | 66 | 33.0 | | | |
| 1993 | 0 | 0 | 309229380 | 0.00 | | | | | | | | | |
| 1994 | 2 | 6 | 314743342 | 0.02 | 2 | 6 | 3.0 | | | | | | |
| 1995 | 1 | 1 | 345525211 | 0.00 | 1 | 1 | 1.0 | | | | | | |
| 1996 | 2 | 3 | 369309647 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1997 | 0 | 0 | 411795024 | 0.00 | | | | | | | | | |
| 1998 | 0 | 0 | 444466377 | 0.00 | | | | | | | | | |
| 1999 | 0 | 0 | | | | | | | | | | | |
| **TOTAL** | **35** | **295** | **4.69E+09** | **4.88E-02** | **28** | **91** | **3** | **7** | **204** | **29** | **0** | **0** | **0** |

**FPSO - Flowlines**

| Exposure (mile-years) | 624 |
|---|---|

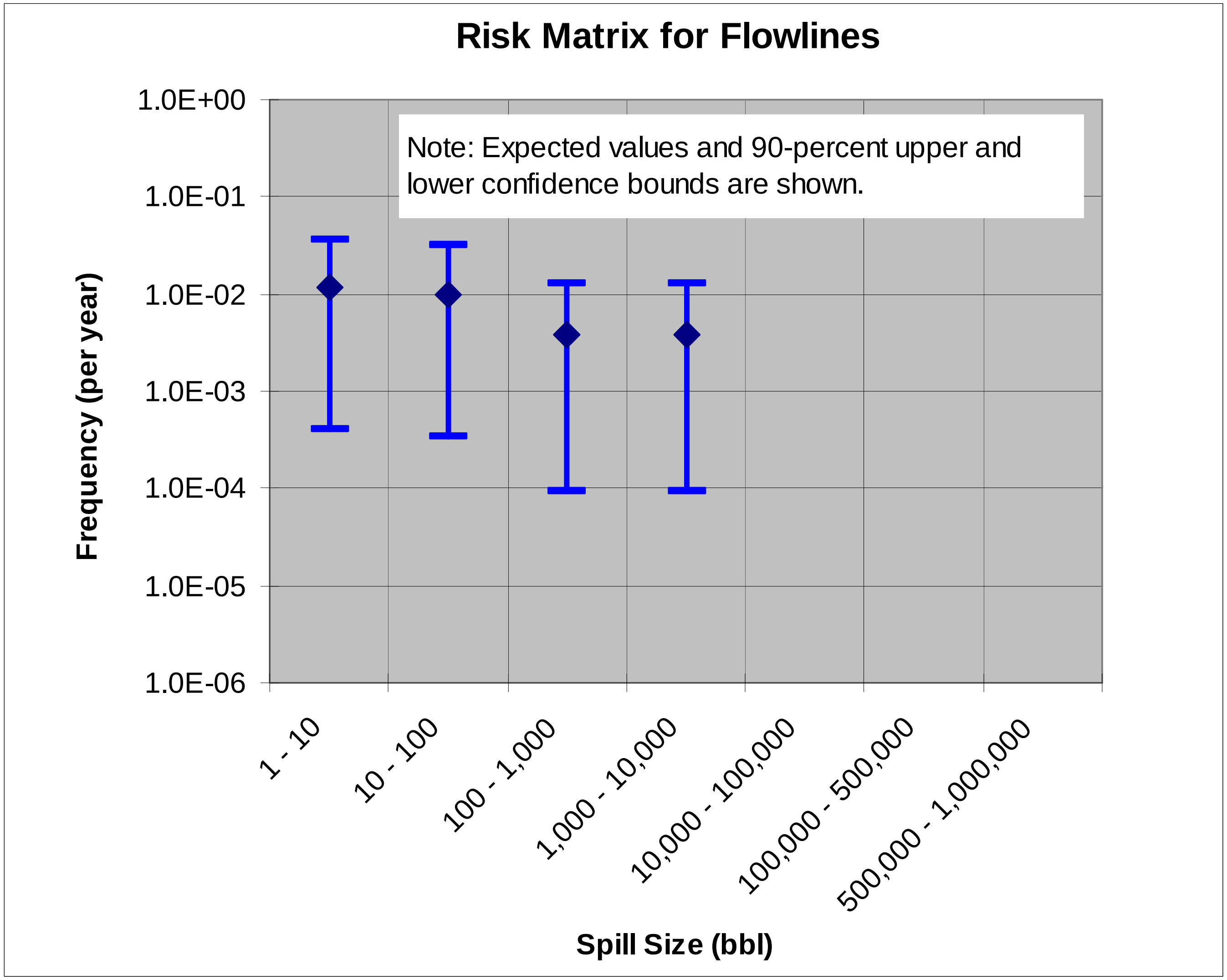
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Spill Size (bbl) | Expected Frequency (per mile-year) | Coefficient of Uncertainty for Frequency | Expected Bias | Coefficient of Uncertainty for Bias | Expected Frequency (per mile-year) | Coefficient of Uncertainty for Frequency |
| 1 - 10 | 3 | 3.7E-04 | 1.08 | 1.0E+00 | 1.00 | 3.7E-04 | 4.0E-01 |
| 10 - 100 | 32 | 3.2E-04 | 1.08 | 1.0E+00 | 1.00 | 3.2E-04 | 4.1E-01 |
| 100 - 1,000 | 320 | 1.2E-04 | 1.14 | 1.0E+00 | 1.00 | 1.2E-04 | 5.5E-01 |
| 1,000 - 10,000 | 3200 | 1.2E-04 | 1.14 | 1.0E+00 | 1.00 | 1.2E-04 | 5.5E-01 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 2.5E-05 | 1.1E+00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.0E+00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.0E+00 |

**Results for 20-year Life:**

| Expected Total (bbl) | 2.8E+02 |
|---|---|
| Std. Dev. in Total (bbl) | 2.8E+02 |

| Expected Max (bbl) | 2.7E+02 |
|---|---|
| Std. Dev. in Max (bbl) | 2.6E+02 |


Risk Matrix for Flowlines
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
Frequency (per year)
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Reported incidents of oil pipeline leaks in the Gulf of Mexico were taken from the USCG spill database for the years 1992 to 1998. The data are summarized below:

Total Pipeline Miles in GOM federal and state waters estimated from MMS and Lousiana data making the following assumptions:
Federal Waters Sum: Include "unknown" mileage in all years
State Waters Sum: Start with 2,500 miles from Mariano Hinojosa (Louisiana) in 2000; Maintain constant State/Federal Percentage for Earlier Years
Percent Inactive: Assume 17 percent today, 0 percent in 1948 and increase it linearly with time
Total Active: Reduce both federal and state together with same percentage inactive
Total Active Liquid: Assume 30 percent of pipeline length is liquid versus gas (NRC Marine Board Study 1994)
Result - 44,715 mile-years from 1992 to 1998
As a check, Marine Board Study in 1994 reported 17,000 total miles with 30 % oil/condensate, giving 5,100 miles for 7 years or 35,700 mile-years.

Total Mile Years in Data:

| | |
|---|---|
| Expected Value | 44715 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 14756 |

| Spill Size Range (bbl) | Count | Frequency (per mile-yr) | Statistically Estimated Frequency (no prior information) k" | n" (mile-yr) | Expected Value (per mile-yr) | Std. Dev. (per mile-yr) | c.o.v. |
|---|---|---|---|---|---|---|---|
| 1 - 10 | 14 | 3.1E-04 | 15 | 44715 | 3.7E-04 | 1.5E-04 | 0.40 |
| 10 - 100 | 12 | 2.7E-04 | 13 | 44715 | 3.2E-04 | 1.3E-04 | 0.41 |
| 100 - 1,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 1,000 - 10,000 | 4 | 8.9E-05 | 5 | 44715 | 1.2E-04 | 6.8E-05 | 0.55 |
| 10,000 - 100,000 | 0 | 0.0E+00 | 1 | 44715 | 2.5E-05 | 2.7E-05 | 1.08 |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because flowliness for study systems will be similar to pipelines in database, although they will be in deeper water than average pipelines in database.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since most of the pipelines in the historical database are in shallower water than the flowlines for the study system. The deepwater effect may lead to a reduction in the frequency of spills (fewer anchor drags and dropped objects), but the difference was not considered to be significant enough (an EQE 1998 study estimated the frequency of spills for deepwater segments of pipeline would be approximately 70-percent of that for shallow water pipeline segments) to be reflected in the expected bias.
- Limit maximum possible spill size per incident to 10,000 bbl because (1) flowline inventory is small (< 10,000 bbl total in parallel lines) and (2) safety systems should shut production in within 45 minutes of a leak occurring (5 hours at 2,000 bbl/hr total in both lines gives 10,000 bbl).

Study System Exposure:

| | |
|---|---|
| Length per Line (miles) | 6 |
| Number of Initial Lines | 4 |
| Service Life (yrs) | 20 |
| Number of Added Lines | 2 |
| Service Life (yrs) | 12 |
| **Exposure (mile-years)** | **624** |

| Spills from Pipelines in the GoM and its Waterways (Source: USCG - Marine Casuality and Pollution Database with input from MMS) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | |
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1992 | 10 | 3055 | 3 | 10 | 3.3 | 4 | 123 | 30.8 | 2 | 922 | 461.0 | 1 | 2000 | 2000.0 |
| 1993 | 2 | 5 | 2 | 5 | 2.5 | | | | | | | | | |
| 1994 | 2 | 4554 | | | | 1 | 10 | 10.0 | | | | 1 | 4544 | 4544.0 |
| 1995 | 5 | 32 | 3 | 8 | 2.7 | 2 | 24 | 12.0 | | | | | | |
| 1996 | 2 | 28 | 1 | 2 | 2.0 | 1 | 26 | 26.0 | | | | | | |
| 1997 | 5 | 223 | 2 | 9 | 4.5 | 2 | 51 | 25.5 | 1 | 163 | 163.0 | | | |
| 1998 | 8 | 10214 | 3 | 9 | 3.0 | 2 | 39 | 19.5 | 1 | 743 | 743.0 | 2 | 9423 | 4711.5 |
| **TOTAL** | **34** | **18111** | **14** | **43** | **3.1** | **12** | **273** | **22.8** | **4** | **1828** | **457.0** | **4** | **15967** | **3991.8** |

**FPSO - Import Flowline Risers**

| | |
|---|---|
| **Exposure (riser-years)** | **104** |

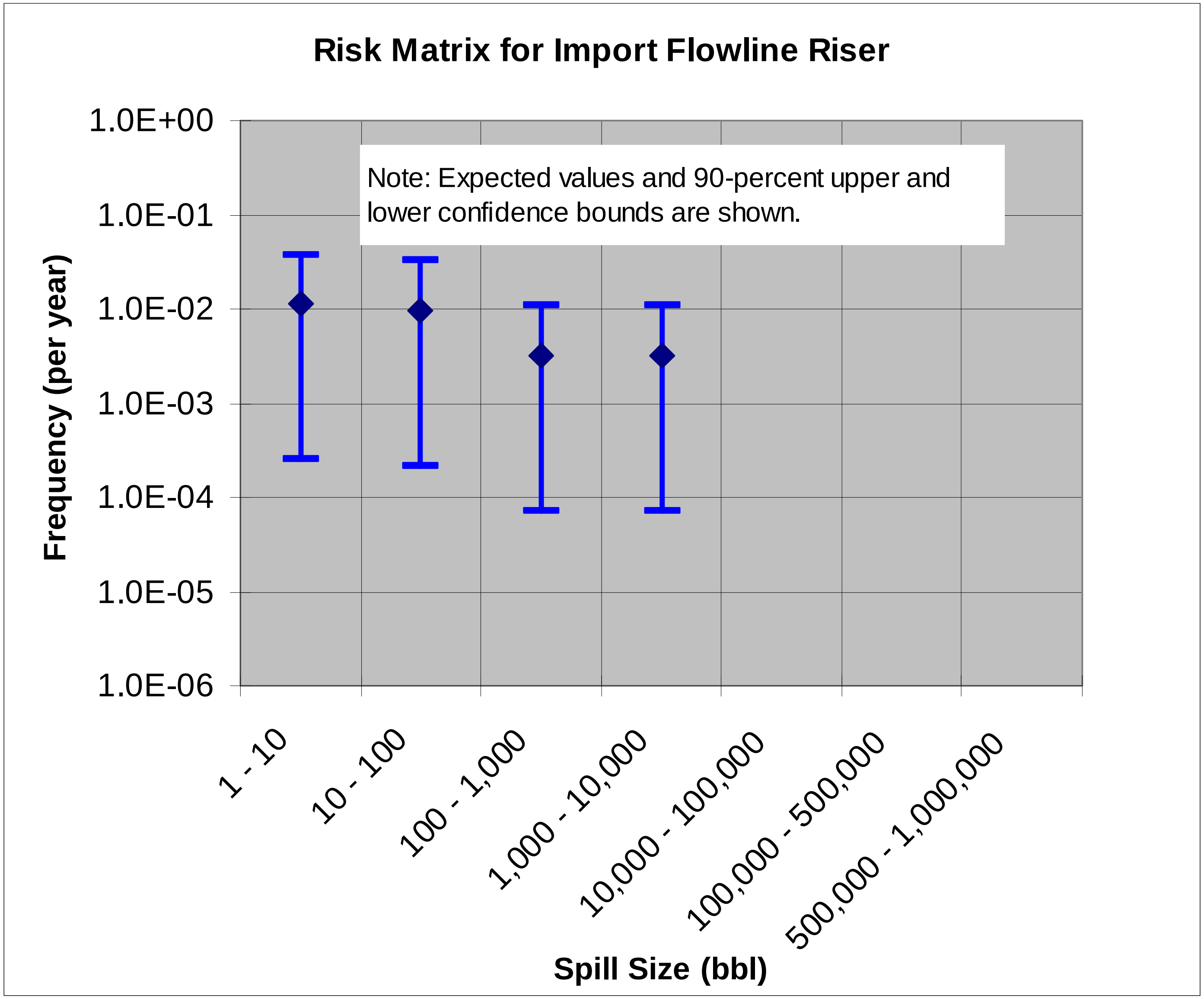
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per riser-year)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per riser-year)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 2.2E-03 | 1.15 | 1.0E+00 | 1.00 | 2.2E-03 | 0.58 |
| 10 - 100 | 32 | 1.9E-03 | 1.15 | 1.0E+00 | 1.00 | 1.9E-03 | 0.58 |
| 100 - 1,000 | 320 | 6.2E-04 | 1.15 | 1.0E+00 | 1.00 | 6.2E-04 | 0.58 |
| 1,000 - 10,000 | 3200 | 6.2E-04 | 1.15 | 1.0E+00 | 1.00 | 6.2E-04 | 0.58 |
| 10,000 - 30,000 | 32000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **2.4E+02** |
| **Std. Dev. in Total (bbl)** | **2.4E+02** |

| | |
|---|---|
| **Expected Max (bbl)** | **2.3E+02** |
| **Std. Dev. in Max (bbl)** | **2.3E+02** |


Risk Matrix for Import Flowline Riser
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
Frequency (per year)
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Use Parloc 93 information for leak frequency from risers, normalized by riser-years: 2 leaks in 565 riser-years for risers with a diameter greater than 8 inches.

Statistical Analysis:

| | |
|---|---|
| Exposure (riser-years) | 565 |
| Leaks | 2 |
| k" | 3 |
| n" (riser-years) | 565 |
| Expected Rate (per riser-year) | 5.31E-03 |
| Coefficient of Uncertainty in Rate | 0.577 |

Distribute spill sizes from risers using the flowline spill-size distribution (see Flowline worksheet for details).

| Spill Size Range (bbl) | Expected Flowline Frequency (per mile-year) | Flowline Leak Distribution | Expected Riser Frequency (per riser year) | Coefficient of Uncertainty in Frequency |
|---|---|---|---|---|
| 1 - 10 | 3.13E-04 | 41% | 2.19E-03 | 0.58 |
| 10 - 100 | 2.68E-04 | 35% | 1.87E-03 | 0.58 |
| 100 - 1,000 | 8.95E-05 | 12% | 6.25E-04 | 0.58 |
| 1,000 - 10,000 | 8.95E-05 | 12% | 6.25E-04 | 0.58 |
| 10,000 - 100,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |
| 100,000 - 500,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |
| 500,000 - 1,000,000 | 0.00E+00 | 0% | 0.00E+00 | 0.00 |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias because import risers will be in deeper water (which may increase the frequency) but more modern (which may decrease the frequency) than the risers in the database.
- Apply a coefficient of uncertainty of 1.0 in extrapolating the historical data since the risers in the historical database are not very representative of import risers on floating production systems in deepwater.
- Limit maximum possible spill size per incident to 10,000 bbl because (1) flowline inventory is small (< 10,000 bbl total in parallel lines) and (2) safety systems should shut production in within 45 minutes of a leak occurring (5 hours at 2,000 bbl/hr total in both lines gives 10,000 bbl).

Study System Import Risers:

| | |
|---|---|
| 4 Initial Flowlines | 4 |
| Years of Service | 20 |
| 2 Added Flowlines | 2 |
| Years of Service | 12 |
| **Total Riser-Years:** | **104** |

**FPSO - Topsides**

| | |
|---|---|
| **Exposure (bbl produced)** | **7.19E+08** |

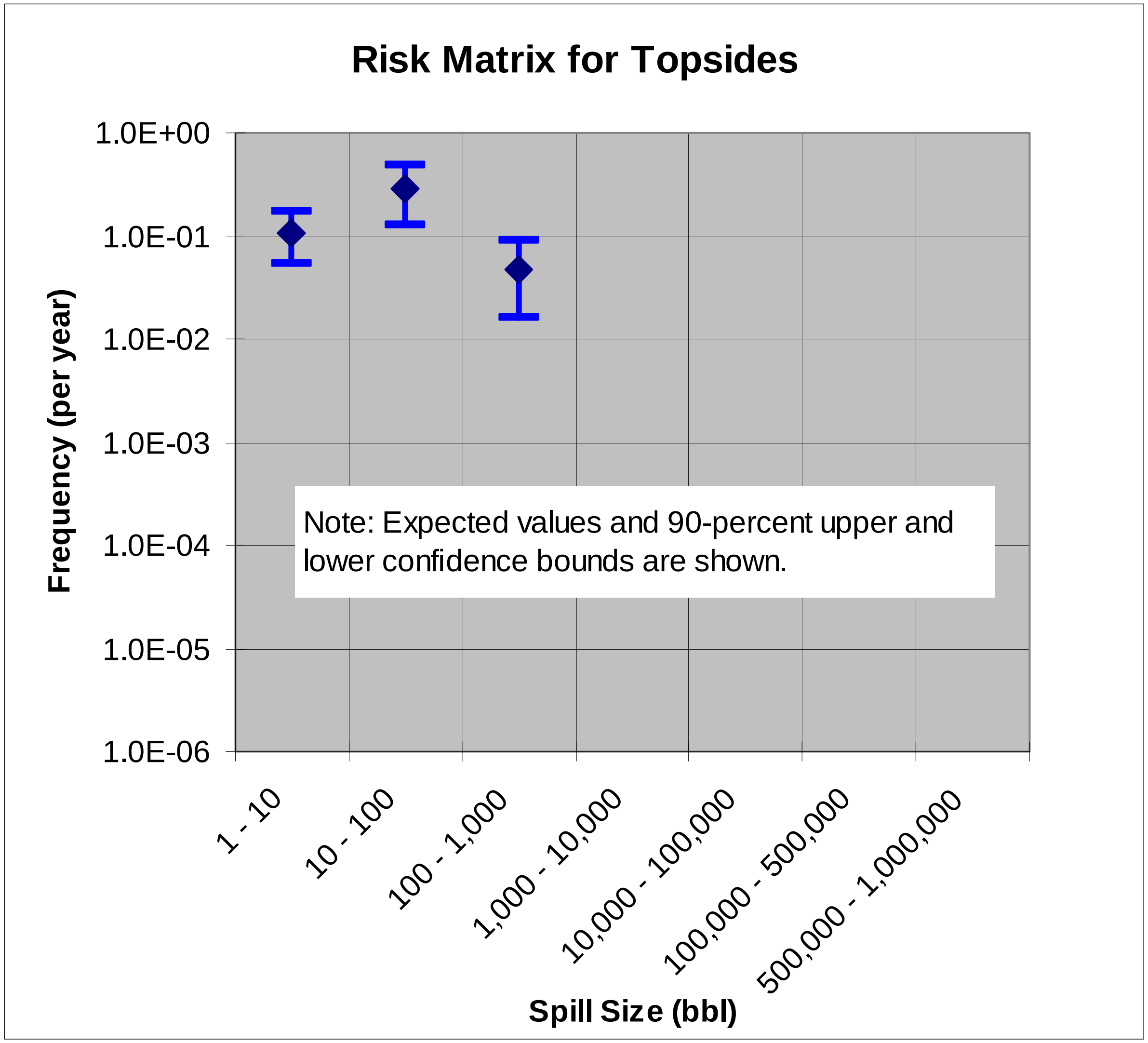
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per bbl)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 3.0E-09 | 0.35 | 1.0E-01 | 0.33 | 3.0E-08 | 0.10 |
| 10 - 100 | 32 | 7.8E-09 | 0.39 | 1.0E+00 | 0.33 | 7.8E-09 | 0.20 |
| 100 - 1,000 | 320 | 1.3E-09 | 0.50 | 1.0E+00 | 0.00 | 1.3E-09 | 0.50 |
| 1,000 - 10,000 | 3200 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 3.3E-10 | 1.00 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **4.9E+02** |
| **Std. Dev. in Total (bbl)** | **1.7E+02** |

| | |
|---|---|
| **Expected Max (bbl)** | **2.1E+02** |
| **Std. Dev. in Max (bbl)** | **5.9E+01** |




F.160 – Oil Spill Risk Assessment for FPSO

**Basis:**

Reported incidents of oil spills from "platforms" in the Gulf of Mexico were taken from the MMS pipeline and platform spill database (provided by Cheryl Anderson of MMS) for the years 1980 to 1999. The data are summarized below. Use only data from 1990 to present to account for changes in operating procedures due to implementation of API RP14C.

Process equipment included in data: separators, flare line systems, heaters/treaters, sump systems, pumps, storage tanks, compressors, pig launchers, valves and piping.

Substances included in spill data: oil, condensate, fuel, glycol.

Incidents involving supply vessels and barges (e.g., transfer of fluids to/from a vessel) have been filtered out and are not included in this analysis. The USCG data base is considered to be a more comprehensive source of information about these incidents and activities (included in Supply Vessels worksheet).

Assume risk is proportional to the volume of production - total production data are available for GOM from 1985-1998.

Total GOM Production bbls in Data:

| | |
|---|---|
| Expected Value (bbl) | 3.1E+09 |
| Coefficient of Uncertainty | 0 |
| Standard Deviation (bbl) | 0 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per bbl) | k" | n" (bbl) | Expected Value (/bbl) | Std. Dev. (/bbl) | Coefficient of Uncertainty |
| 1 - 10 | 90 | 2.9E-08 | 91 | 3.1E+09 | 3.0E-08 | 3.1E-09 | 0.105 |
| 10 - 100 | 23 | 7.5E-09 | 24 | 3.1E+09 | 7.8E-09 | 1.6E-09 | 0.204 |
| 100 - 1,000 | 3 | 9.8E-10 | 4 | 3.1E+09 | 1.3E-09 | 6.5E-10 | 0.500 |
| 1,000 - 10,000 | 0 | 0.0E+00 | 1 | 3.1E+09 | 3.3E-10 | 3.3E-10 | 1.000 |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Reduce spill frequency for the 1 to 10 bbl category by ten due to (1) capability to contain spills on deck due to the solid decking and combing and (2) location of fuel tanks in hull. Assume no extrapolation bias for spills between 10 and 1,000 bbl because estimated frequencies are for similar types of process systems. Limit maximum possible spill size per incident to 1,000 bbl because there is limited inventory of product and other fluids in the topsides that can be spilled at any one time.

- Apply a coefficient of uncertainty of 0.33 in extrapolating the data for the spill sizes less than 100 bbl because there are no data from FPSO process systems in the historical database.

Exposure for Study System:

| | |
|---|---|
| Production from Platform Wells (bbl) | 0.00E+00 |
| Production from Subsea Wells (bbl) | 7.19E+08 |
| **Total Production (bbl)** | **7.19E+08** |

**Spills from Oil/Gas Process Activities in the GoM**

**(Source: MMS - TIMS Database)**

| | | | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | | 10,000 - 100,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Total Production (bbl)** | **Barrels Spilled per 1E6 bbl Produced** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1980 | 27 | 1678 | | | 23 | 73 | 3.2 | 3 | 149 | 49.7 | | | | 1 | 1456 | 1456.0 | | | |
| 1981 | 21 | 135 | | | 19 | 62 | 3.3 | 2 | 73 | 36.5 | | | | | | | | | |
| 1982 | 26 | 79 | | | 25 | 67 | 2.7 | 1 | 12 | 12.0 | | | | | | | | | |
| 1983 | 48 | 280 | | | 43 | 127 | 3.0 | 5 | 153 | 30.6 | | | | | | | | | |
| 1984 | 39 | 172 | | | 38 | 122 | 3.2 | 1 | 50 | 50.0 | | | | | | | | | |
| 1985 | 34 | 141 | 351133870 | 0.40 | 32 | 100 | 3.1 | 2 | 41 | 20.5 | | | | | | | | | |
| 1986 | 24 | 75 | 356398376 | 0.21 | 24 | 75 | 3.1 | | | | | | | | | | | | |
| 1987 | 19 | 84 | 328243087 | 0.26 | 17 | 49 | 2.9 | 2 | 35 | 17.5 | | | | | | | | | |
| 1988 | 12 | 103 | 301704812 | 0.34 | 10 | 33 | 3.3 | 2 | 70 | 35.0 | | | | | | | | | |
| 1989 | 12 | 355 | 281160011 | 1.26 | 10 | 44 | 4.4 | 1 | 11 | 11.0 | 1 | 300 | 300.0 | | | | | | |
| 1990 | 15 | 91 | 274955773 | 0.33 | 13 | 47 | 3.6 | 2 | 44 | 22.0 | | | | | | | | | |
| 1991 | 11 | 477 | 295129769 | 1.62 | 7 | 33 | 4.7 | 3 | 94 | 31.3 | 1 | 350 | 350.0 | | | | | | |
| 1992 | 9 | 32 | 305282682 | 0.10 | 9 | 32 | 3.6 | | | | | | | | | | | | |
| 1993 | 9 | 42 | 309229380 | 0.14 | 8 | 23 | 2.9 | 1 | 19 | 19.0 | | | | | | | | | |
| 1994 | 6 | 16 | 314743342 | 0.05 | 6 | 16 | 2.7 | | | | | | | | | | | | |
| 1995 | 16 | 594 | 345525211 | 1.72 | 11 | 41 | 3.7 | 4 | 118 | 29.5 | 1 | 435 | 435.0 | | | | | | |
| 1996 | 21 | 271 | 369309647 | 0.73 | 15 | 52 | 3.5 | 6 | 219 | 36.5 | | | | | | | | | |
| 1997 | 13 | 260 | 411795024 | 0.63 | 10 | 33 | 3.3 | 2 | 57 | 28.5 | 1 | 170 | 170.0 | | | | | | |
| 1998 | 16 | 314 | 444466377 | 0.71 | 11 | 35 | 3.2 | 5 | 279 | 55.8 | | | | | | | | | |
| 1999 | 10 | 78 | | | 7 | 25 | 3.6 | 3 | 53 | 17.7 | | | | | | | | | |
| **TOTAL** | **388** | **5277** | **4.69E+09** | **6.09E-01** | **338** | **1089** | **3** | **45** | **1477** | **33** | **4** | **1255** | **314** | **1** | **1456** | **1456** | **0** | **0** | **0** |

**FPSO - Shuttle Tanker**

| | |
|---|---|
| **Exposure (port calls)** | **3196** |

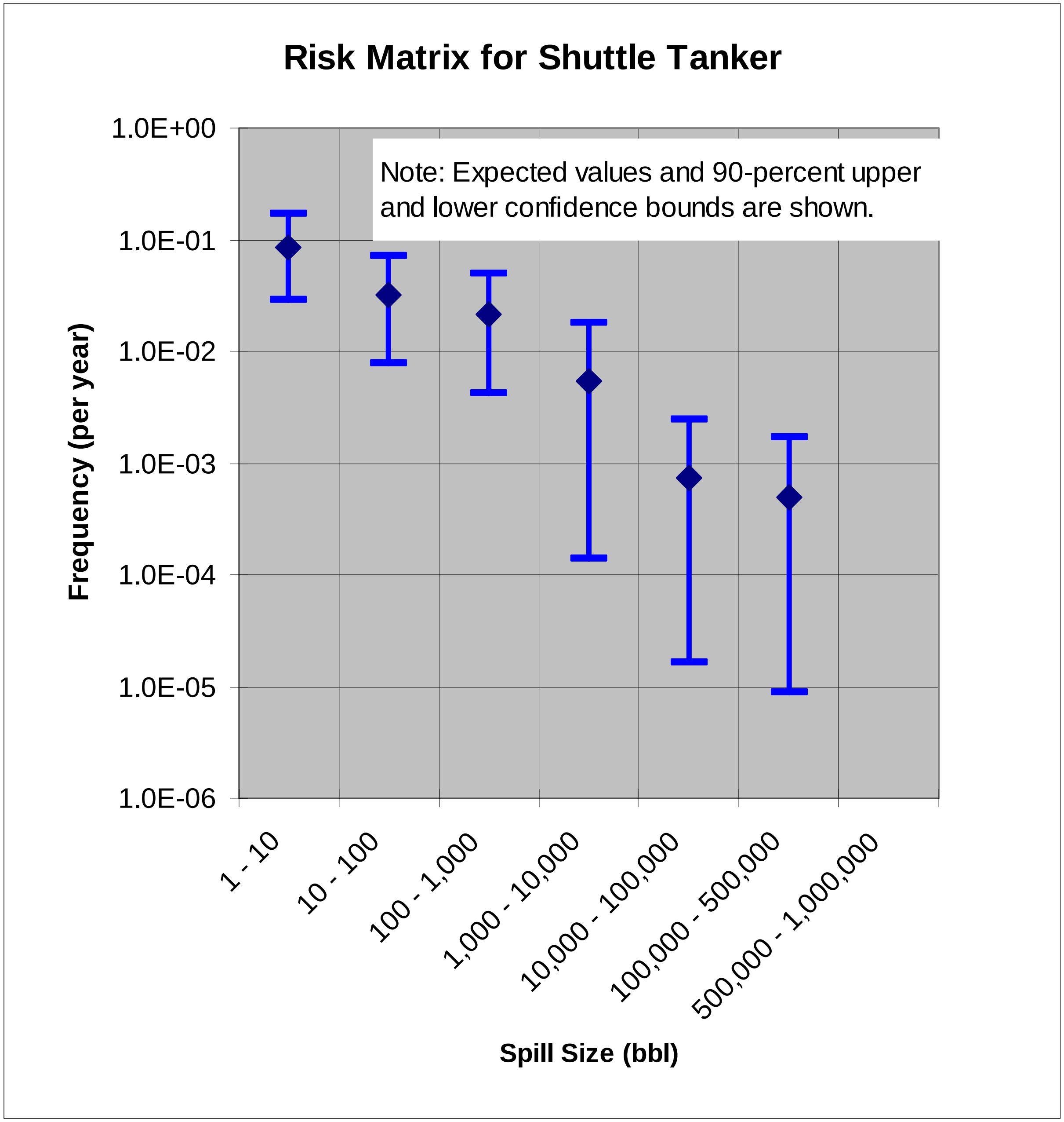
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per call)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per call)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 5.4E-04 | 0.51 | 1.0E+00 | 0.33 | 5.4E-04 | 0.39 |
| 10 - 100 | 32 | 2.0E-04 | 0.61 | 1.0E+00 | 0.33 | 2.0E-04 | 0.52 |
| 100 - 1,000 | 320 | 1.4E-04 | 0.68 | 1.0E+00 | 0.33 | 1.4E-04 | 0.60 |
| 1,000 - 10,000 | 3200 | 3.4E-05 | 1.13 | 1.0E+00 | 0.33 | 3.4E-05 | 1.08 |
| 10,000 - 100,000 | 32000 | 4.7E-06 | 1.16 | 1.0E+00 | 0.33 | 4.7E-06 | 1.11 |
| 100,000 - 500,000 | 171000 | 3.1E-06 | 1.19 | 1.0E+00 | 0.33 | 3.1E-06 | 1.15 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **2.7E+03** |
| **Std. Dev. in Total (bbl)** | **2.1E+03** |

| | |
|---|---|
| **Expected Max (bbl)** | **2.6E+03** |
| **Std. Dev. in Max (bbl)** | **2.1E+03** |


Risk Matrix for Shuttle Tanker
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
Frequency (per year)
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Risk of a spill from a shuttle tanker is assumed to be proportional to the number of docking or port calls (in field and at the terminal) because this is where most spills occur due to the number of operations (including offloading) and difficulties in navigation (traffic and shore).

The USCG database of spills from tank ships was used to estimate the frequency of different spill sizes. Data from the years 1992-1999 were used in this analysis. Data earlier than 1992 were not included due to the effect of OPA 90 on tanker risks in the Gulf of Mexico. A comparison of data for for the period 1985-1991 with those for the period 1992-1999 shows a significant decrease in spill frequencies and sizes in the 1992-1999 period.

The data base was searched for petroleum spills from tank ships. Substances considered included crude oil, fuel, diesel and lubricating oil. Incidents related to bunkering are excluded since fuel will not be supplied to the FPSO like it is to VLCC and ULCC tankers in the lightering zone.

Incidents were included from the following locations to represent the "Gulf of Mexico": Gulf of Mexico, Sabine/Neches River, Corpus Christi Ship Channel and Harbor, Galveston Bay, Houston Ship Channel, Lower and Upper Mississippi River, and Intercoastal Waterway - Gulf.

The database includes incidents related to tanker transit, discharging at terminals and refineries, and offloading from VLCCs and ULCCs to shuttle tankers in lightering zones. As a rough picture of annual Gulf of Mexico tanker activities in the 1990's, about 1,300 non-VLCC and non-ULCC tankers import oil directly to port, about 500 VLCC and ULCC tankers import oil to the lightering zones, about 1,300 shuttle tankers bring oil from the lightering zones to port. This activity gives about 1,300 lightering lifts and 2,600 port discharges per year. Since the FPSO offloading/shuttle tanker/discharge operations will be very similar in nature to existing operations in the Gulf of Mexico, it is assumed that these data can be applied to the Study FPSO in accordance with the estimated number of docking calls that will be required. Therefore, a rough approximation of the number of docking calls (a call to a VLCC or ULCC is included) per year by shuttle-tanker like tankers is 2,600 (port) + 1,300 (lightering) = 3,900 calls. In addition, there are about 200 docking calls by VLCC and ULCC tankers to LOOP. Hence, the incidents in the USCG database correspond to approximately 4,100 docking calls per year by tankers. This estimate was checke

(Note: These numbers were obtained from information about the average imports to the US (7.5 million bbl per day), imports to the GOM (60 percent of US imports), US imports lightered (15 percent), lightering percentage in GOM (95 percent), and percentage of US imports into LOOP (12.5 percent). In order to get docking calls, the average VLCC/ULCC cargo was assumed to be 2 million bbls and the average shuttle-tanker like cargo was assumed to be 500,000 bbls.)

Data includes spills both from shuttle tankers and from VLCC and ULCC tankers offloading in lightering zones and at LOOP. Therefore, these frequencies are assumed to incorporate spills both from the shuttle tanker and from the FPSO during offloading.

Total Exposure (docking calls) in GOM Data:

| | |
|---|---|
| Years (1992-1999) | 8 |
| Expected Docking Calls per Year | 4100 |
| Expected Total Docking Calls | 32800 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 10824 |

**Gulf of Mexico Data**

| Spill Size Range | Data | Exposure | Number of | Expected | Statistically-Based Estimates for Frequencies based on Raw Data | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (bbl) | Source | Years | Incidents | Docking Calls | $k_{GOM}$ | $n_{GOM}$ (calls) | Expected (/call) | Std Dev (/call) | c.o.v. |
| 1 - 10 | USCG | 8 (1992-1999) | 15 | 32800 | 16 | 32800 | 5.4E-04 | 2.1E-04 | 0.39 |
| 10 - 100 | USCG | 8 (1992-1999) | 5 | 32800 | 6 | 32800 | 2.0E-04 | 1.1E-04 | 0.52 |
| 100 - 1,000 | USCG | 8 (1992-1999) | 3 | 32800 | 4 | 32800 | 1.4E-04 | 8.1E-05 | 0.60 |
| 1,000 - 10,000 | USCG | 8 (1992-1999) | 0 | 32800 | 1 | 32800 | 3.4E-05 | 3.7E-05 | 1.08 |
| 10,000 - 100,000 | USCG | 8 (1992-1999) | 0 | 32800 | GOM Data Combined with World Data to Develop a Realistic Estimate | | | | |
| 100,000 - 500,000 | USCG | 8 (1992-1999) | 0 | 32800 | GOM Data Combined with World Data to Develop a Realistic Estimate | | | | |
| 500,000 - 1,000,000 | | | | | | | | | |

Since there are no incidents in the Gulf of Mexico for spill-sizes greater than 10,000 bbl, the estimated frequencies for these spill sizes are based on a combination of Gulf of Mexico data (no spills between 1992 and 1999) and world-wide data. Data obtained from ITOPF for all tanker operations world-wide for the years 1992-1999 are used. There have been 10 incidents world-wide with spills between 10,000 and 100,000 bbls and 6 incidents world-wide with spills greater than 100,000 bbls between 1992 and 1999. Note that these 6 incidents include spills greater than 500,000 bbls, but they are included in this category because (1) they are representative of catastrophic types of events and (2) this approach is conservative. In addition, there are approximately 90,000 docking calls per year for tankers world-wide (neglecting the small percentage of docking calls in the Gulf of Mexico). A coefficient of uncertainty of 0.33 is applied to this estimated number of world-wide docking calls.

Tanker operations in the rest of the world are not considered to be representative to those in the Gulf of Mexico for the following reasons, in order of importance: 1) The Regulatory Environment in the Gulf of Mexico is more restrictive than that world wide on average; 2) The Environmental Conditions in the Gulf of Mexico are less severe than those world wide on average; 3) The Consequences of Grounding are significantly less in the Gulf of Mexico compared to those world wide on average due to the lack of rocky coasts in the Gulf of Mexico; 4) The shuttle tankers to be used in the Gulf of Mexico will have a Smaller Parcel Size than those used world wide on average; 5) The Gulf of Mexico has Less Congested Waterways than those in other ports world wide on average; and 6) Newer Vessels will be used in the Gulf of Mexico (due to requirements for double hulls and the Jones Act) compared to those used world wide on average.

In order to account for the differences in tanker operations between the Gulf of Mexico and the world, the statistically-estimated frequencies based on world-wide data have been adjusted down. The statistically-based value for the expected frequency was reduced by a factor of 1/3. The basis for this factor of 1/3 is that the frequencies of spills in the Gulf of Mexico in smaller spill-size categories (50-5,000 bbls and >5,000 bbls) were both approximately 40 percent of the world-wide frequencies between 1992 and 1999. A coefficient of uncertainty of 1.0 was applied to this reduction factor to account for the uncertainty in estimating this reduction factor from data for smaller spill sizes because values as small as 1/10 and smaller were considered to be possible values for this adjustment factor.

Total Exposure (docking calls) in World Data:

| | |
|---|---|
| Years (1992-1999) | 8 |
| Expected Docking Calls per Year | 90000 |
| Expected Total Docking Calls | 720000 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 237600 |

**World Data for Large Spills**

| Spill Size Range (bbl) | Data Source | Exposure Years | Number of Incidents | Expected Docking Calls | Statistically-Based Estimates for Frequencies based on Raw Data | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | $k_{world}$ | $n_{world}$ (calls) | Expected (per call) | Std Dev (per call) | Coeff. of Uncertainty |
| 1 - 10 | | | | | | | | | |
| 10 - 100 | | | | | | | | | |
| 100 - 1,000 | | | | | | | | | |
| 1,000 - 10,000 | | | | | | | | | |
| 10,000 - 100,000 | ITOPF | 8 (1992-1999) | 10 | 720000 | 11 | 720000 | 1.5E-05 | 4.6E-06 | 0.30 |
| 100,000 - 500,000 | ITOPF | 8 (1992-1999) | 6 | 720000 | 7 | 720000 | 9.7E-06 | 3.7E-06 | 0.38 |
| 500,000 - 1,000,000 | | | | | | | | | |

| Spill Size (bbl) | Expert-Based Adjustment to Raw Data | | Expert-Adjusted Estimates for Frequencies | | | | |
|---|---|---|---|---|---|---|---|
| | Expected Bias | Coefficient of Uncertainty in Bias | Expected (per call) | Std Dev (per call) | Coeff. of Uncertainty | $k^*_{world}$ | $n^*_{world}$ (calls) |
| 1 - 10 | | | | | | | |
| 10 - 100 | | | | | | | |
| 100 - 1,000 | | | | | | | |
| 1,000 - 10,000 | | | | | | | |
| 10,000 - 100,000 | 0.33 | 1.0 | 5.1E-06 | 5.3E-06 | 1.04 | 0.9 | 180000 |
| 100,000 - 500,000 | 0.33 | 1.0 | 3.2E-06 | 3.5E-06 | 1.07 | 0.9 | 270000 |
| 500,000 - 1,000,000 | | | | | | | |

The Gulf of Mexico data for spills greater than 10,000 bbls (no spills) are then statistically combined with the adjusted data from the world to obtain the estimated frequency for large spills in the Gulf of Mexico.

**Combined GOM and Adjusted World Data for Large Spills**

| Combined GOM and World Data for Large Spills | | | | | | |
|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | $k_{total}$ | $n_{total}$ (calls) | Coefficient of Uncertainty in $n_{total}$ | Expected (per call) | Std Dev (per call) | Coeff. of Uncertainty |
| 1 - 10 | | | | | | |
| 10 - 100 | | | | | | |
| 100 - 1,000 | | | | | | |
| 1,000 - 10,000 | | | | | | |
| 10,000 - 100,000 | 0.9 | 212800 | 0.28 | 4.7E-06 | 5.2E-06 | 1.11 |
| 100,000 - 500,000 | 0.9 | 302800 | 0.30 | 3.1E-06 | 3.6E-06 | 1.15 |
| 500,000 - 1,000,000 | | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data since there are no historical data available for the performance of FPSO's in the Gulf of Mexico.
- For the largest spill-size category, it is considered to be much more likely that the spill size will be near 100,000 bbl versus 500,000 bbl since a total loss of the vessel will occur if between 100,000 and 200,000 bbls are spilled. Therefore, the representative spill-size for the largest category (100,000 to 500,000 bbls) is obtained by assuming that the logarithm of the spill size has a triangular distribution (versus a uniform distribution) with the maximum likelihood at 100,000 bbls and the minimum likelihood at 500,000 bbls, giving a representative value of 171,000 bbls. (Note that this same approach is used for the largest spill-size category for oil pipelines.)

Exposure for Study System (docking calls):

| | |
|---|---|
| Shuttle Tanker Cargo (bbl) | 450000 |
| Total Production (bbl) | 7.19E+08 |
| **Total Docking Calls (2 per trip)** | **3196** |

**Gulf of Mexico Spills:**

**Gulf of Mexico Spill Data Used in Analysis:**

**Spills from Tank Ship (Data Filtered by Cargo Spilled*) in the GoM and its Waterways**

**(Source: USCG - Marine Casuality and Pollution Database)**

| | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1992 | 2 | 20 | 1 | 2 | 1.8 | 1 | 18 | 18.0 | 0 | 0 | | | | |
| 1993 | 10 | 241 | 7 | 26 | 3.7 | 2 | 72 | 35.8 | 1 | 144 | 143.7 | | | |
| 1994 | 1 | 5 | 1 | 5 | 5.0 | 0 | 0 | | 0 | 0 | | | | |
| 1995 | 2 | 802 | 0 | 0 | | 0 | 0 | | 2 | 802 | 401.0 | | | |
| 1996 | 2 | 16 | 1 | 3 | 2.7 | 1 | 13 | 13.0 | 0 | 0 | | 0 | 0 | |
| 1997 | 2 | 11 | 2 | 11 | 5.4 | 0 | 0 | | 0 | 0 | | | | |
| 1998 | 3 | 23 | 2 | 2 | 1.0 | 1 | 21 | 21.3 | 0 | 0 | | | | |
| 1999 | 1 | 9 | 1 | 9 | 8.9 | | | | 0 | 0 | | | | |
| **TOTAL** | **23** | **1127** | **15** | **57** | **4** | **5** | **124** | **25** | **3** | **946** | **315** | **0** | **0** | |

*Note: Data to include only spills associated with tankers carrying crude oil.

**Comparison of Pre-1992 and Post-1992 Data Sets for Gulf of Mexico:**

| Year | Number of "Crude Carrier*" Spills for each Spill Size (bbl) | | | | | |
|---|---|---|---|---|---|---|
| | **1-10** | **10-100** | **100-1,000** | **1,000-10,000** | **10,000-100,000** | **Total Volume (bbl)** |
| 1985 | 0 | 1 | 0 | 0 | 0 | 30 |
| 1986 | 2 | 1 | 0 | 0 | 0 | 28 |
| 1987 | 4 | 0 | 0 | 0 | 0 | 5 |
| 1988 | 5 | 1 | 0 | 0 | 1 | 15401 |
| 1989 | 3 | 1 | 2 | 0 | 0 | 1146 |
| 1990 | 7 | 2 | 1 | 0 | 0 | 266 |
| 1991 | 5 | 0 | 0 | 0 | 0 | 17 |
| **Sub-Total** | **26** | **6** | **3** | **0** | **1** | **16893** |
| 1992 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1993 | 2 | 1 | 1 | 0 | 0 | 191 |
| 1994 | 2 | 0 | 0 | 0 | 0 | 8 |
| 1995 | 0 | 0 | 1 | 0 | 0 | 179 |
| 1996 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1997 | 1 | 0 | 0 | 0 | 0 | 2 |
| 1998 | 1 | 1 | 0 | 0 | 0 | 22 |
| 1999 | 1 | 0 | 0 | 0 | 0 | 9 |
| **Sub-Total** | **7** | **2** | **2** | **0** | **0** | **411** |

*Note: Crude carriers represent a subset of all tank ships that carry crude oil because other tank ship classifications periodically carry crude oil.

**Gulf of Mexico Port Calls:**

**Estimates for Tanker Activity in the GOM**

| | | |
|---|---|---|
| US Imports (bbl/day) | 7.50E+06 | Source: NRC Lightering Study (1998) |
| Percentage of US Imports in GOM | 60% | Source: NRC Lightering Study (1998) |
| | | |
| Percentage of US Imports Lightered | 25% | Source: NRC Lightering Study (1998) |
| Percentage of US Lightering in GOM | 95% | Source: NRC Lightering Study (1998) |
| Percentage of US Imports to LOOP in GOM | 12.5% | Source: NRC Lightering Study (1998) |
| | | |
| Annual Import to GOM | | |
| Total (bbl) | 1.64E+09 | |
| Lightered (bbl) | 6.50E+08 | |
| Offload to LOOP (bbl) | 3.42E+08 | |
| Direct to Port (bbl) | 6.50E+08 | |
| | | |
| Typical VLCC/ULCC Capacity (bbl) | 2.00E+06 | |
| Typical Shuttle Tanker (ST) Capacity (bbl) | 5.00E+05 | |
| | | |
| Annual Number of ST Trips into GOM and to Port | 1300 | |
| Annual Number of ST Trips from Lightering Zone to Port | 1300 | |
| **Total Annual Number of ST Port Calls** | **3901** | |
| | | |
| Annual Number of VLCC/ULCC Trips Into GOM | 496 | |
| Annual Number of VLCC/ULCC Trips Into Lightering Zone | 325 | Already included as a port call for the Shuttle Tanker |
| **Annual Number of VLCC/ULCC Trips Into LOOP** | **171** | |
| | | |
| **Annual Number of Total Tanker Port Calls** | **4072** | |

**World Spills:**

| World Wide Crude Oil Spills Greater than 10,000 bbls (from ITOPF) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| DATE | VESSEL NAME | LOCATION | PORT | TONNES Released | Approximate bbl Released | Age (years) | Flag | Cause |
| 12/3/92 | Aegean Sea | Spain, North Coast | La Coruna | 73,500 | 514,500 | 19 | Greek | Grounding |
| 1/5/93 | Braer | UK, North Coast | Garths Ness, Shetland | 84,000 | 588,000 | 18 | Liberian | Grounding |
| 1/21/93 | Maersk Navigator | Indonesia, Malacca Straits | Northern Entrance | 25,000 | 175,000 | 4 | Singapore | Collision |
| 3/13/94 | Nassia | Turkey | | 33,000 | 231,000 | 18 | Cypress | Collision |
| 3/30/94 | Seki | United Arab Emirates | Fujairah | 16,000 | 112,000 | 1 | Panama | Collision |
| 2/15/96 | Sea Empress | UK, West Coast | Milford Haven | 72,360 | 506,520 | 20 | Liberian | Grounding |
| 5/3/92 | Geroi Chernomorya | Greece, East Coast | Off Skyros Island | 1,600 | 10,500 | Not Reported | Romanian | Collision |
| 9/20/92 | Nagasaki Spirit | Indonesia, Malacca Straits | Off Belwan Delhi | 13,000 | 84,000 | Not Reported | Liberian | Collision |
| 8/17/93 | Lyria | France, South Coast | Marseille | 2,000 | 14,000 | Not Reported | Liberian | Collision |
| 12/17/93 | Hua Hai 1 | China | Qingdao | 2,200 | 15,000 | Not Reported | Chinese Rep. | Fire/explosion |
| 10/2/94 | Cercal | Portugal | Leixoes | 1,700 | 14,000 | Not Reported | Panamanian | Grounding |
| 12/21/94 | New World | Portugal | | 11,000 | 70,000 | Not Reported | Liberian | Collision |
| 7/23/95 | Sea Prince | South Korea | Yosu | 5,035 | 35,000 | Not Reported | Cypriot | Grounding |
| 2/8/97 | San Jorge | Uruguay | Punta del Este | 5,200 | 36,000 | Not Reported | | Grounding |
| 2/28/97 | Nissos Amorgos | Venezuela | Maracaibo | 3,600 | 25,000 | Not Reported | Greek | Grounding |
| 3/15/99 | Estrella Pampeana | Argentina | | 4,077 | 30,900 | Not Reported | Liberian | Collision |

| Comparison of Gulf of Mexico with Rest of World (1992-1999) | | |
|---|---|---|
| | Spill Size | |
| | 50-5,000 bbl | >5,000 bbl |
| **Gulf of Mexico** | | |
| Total Calls | 32800 | 32800 |
| Number of Spills | 3 | 0 |
| Estimated Frequency (per call) | 1.22E-04 | 3.05E-05 |
| | | |
| **Rest of World** | | |
| Total Calls | 720000 | 720000 |
| Number of Spills | 193 | 52 |
| Estimated Frequency (per call) | 2.69E-04 | 7.36E-05 |
| | | |
| **Ratio of Frequencies: GOM/Rest of World** | **0.45** | **0.41** |

**World Port Calls:**

| Tanker Size (dwt) | Voyages/yr | Year: 1990 | Year: 1991 | Year: 1992 | Year: 1993 | Year: 1994 | Year: 1995 | Year: 1996 | Year: 1997 | Year: 1998 | Year: 1999 | Year: 2000 | 10-year Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Total Number of Tankers World Wide by Year** | | | | | | | | | | | |
| 50-80 | 27 | 367 | 379 | 383 | 373 | 378 | 371 | 261 | 263 | 261 | 260 | 320 | 329 |
| 80-120 | 23 | 432 | 454 | 469 | 486 | 496 | 487 | 481 | 492 | 503 | 527 | 561 | 490 |
| 120-200 | 13 | 207 | 215 | 234 | 249 | 252 | 247 | 309 | 312 | 314 | 316 | 257 | 265 |
| 200-300 | 0 | 322 | 340 | 353 | 357 | 362 | 355 | 355 | 368 | 365 | 260 | 361 | 345 |
| 300+ | 0 | 84 | 84 | 84 | 86 | 86 | 84 | 73 | 73 | 72 | 68 | 40 | 76 |
| **Total Voyages/yr** | | **22,536** | **23,470** | **24,170** | **24,486** | **24,890** | **24,429** | **22,127** | **22,473** | **22,698** | **23,249** | **24,884** | **23,583** |
| | | **Ave # port calls/voyage [50M to 120M dwt]= 4.1** | | | | | **Ave # port calls/voyage [120M dwt and up]= 3.5** | | | | | | |
| **Total Port Calls/yr** | | **90,783** | **94,550** | **97,272** | **98,450** | **100,083** | **98,232** | **88,311** | **89,706** | **90,613** | **92,856** | **100,020** | **94,625** |

**FPSO - Cargo Tank**

| **Exposure (years)** | **20** |
|---|---|

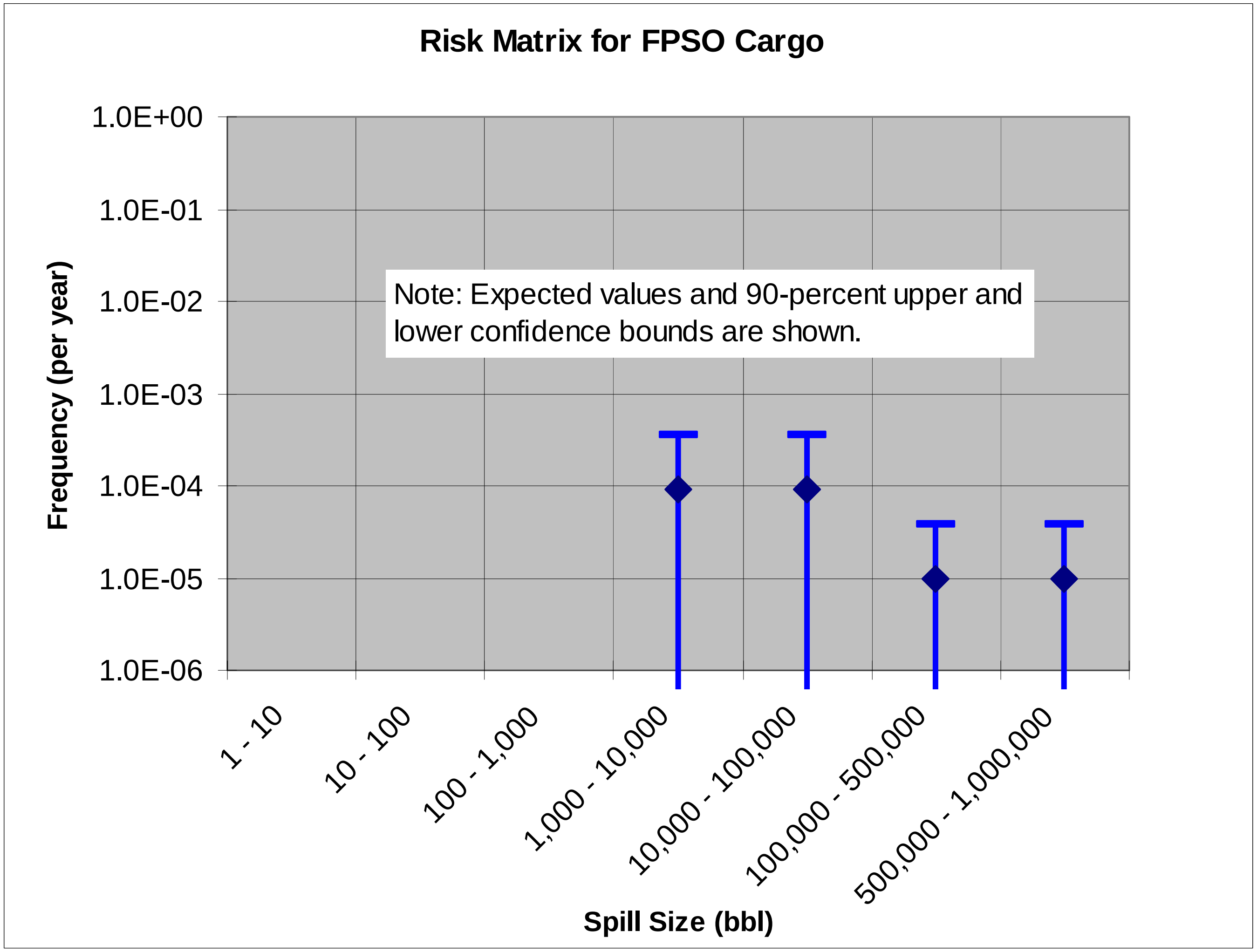
**Input Information**

| Spill Size Range (bbl) | Spill Size (bbl) | Combined (Expert+Data) Estimate: Expected Frequency (per year) | Combined (Expert+Data) Estimate: Coefficient of Uncertainty for Frequency | Expert-Based Extrapolation Bias: Expected Bias | Expert-Based Extrapolation Bias: Coefficient of Uncertainty for Bias | Data-Based Estimate: Expected Frequency (per year) | Data-Based Estimate: Coefficient of Uncertainty for Frequency |
|---|---|---|---|---|---|---|---|
| 1 - 10 | 3 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 10 - 100 | 32 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100 - 1,000 | 320 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 1,000 - 10,000 | 3200 | 9.0E-05 | 1.41 | 4.5E-02 | 1.00 | 2.0E-03 | 1.00 |
| 10,000 - 100,000 | 32000 | 9.0E-05 | 1.41 | 4.5E-02 | 1.00 | 2.0E-03 | 1.00 |
| 100,000 - 500,000 | 350000 | 1.0E-05 | 1.41 | 5.0E-03 | 1.00 | 2.0E-03 | 1.00 |
| 500,000 - 1,000,000 | 707000 | 1.0E-05 | 1.41 | 5.0E-03 | 1.00 | 2.0E-03 | 1.00 |

**Results for 20-year Life:**

| **Expected Total (bbl)** | **2.7E+02** |
|---|---|
| **Std. Dev. in Total (bbl)** | **2.4E+02** |

| **Expected Max (bbl)** | **2.7E+02** |
|---|---|
| **Std. Dev. in Max (bbl)** | **2.4E+02** |


Risk Matrix for FPSO Cargo
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
Frequency (per year)
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

This category represents a catastrophic, structural failure of the FPSO due to a hurricane or a high-energy collision with a vessel other than the shuttle tanker. All other spills from the FPSO cargo tanks are accounted for in the Shuttle Tanker category (from lightering data).

No known incidents of this type have occurred for FPSO operations to-date worldwide (approximately 500 FPSO-years).

Statistical Analysis:

| | |
|---|---|
| Exposure (years) | 500 |
| Major Accidents | 0 |
| k" | 1 |
| n" (years) | 500 |
| Expected Rate (per yr) | 0.002 |
| Coefficient of Uncertainty in Rate | 1 |

(Note that this expected rate is identical to that estimated by MacDonald et al. (1999) for the collision frequency of an FPSO in the Gulf of Mexico.)

Expert-Based Adjustment to Raw Data:

- Reduce frequency of occurrence by a factor of ten because the estimated collision rate of 0.002 per year in MacDonald et al. (1999) is considered to be overly conservative. MacDonald's estimate is based on the frequency of ships crossing a given point (representing the FPSO location) based on historical ship passage data for the Gulf. That estimate is considered to be overly conservative because it does not account for the effect that the presence of the FPSO would have on shipping lanes and patterns, nor the effects of collision avoidance measures, nor the manning and human intervention on both the FPSO and passing ships. A reduced frequency is consistent with the raw data in that there have been no collisions of this type in world-wide FPSO operations.
- Distribute the total frequency of total system failure across the different spill size categories according to the storage present in the cargo tank and the likelihood of a partial versus complete loss of the cargo:
    - 1,000 – 10,000 bbl: 45% chance if total system failure occurs (assume 90% chance that spill is less than 100,000 bbl and divide evenly between the 1,000 -10,000 and 10,000 - 100,000 bbl categories);
    - 10,000 – 100,000 bbl: 45% chance if total system failure occurs (assume 90% chance that spill is less than 100,000 bbl and divide evenly between the 1,000 -10,000 and 10,000 - 100,000 bbl categories);
    - 100,000 – 500,000 bbl: 5% chance if total system failure occurs (assume 10% chance that spill is greater than 100,000 bbl and divide evenly between the 100,000 - 500,000 and 500,000 - 1,000,000 bbl categories), use an average volume of 350,000 bbl to reflect the most common operating condition;
    - 500,000 – 1,000,000 bbl: 5% chance if total system failure occurs (assume 10% chance that spill is greater than 100,000 bbl and divide evenly between the 100,000 - 500,000 and 500,000 - 1,000,000 bbl categories).
- Apply a coefficient of uncertainty of 1.0 to the expert-based adjustment due to lack of relevant data on this type of a failure.

Exposure for Study System:

| | |
|---|---|
| Production Life (years) | **20** |

**FPSO - Supply Vessels**

| | |
|---|---|
| **Exposure (docking calls)** | **8487** |

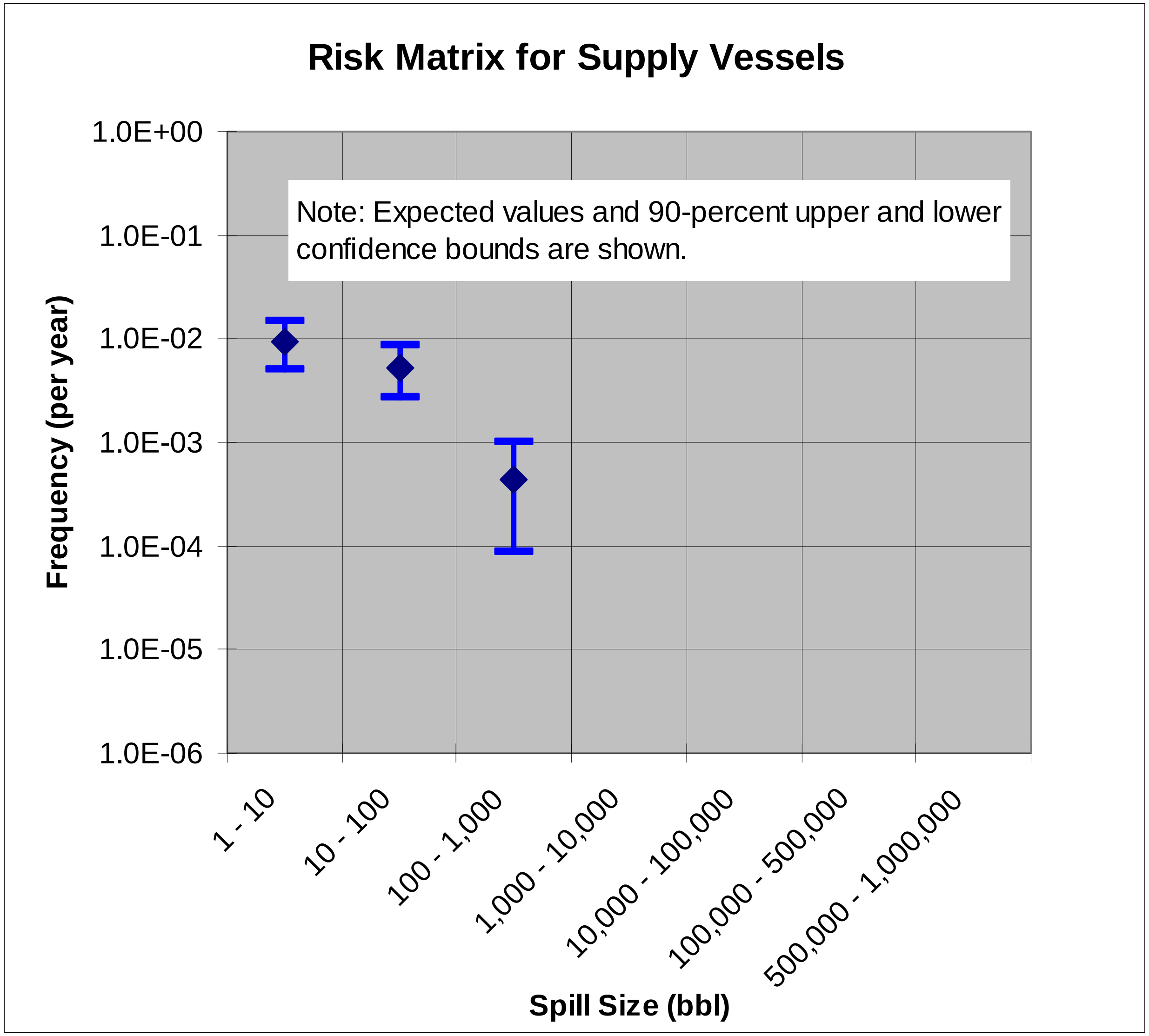
**Input Information**

| | | Combined (Expert+Data) Estimate | | Expert-Based Extrapolation Bias | | Data-Based Estimate | |
|---|---|---|---|---|---|---|---|
| **Spill Size Range (bbl)** | **Spill Size (bbl)** | **Expected Frequency (per call)** | **Coefficient of Uncertainty for Frequency** | **Expected Bias** | **Coefficient of Uncertainty for Bias** | **Expected Frequency (per call)** | **Coefficient of Uncertainty for Frequency** |
| 1 - 10 | 3 | 2.2E-05 | 0.32 | 1.0E+00 | 0.00 | 2.2E-05 | 0.32 |
| 10 - 100 | 32 | 1.2E-05 | 0.34 | 1.0E+00 | 0.00 | 1.2E-05 | 0.34 |
| 100 - 1,000 | 320 | 1.0E-06 | 0.67 | 1.0E+00 | 0.00 | 1.0E-06 | 0.67 |
| 1,000 - 10,000 | 3200 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 3.4E-07 | 1.08 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **6.7E+00** |
| **Std. Dev. in Total (bbl)** | **2.2E+00** |

| | |
|---|---|
| **Expected Max (bbl)** | **6.4E+00** |
| **Std. Dev. in Max (bbl)** | **2.1E+00** |



Risk Matrix for Supply Vessels
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
Frequency (per year)
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Risk of a spill from a supply vessel is assumed to be proportional to the number of docking or port calls (in field and at the terminal) because this is where most spills occur due to the number of operations (including offloading) and difficulties in navigation (traffic and shore).

The USCG database of spills from offshore supply vessels (OSVs) was used to estimate the frequency of different spill sizes. Data from the years 1985-1999 were used in this analysis.

The data base was searched for petroleum spills from supply vessels. Substances considered included crude, fuel, diesel, lubricating oil and drilling mud.

Incidents were included from the following locations to represent the "Gulf of Mexico": Gulf of Mexico, Sabine/Neches River, Corpus Christi Ship Channel and Harbor, Galveston Bay, Houston Ship Channel, Lower and Upper Mississippi River, and Intercoastal Waterway - Gulf.

The database includes incidents related to vessel transit and docking calls at platorms and ports. A rough picture of supply vessel activity in the GOM (based on discussions with Edison Chouest): 300 boats making an average of 2 dock calls per day = 300x2x365 = 219,000 docking calls per year.

| Total Docking Calls in Data (15 yrs): | |
|---|---|
| Expected Value | 3285000 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 1084050 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per call) | k" | n" (calls) | Expected Value (/call) | Std. Dev. (/call) | c.o.v. |
| 1 - 10 | 65 | 2.0E-05 | 66 | 3285000 | 2.2E-05 | 7.2E-06 | 0.32 |
| 10 - 100 | 36 | 1.1E-05 | 37 | 3285000 | 1.2E-05 | 4.3E-06 | 0.34 |
| 100 - 1,000 | 2 | 6.1E-07 | 3 | 3285000 | 1.0E-06 | 6.8E-07 | 0.67 |
| 1,000 - 10,000 | 0 | 0.0E+00 | 1 | 3285000 | 3.4E-07 | 3.6E-07 | 1.08 |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data because supply vessels for these systems will be larger and more modern (dynamically-positioned) than the typical vessels that comprise the historical data.
- Limit maximum possible spill size to 1,000 bbl to be consistent with cargo capacity for typical supply vessels (less than 1,000 bbl).

Exposure for Study System:

| | |
|---|---|
| 1 trip per 3 days during production | 0.333333333 |
| Days of Production (20 years) | 7300 |
| Trips | 2433 |
| | |
| 1 trip per 3 days during drilling/workover | 0.333333333 |
| 6 Subsea Wells (20 years) | |
| Drilling & Completion (3*90 + 120 days) | 390 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 600 |
| Hydraulic (1/5 per well-yr @ 20 days) | 480 |
| Change out (1/8 per well-yr @ 50 days) | 750 |
| Recompletion (1/10 per well-yr @ 50 days) | 600 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 650 |
| Trips | 1330 |
| 3 Subsea Wells (12 years) | |
| Drilling & Completion (3*90 + 90 days) | 360 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 |
| Change out (1/8 per well-yr @ 50 days) | 225 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 |
| Trips | 480 |
| | |
| **Docking calls (trips*2)** | **8487** |

| Spills from OSV Activities in the GoM and its Waterways (Source: USCG - Marine Casuality and Pollution Database) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 - 10 bbl | | | 10 - 100 bbl | | | 100 - 1,000 bbl | | | 1,000 - 10,000 bbl | | | 10,000 - 100,000 bbl | | |
| Year | Total Number of Spills | Total Volume Spilled (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) | Number of Spills | Total Volume Spilled (bbl) | Average Spill Size (bbl) |
| 1985 | 0 | 0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1986 | 7 | 34 | 6 | 17 | 2.8 | 1 | 17 | 17.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1987 | 4 | 42 | 3 | 6 | 2.0 | 1 | 36 | 36.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1988 | 3 | 40 | 2 | 10 | 5.0 | 1 | 30 | 30.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1989 | 5 | 30 | 4 | 9 | 2.3 | 1 | 21 | 21.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1990 | 10 | 78 | 7 | 24 | 3.4 | 3 | 54 | 18.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1991 | 11 | 78 | 9 | 37 | 4.1 | 2 | 41 | 20.5 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1992 | 3 | 39 | 2 | 7 | 3.5 | 1 | 32 | 32.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1993 | 8 | 191 | 3 | 9 | 3.0 | 5 | 182 | 36.4 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1994 | 10 | 21 | 10 | 21 | 2.1 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1995 | 10 | 534 | 3 | 9 | 3.0 | 6 | 211 | 35.2 | 1 | 314 | 314.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1996 | 9 | 161 | 5 | 18 | 3.6 | 4 | 143 | 35.8 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1997 | 10 | 103 | 6 | 26 | 4.3 | 4 | 77 | 19.3 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1998 | 9 | 257 | 4 | 11 | 2.8 | 4 | 116 | 29.0 | 1 | 130 | 130.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| 1999 | 4 | 193 | 1 | 3 | 3.0 | 3 | 190 | 63.3 | 0 | 0 | 0.0 | 0 | 0 | 0.0 | 0 | 0 | 0.0 |
| **TOTAL** | **103** | **1801** | **65** | **207** | **3** | **36** | **1150** | **32** | **2** | **444** | **222** | **0** | **0** | **0** | **0** | **0** | **0** |

**FPSO - Drilling and Intervention**

| | |
|---|---|
| **Exposure (man-days)** | **137952** |

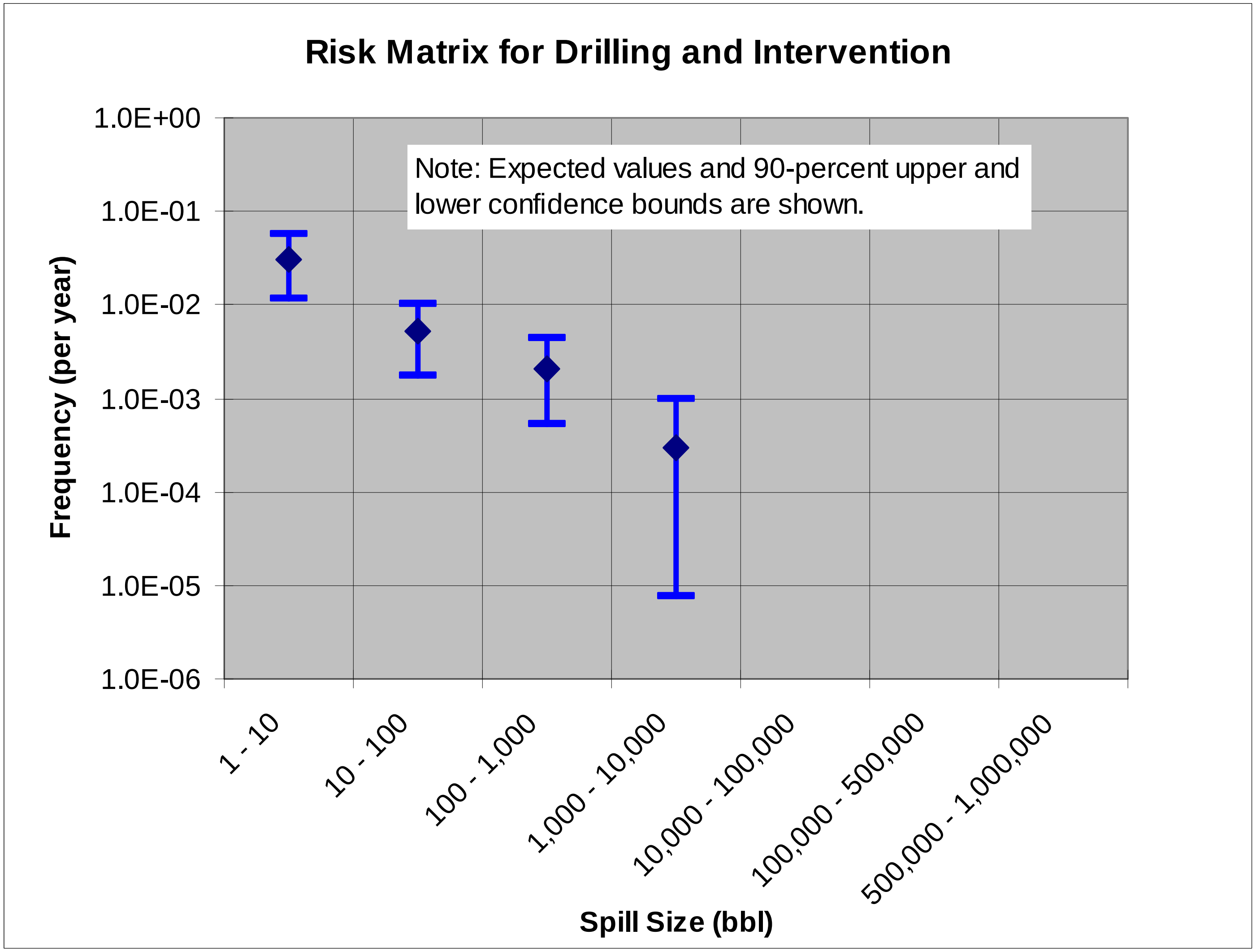
**Input Information**

| Spill Size Range (bbl) | Spill Size (bbl) | Combined (Expert+Data) Estimate: Expected Frequency (per man-day) | Combined (Expert+Data) Estimate: Coefficient of Uncertainty for Frequency | Expert-Based Extrapolation Bias: Expected Bias | Expert-Based Extrapolation Bias: Coefficient of Uncertainty for Bias | Data-Based Estimate: Expected Frequency (per man-day) | Data-Based Estimate: Coefficient of Uncertainty for Frequency |
|---|---|---|---|---|---|---|---|
| 1 - 10 | 3 | 4.4E-06 | 0.46 | 1.0E+00 | 0.33 | 4.4E-06 | 0.31 |
| 10 - 100 | 32 | 7.7E-07 | 0.51 | 1.0E+00 | 0.33 | 7.7E-07 | 0.39 |
| 100 - 1,000 | 320 | 3.0E-07 | 0.59 | 1.0E+00 | 0.33 | 3.0E-07 | 0.49 |
| 1,000 - 10,000 | 3200 | 4.3E-08 | 1.13 | 1.0E+00 | 0.33 | 4.3E-08 | 1.08 |
| 10,000 - 100,000 | 32000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 100,000 - 500,000 | 225000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |
| 500,000 - 1,000,000 | 707000 | 0.0E+00 | 0.00 | 1.0E+00 | 0.00 | 0.0E+00 | 0.00 |

**Results for 20-year Life:**

| | |
|---|---|
| **Expected Total (bbl)** | **3.7E+01** |
| **Std. Dev. in Total (bbl)** | **2.3E+01** |

| | |
|---|---|
| **Expected Max (bbl)** | **3.6E+01** |
| **Std. Dev. in Max (bbl)** | **2.2E+01** |


Risk Matrix for Drilling and Intervention
Note: Expected values and 90-percent upper and lower confidence bounds are shown.
Frequency (per year)
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
100,000 - 500,000
500,000 - 1,000,000
Spill Size (bbl)

**Basis:**

Risk of a spill from drilling and well intervention is assumed to be proportional to the number of man-days of operations. This approach means that operations that require a larger crew will have a greater risk of oil spill because more activities and difficulties are involved. It is also used here because information about man-days of drill crew operations in the GOM is available from IADC, an average of 1.3 million man-days per year in the 1990's. One concern is that the IADC information includes activities in state waters while the MMS data may only include OCS waters, therefore the denominator may be overestimated slightly.

The MMS platform data base (1980-1999) was used to identify drilling activity-related incidents. These incidents include exploratory drilling, development drilling and well workovers and completions. Substances reported in the data base include crude, fuel, diesel, drilling fluids and drilling mud. Rig types include both platform and MODU rigs.

| Total man-days in Data (20 yrs): | |
|---|---|
| Expected Value | 26000000 |
| Coefficient of Uncertainty | 0.33 |
| Standard Deviation | 8580000 |

| | | | Statistically Estimated Frequency (no prior information) | | | | |
|---|---|---|---|---|---|---|---|
| Spill Size Range (bbl) | Count | Frequency (per man-day) | k" | n" (man-day) | Expected Value (per man-day) | Std. Dev. (per man-day) | c.o.v. |
| 1 - 10 | 103 | 4.0E-06 | 104 | 26000000 | 4.4E-06 | 1.4E-06 | 0.31 |
| 10 - 100 | 17 | 6.5E-07 | 18 | 26000000 | 7.7E-07 | 3.0E-07 | 0.39 |
| 100 - 1,000 | 6 | 2.3E-07 | 7 | 26000000 | 3.0E-07 | 1.5E-07 | 0.49 |
| 1,000 - 10,000 | 0 | 0.0E+00 | 1 | 26000000 | 4.3E-08 | 4.6E-08 | 1.08 |
| 10,000 - 100,000 | 0 | 0.0E+00 | | | | | |
| 100,000 - 500,000 | 0 | 0.0E+00 | | | | | |
| 500,000 - 1,000,000 | 0 | 0.0E+00 | | | | | |

Expert-Based Adjustment to Raw Data:

- Assume no extrapolation bias.
- Apply a coefficient of uncertainty of 0.33 in extrapolating the historical data because there are relatively few historical data available for deep-water drilling in the Gulf of Mexico (compared to shallow-water drilling).
- Although they have not occurred in the data record, the possiblity for spills larger than 10,000 bbl was evaluated. The estimated frequency was considered to be negligibly small because the reservoir characteristics will be relatively well known since significant exploration and development drilling will have taken place before the production life begins.

Exposure for Study System:

| 6 Subsea Wells (20 years) | days | crew | man-days |
|---|---|---|---|
| Drilling & Completion (3*90 + 120 days) | 390 | 40 | 15600 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 600 | 4 | 2400 |
| Hydraulic (1/5 per well-yr @ 20 days) | 480 | 8 | 3840 |
| Change out (1/8 per well-yr @ 50 days) | 750 | 8 | 6000 |
| Recompletion (1/10 per well-yr @ 50 days) | 600 | 40 | 24000 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 520 | 40 | 20800 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 650 | 40 | 26000 |
| | | | |
| 3 Subsea Wells (12 years) | | | |
| Drilling & Completion (3*90 + 90 days) | 360 | 40 | 14400 |
| Coiled Tubing (1/4 per well-yr @ 20 days) | 180 | 4 | 720 |
| Hydraulic (1/5 per well-yr @ 20 days) | 144 | 8 | 1152 |
| Change out (1/8 per well-yr @ 50 days) | 225 | 8 | 1800 |
| Recompletion (1/10 per well-yr @ 50 days) | 180 | 40 | 7200 |
| Sidetrack/Deepening (1/15 per well-yr @ 65 days) | 156 | 40 | 6240 |
| Replace Wellhead (1/12 per well-yr @ 65 days) | 195 | 40 | 7800 |
| | | | |
| | | **Total (man-days):** | **137952** |

| Spills from Drilling Activities in the GoM (Source: MMS - TIMS Database) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | <= 10 bbl | | | > 10 bbl & <= 100 bbl | | | 100 - 1,000 bbl | | |
| **Year** | **Total Number of Spills** | **Total Volume Spilled (bbl)** | **Total Production** | **Barrels Spilled per 1E6 bbl Produced** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1980 | 8 | 353 | | | 6 | 17 | 2.8 | 1 | 50 | 50.0 | 1 | 286 | 286.0 |
| 1981 | 4 | 253 | | | 1 | 4 | 4.0 | 2 | 39 | 19.5 | 1 | 210 | 210.0 |
| 1982 | 13 | 50 | | | 13 | 50 | 3.8 | | | | | | |
| 1983 | 14 | 77 | | | 13 | 52 | 4.0 | 1 | 25 | 25.0 | | | |
| 1984 | 2 | 6 | | | 2 | 6 | 3.0 | | | | | | |
| 1985 | 13 | 98 | 351133870 | 0.28 | 12 | 48 | 4.0 | 1 | 50 | 50.0 | | | |
| 1986 | 7 | 31 | 356398376 | 0.09 | 7 | 31 | 4.4 | | | | | | |
| 1987 | 10 | 106 | 328243087 | 0.32 | 7 | 18 | 2.6 | 3 | 88 | 29.3 | | | |
| 1988 | 0 | 0 | 301704812 | 0.00 | | | | | | | | | |
| 1989 | 7 | 184 | 281160011 | 0.65 | 4 | 11 | 2.8 | 2 | 56 | 28.0 | 1 | 117 | 117.0 |
| 1990 | 4 | 127 | 274955773 | 0.46 | 3 | 17 | 5.7 | | | | 1 | 110 | 110.0 |
| 1991 | 4 | 14 | 295129769 | 0.05 | 4 | 14 | 3.5 | | | | | | |
| 1992 | 2 | 102 | 305282682 | 0.33 | 1 | 2 | 2.0 | 1 | 100 | 100.0 | | | |
| 1993 | 1 | 3 | 309229380 | 0.01 | 1 | 3 | 3.0 | | | | | | |
| 1994 | 1 | 3 | 314743342 | 0.01 | 1 | 3 | 3.0 | | | | | | |
| 1995 | 4 | 8 | 345525211 | 0.02 | 4 | 8 | 2.0 | | | | | | |
| 1996 | 4 | 19 | 369309647 | 0.05 | 3 | 7 | 2.3 | 1 | 12 | 12.0 | | | |
| 1997 | 2 | 3 | 411795024 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1998 | 5 | 32 | 444466377 | 0.07 | 4 | 11 | 2.8 | 1 | 21 | 21.0 | | | |
| 1999 | 2 | 7 | | | 2 | 7 | 3.5 | | | | | | |
| **TOTAL** | **107** | **1476** | **4.69E+09** | **1.56E-01** | **90** | **312** | **3** | **13** | **441** | **34** | **4** | **723** | **181** |

**Spills from Completion/Workover Activities in the GoM**

**(Source: MMS - TIMS Database)**

| | | | | | <= 10 bbl | | | > 10 bbl & <= 100 bbl | | | >100 bbl | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Total Number of Spills** | **Total Volume Spilled** | **Total Production** | **Barrels Spilled per 1E6 bbl Produced** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** | **Number of Spills** | **Total Volume Spilled (bbl)** | **Average Spill Size (bbl)** |
| 1980 | 0 | 0 | | | | | | | | | | | |
| 1981 | 3 | 68 | | | 2 | 4 | 2.0 | 1 | 64 | 64.0 | | | |
| 1982 | 1 | 3 | | | 1 | 3 | 3.0 | | | | | | |
| 1983 | 1 | 2 | | | 1 | 2 | 2.0 | | | | | | |
| 1984 | 0 | 0 | | | | | | | | | | | |
| 1985 | 1 | 5 | 351133870 | 0.01 | 1 | 5 | 5.0 | | | | | | |
| 1986 | 0 | 0 | 356398376 | 0.00 | | | | | | | | | |
| 1987 | 1 | 3 | 328243087 | 0.01 | 1 | 3 | 3.0 | | | | | | |
| 1988 | 0 | 0 | 301704812 | 0.00 | | | | | | | | | |
| 1989 | 1 | 6 | 281160011 | 0.02 | 1 | 6 | 6.0 | | | | | | |
| 1990 | 1 | 8 | 274955773 | 0.03 | 1 | 8 | 8.0 | | | | | | |
| 1991 | 0 | 0 | 295129769 | 0.00 | | | | | | | | | |
| 1992 | 0 | 0 | 305282682 | 0.00 | | | | | | | | | |
| 1993 | 0 | 0 | 309229380 | 0.00 | | | | | | | | | |
| 1994 | 3 | 172 | 314743342 | 0.55 | 1 | 6 | 6.0 | 1 | 25 | 25.0 | 1 | 141 | 141.0 |
| 1995 | 1 | 4 | 345525211 | 0.01 | 1 | 4 | 4.0 | | | | | | |
| 1996 | 1 | 5 | 369309647 | 0.01 | 1 | 5 | 5.0 | | | | | | |
| 1997 | 2 | 3 | 411795024 | 0.01 | 2 | 3 | 1.5 | | | | | | |
| 1998 | 3 | 276 | 444466377 | 0.62 | | | | 2 | 106 | 53.0 | 1 | 170 | 170.0 |
| 1999 | 0 | 0 | | | | | | | | | | | |
| **TOTAL** | **19** | **555** | **4.69E+09** | **1.03E-01** | **13** | **49** | **4** | **4** | **195** | **49** | **2** | **311** | **156** |