The Management of Risks during the Operating Phase of the Terra Nova Project

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Abstract

In the Offshore Oil and Gas industry, Safety Plans are produced in order to demonstrate to the regulatory authorities that all hazards have been identified and their associated risks appropriately assessed and reduced to an acceptable level. One of the requirements of a Safety Plan is that a Quantified Risk Assessment (QRA) be carried out of the installation and its equipment. A QRA is a means of identifying potential hazards to the installation, plant, process, personnel and environment, and assessing the likelihood of their occurrence and the subsequent consequences. The results are usually presented in event tree format, as a Risk Profile of the asset (that is, a record of the detrimental events associated with an asset or activity, along with their probable frequency and consequences). The challenge to the operator is to develop a risk profile in a manner that can be accessed and used during operations to assist in the decision making process for issues that impact risk, safety and overall asset integrity.

This paper describes how the Terra Nova offshore oil production project manages risks to personnel, releases to the environment and the integrity of the asset to meet target levels of safety and overall regulatory requirements. The paper details the proprietary, interactive software package used to capture the project risk profile for the operational phase. The tool allows interrogation of the data / risk profile and sensitivity analyses to be conducted to assist in day to day operating decisions. The risk profile supports the Safety Plan and will be used to demonstrate to the regulatory authorities how operating decisions taken ensure that all reasonable measures have been taken to ensure risks are As Low As Reasonably Practicable (ALARP). The paper describes how the risk profile will be updated, as new FPSO-specific information becomes available and how the software tool will be used as a through-life record of the asset and a communication aid, as well as ensuring that the best information is used in ongoing safety-related decision-making.

The Terra Nova Project

The Terra Nova oilfield has an estimated total recoverable oil resources of 400 million barrels and is located 350 km east south-east of St. John's, Newfoundland on the Grand Banks in a water depth of 90 to 100m. Figure 1-1 shows the field arrangement.

The Terra Nova field is being developed with a Floating, Production, Offloading and Storage Vessel (FPSO) is moored on location and connected via a spider buoy and turret to risers and protected flowlines. The development concept is shown in Figure 1-2. Product will be offloaded from the stern of the vessel into a dynamically positioned shuttle tanker. The FPSO will be attended by a standby vessel and serviced by supply vessels. The primary personal transfer will be by means of helicopter.

Figure 1-3 provides an overall field layout and a typical layout of a subsea system showing drill centre HOST, a flowline and a riser is provide in Figure 1-4.

Regulatory and Certification Regime

The Terra Nova field (FPSO vessel and subsea facilities) has been developed under the Newfoundland Offshore Regulations, which fall under the jurisdiction of the Canada-Newfoundland Offshore Petroleum Board. When the FPSO is disconnected from its mooring system, the installation will be considered a "ship" as defined by the Canada Shipping Act, and consequently will fall under Transport Canada jurisdiction. The vessel and marine systems are also classed to Lloyd's Register (LR) rules for "Floating Offshore Structures at a Fixed Location".

In their role of certifying agent, LR recognizes that the concept of As Low As Reasonably Practicable (ALARP) can be applied to other (non-safety related) risks. This allows expenditure to be matched to risk levels and applies at the design, construction and operational stages.

The Terra Nova Safety Management System

Safety Management at Terra Nova is achieved through the use of a Petro-Canada corporately adopted Total Loss Management (TLM) Philosophy (Figure 1-5) that provides a uniform statement of the asset's expectation for the management of loss control within their operations. This integrates the management of safety with other critically important aspects of the company business such as, health of our personnel, the impact of our operations on the environment and the quality of our work processes by focusing our efforts on the management of controllable losses. Plans are developed and planned actions are implemented and followed up to assure that the company's TLM philosophy is put into action.

The Terra Nova Risk Management Process

Figure 1-6, General Risk Management Framework, presents an overview structure of the Terra Nova risk management process. In general terms, the process is a rigorous, systematic way of assessing the risks associated with hazardous activities; analysing their significance; taking rational decisions to mitigate their impact; and demonstrating that the residual risks are ALARP.

Figure 1-7, Framework for QRA, provides a schematic overview of the steps followed in the QRA for the Terra Nova development.

Hazard/Failure Case Identification

A systematic approach was used to identify hazards resulting from the development of the Terra Nova asset from concept stage to operations. A range of techniques were used including preliminary hazard analysis, What-if?, Major Hazards Review (MHR), Hazard Identifications (HAZID) study and Hazard and Operability (HAZOP) study, Failure Mode and Effect Analysis (FMEA). Experiences from other similar operations were also assessed.

To provide guidance to the hazard assessment process, definitions of types of accident events were proposed. These are:

- Occupational Accidental Event - one where there is very little possibility of loss of life, minor adverse impact on the environment or to the installation, but nevertheless, some adverse impact could occur. These accidents are associated with "slips, trips and falls" where the main means of control are the management systems, e.g. procedures, training, personnel protection, good housekeeping, etc.
- Design Accidental Event – one where there may be potential for loss of life, some impact on the environment, or damage to the asset (installation). The installation and its associated safety and environmental protection systems are able to contain or control the initial effects and prevent the accident escalating into a major accidental event.
- Major Accidental Event - one where there is the potential for considerable loss of life, adverse impact on the environment, or considerable damage to the asset (installation). The consequences of these events are outside the design criteria for the installation. Major accidental events were identified in the QRA and are subject to varying degrees of scales of analysis (qualitative and quantitative). The hazard identification process identified a wide range of possible hazards. These hazards were screened to identify those that had the potential to lead to major accidental events. These hazards formed the basis of the failure case scenarios.

Major hazards identified for Terra Nova include:

- Hydrocarbon loss of containment. Events leading to such losses include:
  - Subsea events
  - Turret events
  - Topsides events
  - Cargo system
  - Offloading events
  - Non process hydrocarbon and chemical fires
- Structural Failure. Events leading to structural failure include:
  - Accidental events (i.e. fire, explosion, ship collision, iceberg collision, dropped object and swing load)
  - Extreme environmental conditions

  - Failure in design
  - Loss of mooring/station keeping
  - Sea ice
  - Vessel icing
  - Visibility
- Physical impacts such as marine vessel collisions, iceberg collision, dropped objects and swinging loads, dragged anchors and scouring icebergs
- Transportation hazards such as helicopter
- Other hazards including mechanical failure, diving, blowouts and occupational

Since hydrocarbon and non-hydrocarbon events are substantially different in nature, they were treated separately using different techniques, as shown in Figure 1-7, Framework for QRA. The hydrocarbon events were divided into process and non-process events. The non-process hydrocarbon release scenarios were analysed directly, based on experience. The events of most concern from an overall risk perspective were the hydrocarbon release events and these were analysed in greater detail. For the purposes of the risk analysis, the overall FPSO process area was divided into process sections that could be isolated. The equipment in these sections was assessed from the point of view of potential oil and gas releases. The release scenarios from each of these process sections were determined from the specific equipment types or components in the process areas and their specific location. Analyses were conducted separately for gas and oil releases because the analysis techniques differ

The process-related hydrocarbon failure case scenarios were analysed in detail in terms of frequency, consequence, risk analyses and estimations. The potential for escalation and the impairment of safety critical systems were also assessed quantitatively. These risk results were subjected to uncertainty and sensitivity analyses.

Major accidental events were used to determine loss of installation integrity and impairment of safety functions, e.g. Temporary Safe Refuge (TSR), escape routes, heli-deck, lifeboats. All hazards leading to these events have been recorded within a hazard registry.

Target Levels of Safety

Target levels of safety have been defined by Petro-Canada for theTerra Nova development. The criteria for risk acceptability for the project are based not only on corporate policy but also on regulatory expectations and past experience from similar operations. Two types of criteria have been established, namely risk-based criteria and impairment-based criteria. Risk-based criteria relate to personnel safety and pollution from accidental releases, whilst impairment-based criteria relate to safety critical systems and the FPSO integrity.

These criteria were part of the development plan application and have been adopted by the project as part of the basis of design.

Comparison of estimated risk levels with targets has been performed within the QRA.

Risk-based criteria should be met at all stages of the project, but often the level of detail of information required, cannot be fully defined in a risk assessment. In these instances, the impairment-based criteria can be used to distinguish accidental events that have the potential for severe impact from those that do not.

Impairment based criteria provide a minimum level of safety for personnel in terms of loss of integrity of safety functions. Risk-criteria are the overriding criteria.

The risk-based and impairment-based Target Levels of Safety criteria for the operating phase of the Terra Nova development are outlined below. The occupational accident frequency for Lost Time Incidents (LTI) is to achieve better than industry average.

Risk-Based Criteria

Individual Risk

Individual risk of accidental fatality to employees while working on the FPSO should not exceed

1×10^{-3} per year.

Occupational Safety

The frequency of LTI's should not exceed 1.2 LTI's per 200,000 working hours.

Environmental Damage

The frequency of release causing temporary damage to the ecological system should not exceed 1×10^{-4} per year for an individual event and 1×10^{-3} for all events.

Impairment-Based Criteria

Accidental loss of integrity of the FPSO should not exceed 1×10^{-4} for any individual event and 1×10^{-3} for all events

Risk Analysis and Quantitative Assessment

The QRA process provides a systematic approach to evaluating the significance of potential hazardous activities as input into rationale decision making. By its nature, QRA is a highly judgmental process that deals with many uncertainties. The inherent uncertainties result in a conservative approach being adopted. A number of very conservative assumptions currently incorporated in the risk analysis results will be revisited as Terra Nova specific data is gathered over time and the risk profile updated.

The results of the frequency analyses were used to populate the branches of the event trees developed for the release scenarios and combined with the results of the consequence analysis to estimate impacts and risk levels.

The QRA takes the hazards identified; the hazard analysis and assessment work and combines it with the impairment criteria, Target Levels of Safety, to develop the risk levels. Risk levels have been calculated for:

- Personnel; Individual Risks, Potential Loss of Life (PLL)
- FPSO Impairment/Loss of Integrity
- Impairment of Safety Systems; TSR, Escape Tunnels, Lifeboats and Heli-deck
- Harm to the Environment; Pollution from Oil

Differing scales of risk analyses were performed on each hazard and may be categorised as qualitative, semi-quantitative and fully quantitative. This was dependent on the significance of the hazard and the level of information available to perform the analysis.

Managing Risks to As Low As Reasonably Practicable (ALARP)

Having carried out the process of identifying hazards, analysing the consequences, estimating the frequency and then calculating the risk to personnel, the environment, or the asset, as appropriate, the risks must be managed to an acceptable level. No industrial activity is risk free, but by due diligence, the risks can be managed to acceptable criteria. Part of this process is the demonstration that the risks are as low as reasonably practicable by the implementation of risk reduction measures. Risk reduction is achieved by a combination of either hazard/consequence reduction or elimination, and frequency reduction. Risk reduction measures can also be justified by comparing the benefit (risk reduction) with the cost (financial cost, operational restriction, etc.). In making this comparison, due account must be made of the uncertainties in the risk assessment process and the social factors of public perception of risk.

Safety assessments are performed in such a manner as to allow the ranking of the risk-exposed operations. This aids the targeting and implementation of the most effective risk measures. Where risk cannot be eliminated or reduced sufficiently, control measures are put in place to reduce the risks to ALARP. These control measures are in proportion to the level of risk and addressed in order of priority with measures being taken to control the highest levels of risk first.

Terra Nova uses a number of tools to demonstrate and provide evidence that risks are ALARP. These include:

- sound engineering judgement provided by companies and individuals with a great deal of design and operating experience with FPSOs in other jurisdictions

- use of systems and designs that are proven and tested in operations
- Ongoing Process Hazard Analysis (PHA) to assess systems and design modifications throughout the project using a range of tools including HAZID and HAZOP with system documentation. Recommendations made during the assessments were documented and tracked to closure through the Terra Nova Safety and Environmental Management System (SEAMS).
- Quantitative Risk Analysis

The main tool used throughout the project to ensure that risks to individuals are within the ALARP region was, and continues to be, Process Hazards Analysis.

Process Hazards Analysis

PHA's were conducted during all phases of the Terra Nova development completed to date and will continue to be conducted on an ongoing basis for the life of the project. All systems have been or will be assessed through the PHA process to ensure that all hazards and uncertainties are identified and assessed. Through this process, Terra Nova is very confident that the risks to personnel during the operating phase are ALARP.

PHA's are conducted using a defined protocol. The assessment teams are made up of representatives from the engineering disciplines involved in the design as well as operations and maintenance personnel and an independent process engineer. Specialist expertise from one of the Alliance members of from external sources is involved in the PHA's as required to ensure all the requisite expertise is brought to bear. Expert facilitators manage the PHA process to ensure the process is followed and the assessment is complete and robust. A scribe supports the facilitator to ensure that the discussions are recorded and the recommendations / action items documented and assigned to a member of the team for follow-up. The range of PHA techniques used by the assessment teams is outlined in the Safety Assessment Plan. Most of the assessments adopted a HAZID / HAZOP approach.

Each PHA team is designed to ensure that expertise and experience in the design, control, operations and maintenance of the system being assessed are available. The process ensures that all hazards are identified, consequences assessed, safeguards identified (existing and recommended) and mitigative measures deemed by the team to be necessary actioned. Through this process, Terra Nova is confident that all reasonable safety precautions have been considered and that risks are ALARP.

The PHA assessments are captured in a report along with recommendation and action items. The later are entered into the SEAMS system for follow-up and tracking to closure by the SEAMS coordinator. The PHA reports are listed in the Safety Assessment Plan.

Figure 1-8 provides an outline of how the PHA process was used to ensure residual risks to operating personnel are within the ALARP region. The systems in place, in addition to PHAs, to assess risks on an ongoing basis are outlined in the following section. Through the rigorous application of these systems, by experienced and trained personnel, Terra Nova is confident that the identified risks will remain in the ALARP region throughout the operating phase and that any new hazards introduced during operations will be identified and thoroughly assessed to ensure the risk profile is not compromised and TLS will continue to be met.

The Terra Nova Risk Profile

During the project phase of the Terra Nova Development, identification of hazards and their impact were assessed. The risk profile for the Terra Nova Development has been recently entered into a specialised software tool developed by RMRI called Data and Decision Management Tool (DDMT). Through the use of DDMT Safety Engineering personnel are able to interact with the risk profile to asses sensitivities of key parameters and assumptions to the individual risk profile for work groups on the FPSO. The tool is used to evaluate the risk-related impact of proposed changes on the FPSO, to conduct cost benefit analyses of potential safety upgrades and to provide input into decisions that have the potential of affecting the risk profile. The purpose of these assessments is to ensure processes and changes are managed such that risks to individuals on the FPSO remain within the ALARP region and that TLS are not violated.

Event Tree Analysis

The QRA risk profile is developed in a series of event trees that use inductive logic to show the range of possible outcomes (consequences) resulting from an initiating event based on the analysis sequence (nodes) chosen. Historical and facility specific data is used to estimate the frequency of the initiating event (initial fault frequency) and the relative probabilities of each of the event tree nodes.

Figure 1-9 shows a typical event tree for a loss of containment (LOC) scenario. Each LOC scenario has the same overall format and is populated by data that reflect the specifics of process area and release sizes.

The results of the risk assessment pertaining to the relative contribution of each major hazard to IR for a personnel on board (POB) manning level of 49 (representing steady-state operations) are summarised in Figure 1-10. Figure 1-11 shows the distribution of individual risk and Figure 1-12 shows the contribution of hazards to average risk. Figure 1-13 summarises results in terms of loss of integrity of the asset.

Ongoing Risk Management Practices

Important in the maintaining of risks to within the ALARP region are the many risk-based systems in place to assess and manage exposures to hazards on an ongoing basis. In addition to the hazard prevention, control and mitigative measures, a number of operating systems and practices have been established to manage risks to personnel, asset damage and accidental environmental releases. These include:

- Job safety analysis procedures which are imbedded in the Control of Work System and Procedures (COWSP)that controls all work carried out on the FPSO
- Procedures in place to manage Simultaneous Operations (SIMOPS) of drilling and operating in the same glory hole
- Precautionary measures planned for severe storm events during which workers would be restricted to the accommodation area and work restricted to tasks critical to safe operations of the FPSO.
- Regularly scheduled safety audits and inspections and the resolution of issues and concerns through the Offshore EH&S Advisor.
- Reporting and investigation of incidents per the event reporting system
- Regular Emergency Response exercises and training
- Regularly scheduled safety drills and exercises conducted on the FPSO and the feedback to the POB of opportunities for improvement
- Sophisticated preventative maintenance program, which includes the prediction of the probability of failure of critical operating components
- Ongoing Process Hazards Analysis (PHA) of all systems and design changes that impact personnel safety.

As specific Terra Nova operating data becomes available, the risk profile will be updated using the interactive software package, Data and Decision Management Tool. The results will be reflected in future updates of risk related documentation including the Operating Phase Safety Plan.

Way Forward

The SMS at Terra Nova was developed from the mature practices at Petro-Canada. A key component of the SMS is the risk profile as it provides a record of detrimental events or upset conditions that could affect the facility along with their probable frequency and consequences. The risk profile and QRA was used to demonstrate that the TLS established for the project were met. The TLS relate to risks to individuals on the FPSO, frequency of environmental releases and frequency of loss of asset integrity. The SMS system also provides the basis for demonstrating that risks are ALARP.

As a way forward, we hope to integrate our safety management system into an asset integrity case and to mature our definition of risk to include capital / asset management.

The asset integrity case is a holistic approach and builds on the techniques used for safety risk assessment and safety related decision making, using them for the broader aspects of asset management. This is done by the production of a collection of risk based Decision Support Models (DSM) for a diverse range of capital investment decisions, thereby identifying and clarifying a number of options. Careful attention is paid to structuring the relationship between risk; uncertainty and return for the capital being employed often using techniques such as "Real Options". This is used to demonstrate that the asset is being managed in such a way that the risks associated with any type of capital invested in the operation of ALARP. The models can relate to a single performance criterion, or depending on their structure and purpose, can be used to guide multiple performance elements.

The asset integrity case, therefore, can be considered as a means to identify a range of beneficial strategic decisions together with the set of arguments to justify their implementation. The integrity case is not a fixed specification of particular models but fluid decision making framework that can be modified as asset conditions change.

The approach and techniques used for safety/risk management and for making safety-related decisions form the substantial basis of the asset integrity case being developed for Terra Nova. The asset integrity case provides DSM to demonstrate that the asset is being managed in such a manner that the risks to any type of capital invested in the operation of the Terra Nova asset are ALARP. Risk models are available to assist in making capital investment decisions and in optimizing OPEX. These models offer the potential to achieve an optimal risk-return balance.

References

1. Terra Nova Operations: “Terra Nova Safety Plan”, Document No TN-PE-SA04-X00-001, Rev M2

2. Terra Nova Alliance: “Terra Nova Quantitative Risk Assessment”, Document No TN-IM-SA15-X00-022, Rev G2

3. Petro-Canada: “Total Loss Management National Standards”, Document No TN-PE-TM12-X00-002, Rev M2

Figure 1-1: Terra Nova Field Location

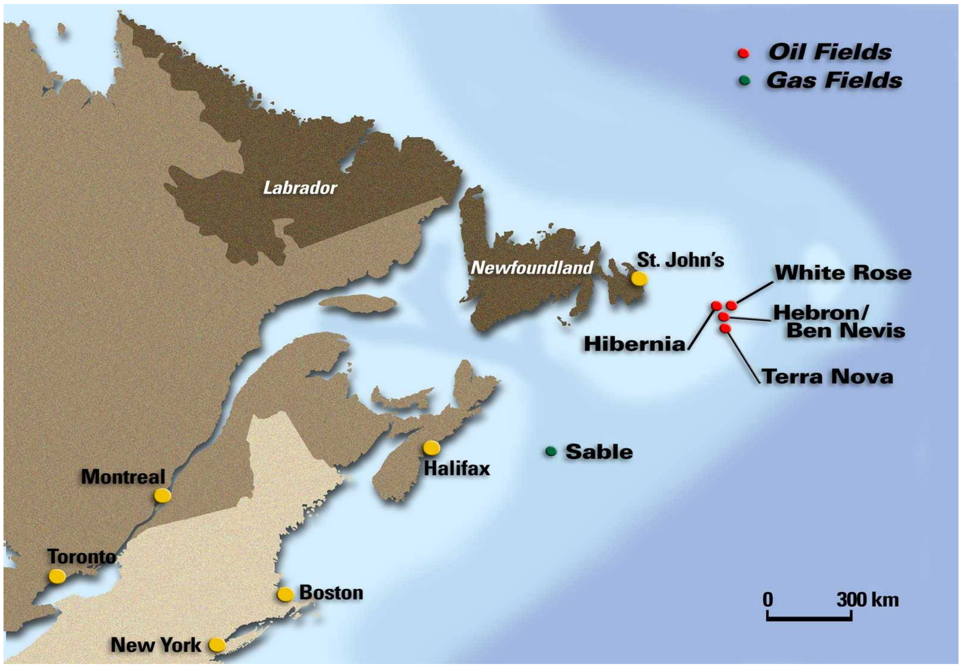


Figure 1-2: Development Concept

Figure 1-3: Overall Field Layout

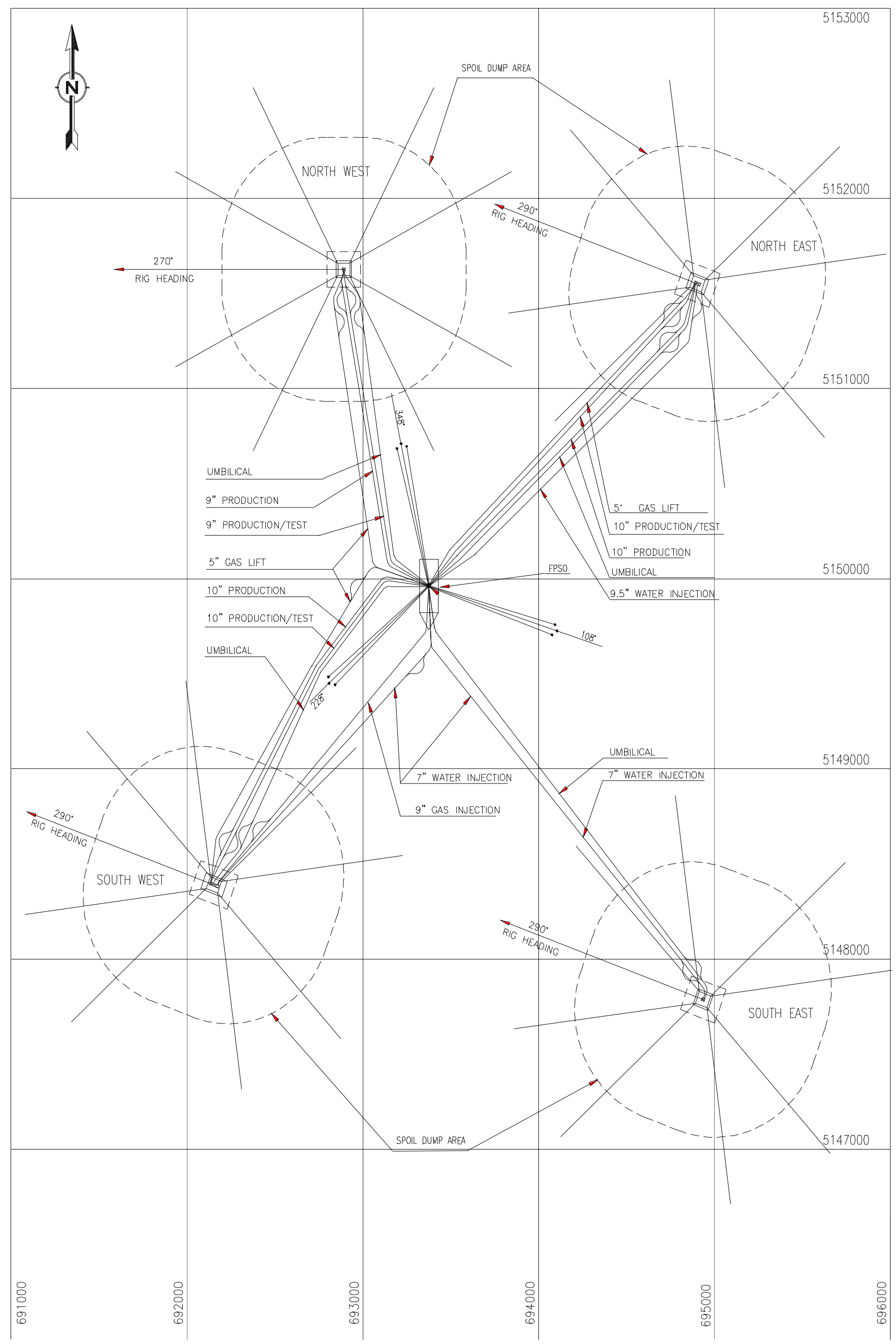


Figure 1-4: Typical Subsea Layout

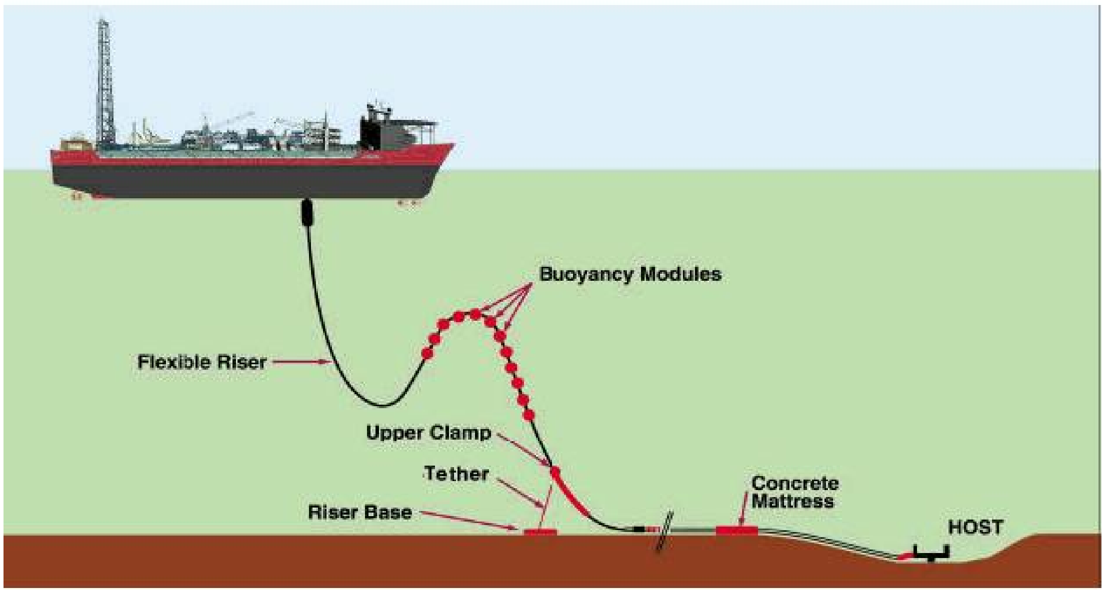


Figure 1-5: TLM Philosophy

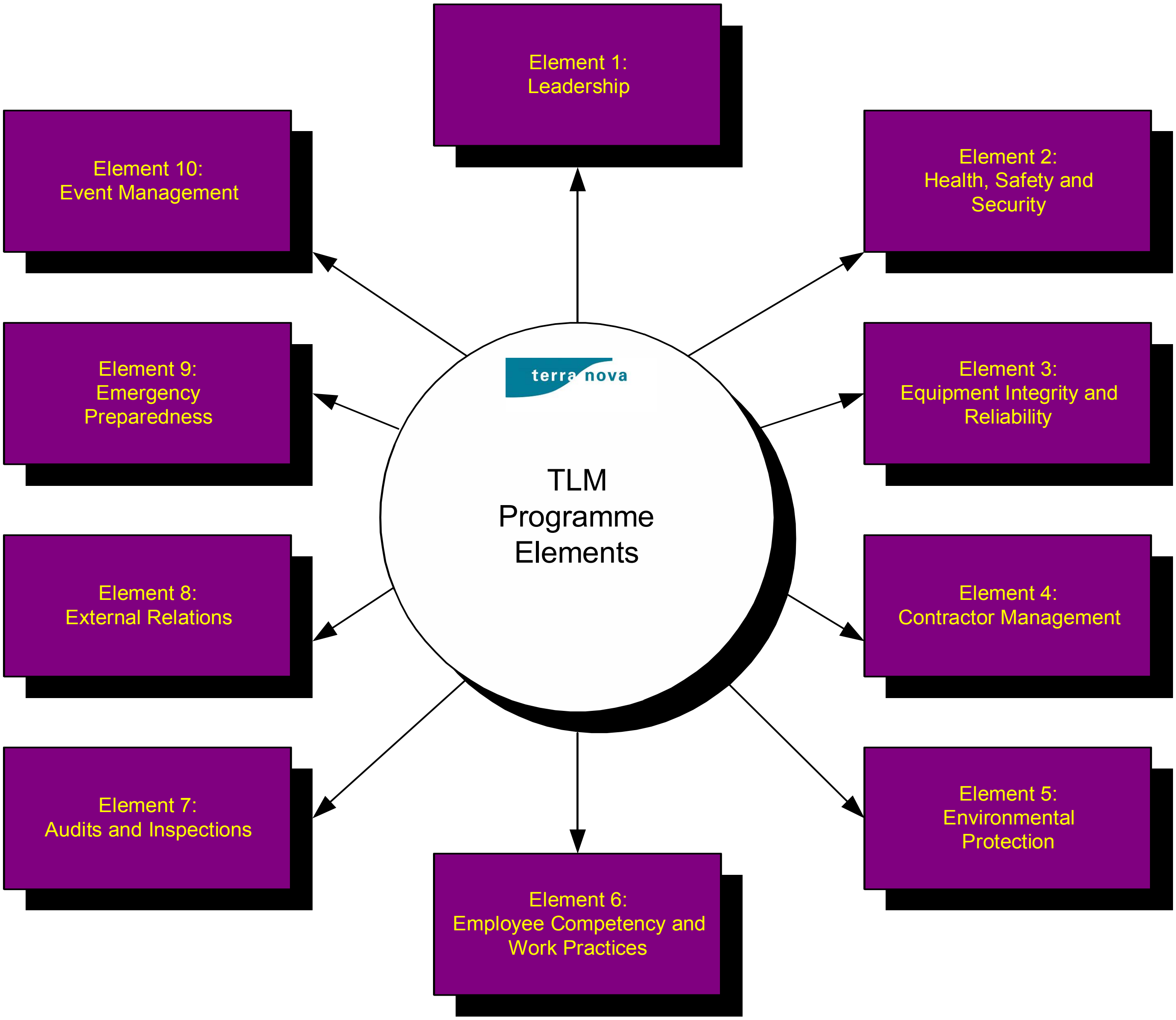


Figure 1-6: General Risk Management Framework

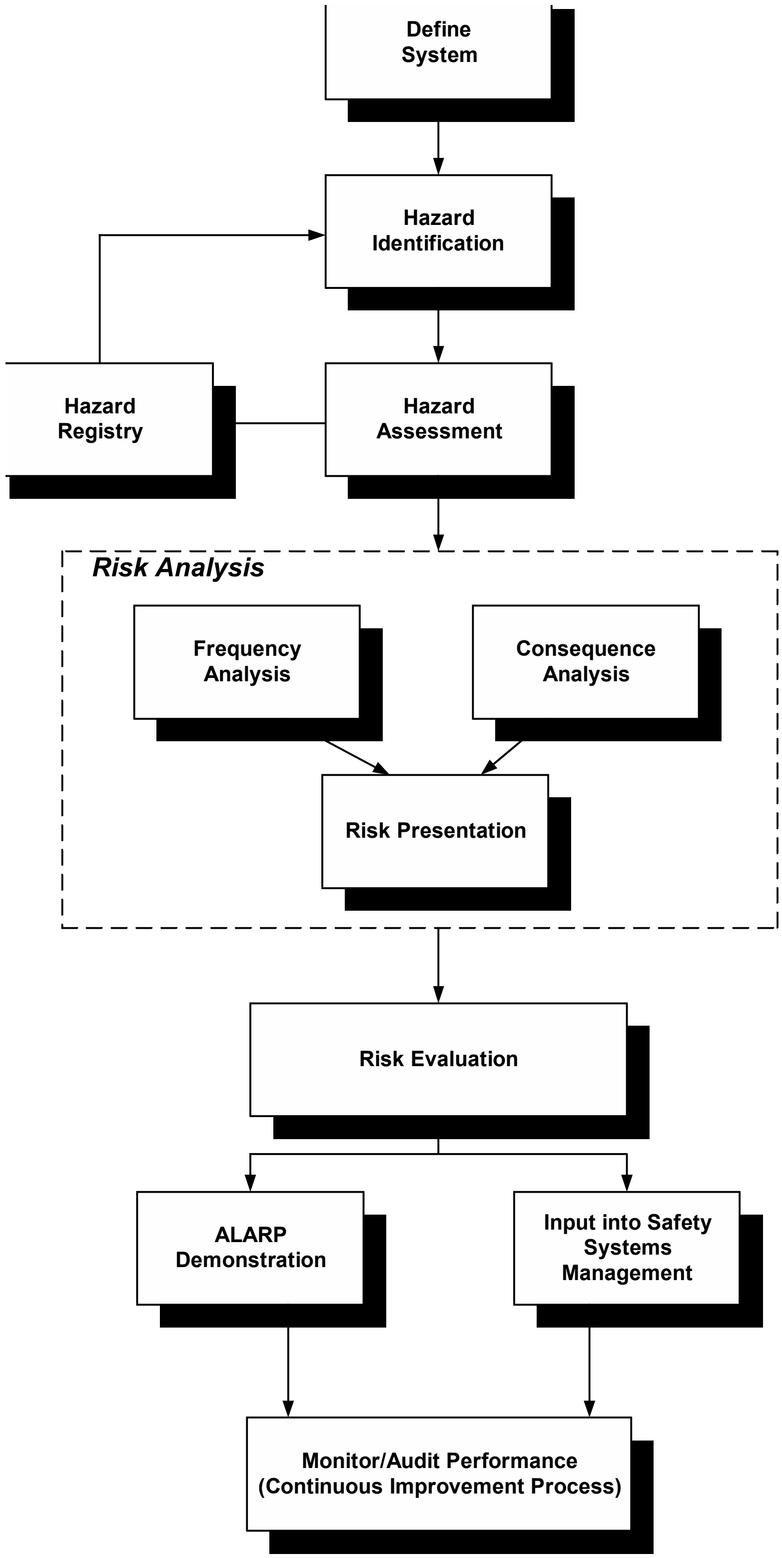


Figure 1-7: Framework for QRA

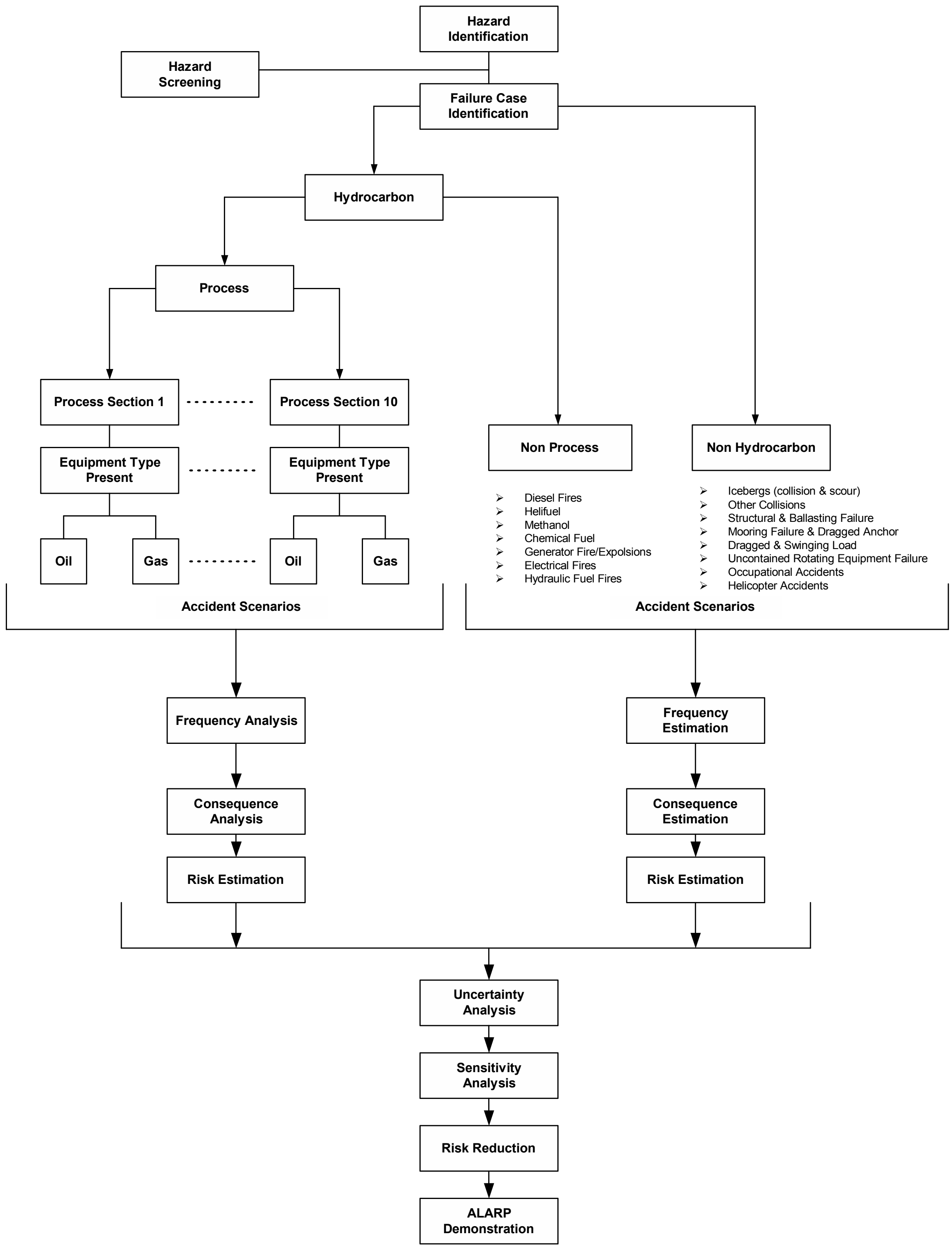


Figure 1-8: Process of Ensuring Residual Risks are ALARP

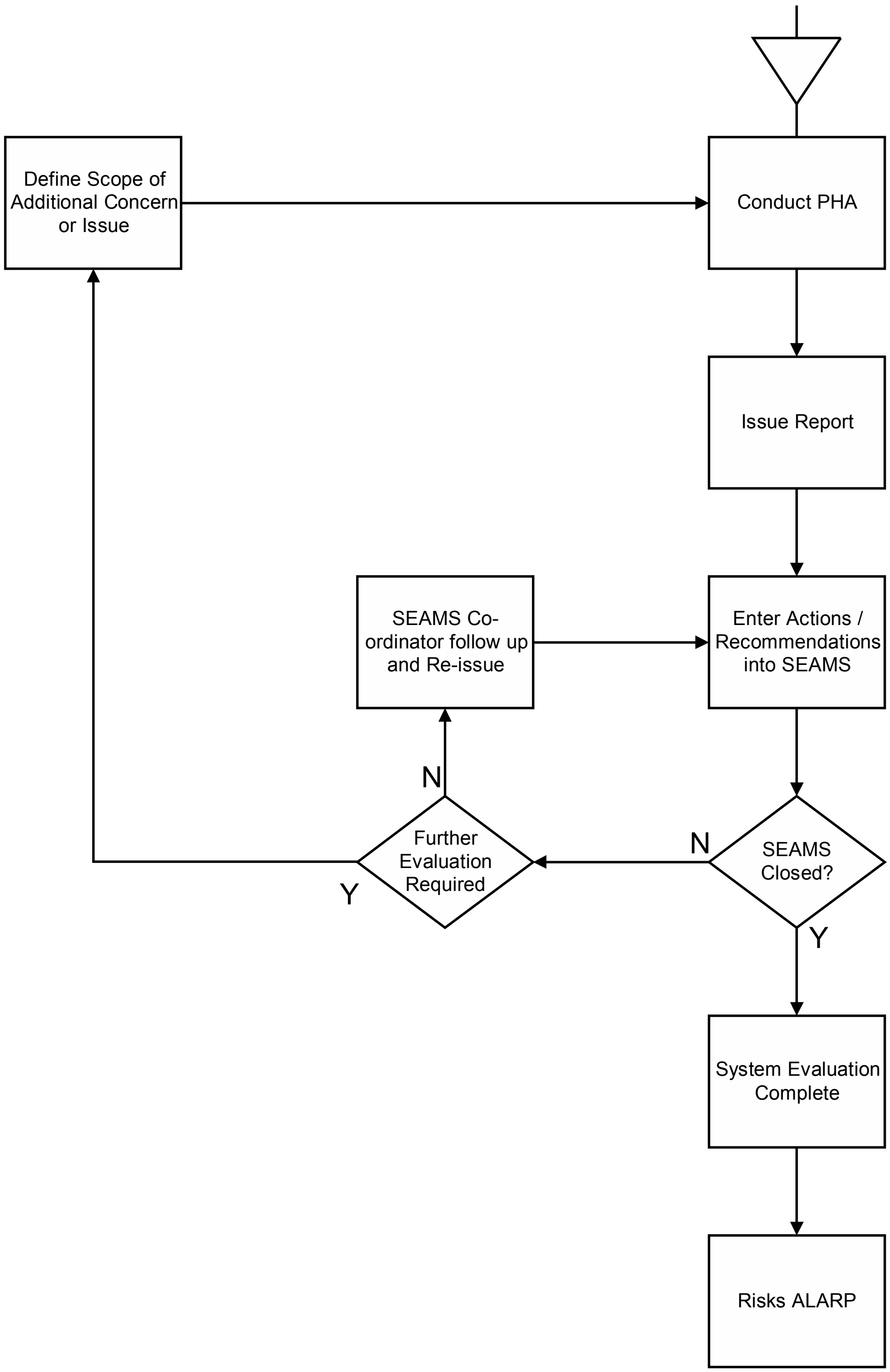


Figure 1-9 Event Tree Loss of Containment Scenario

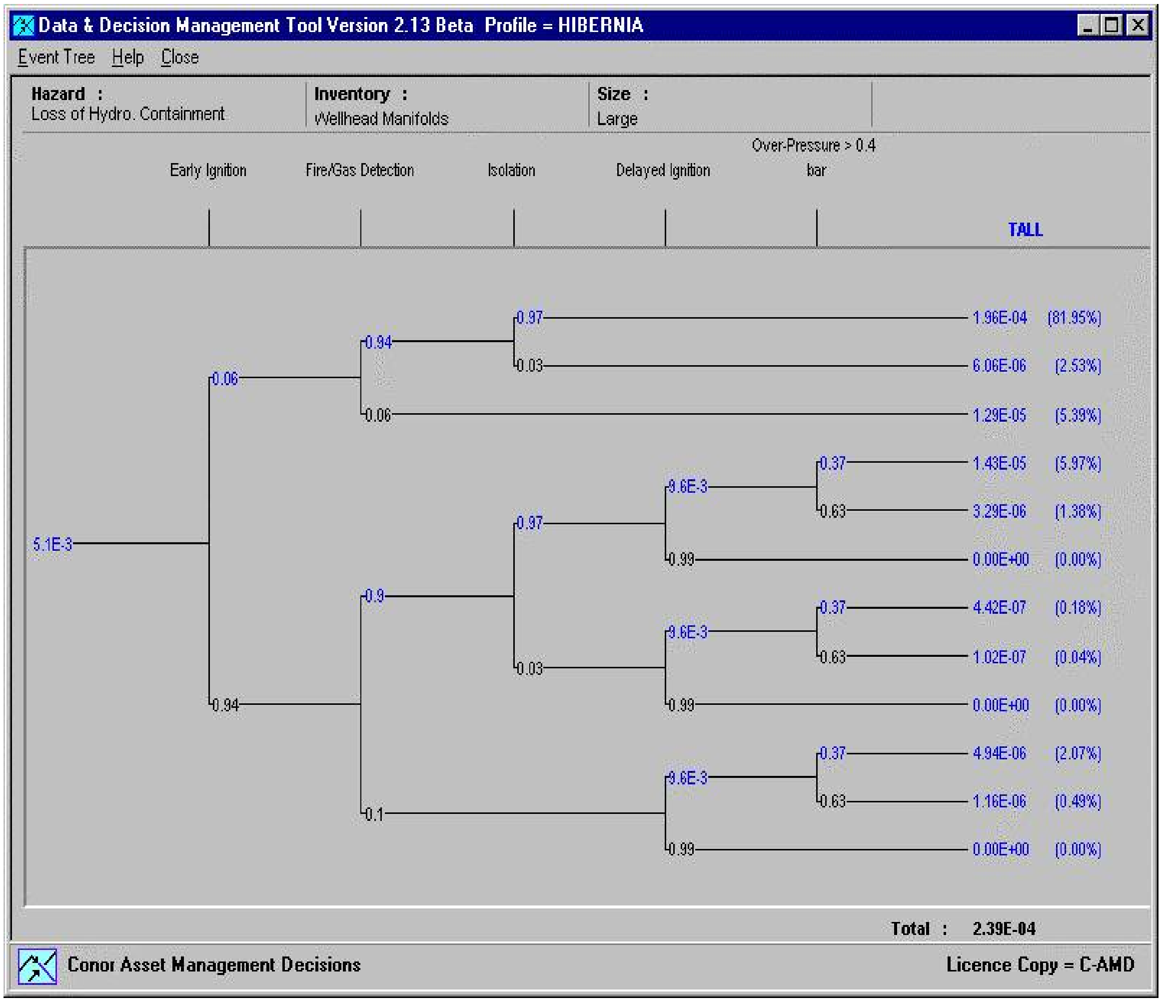
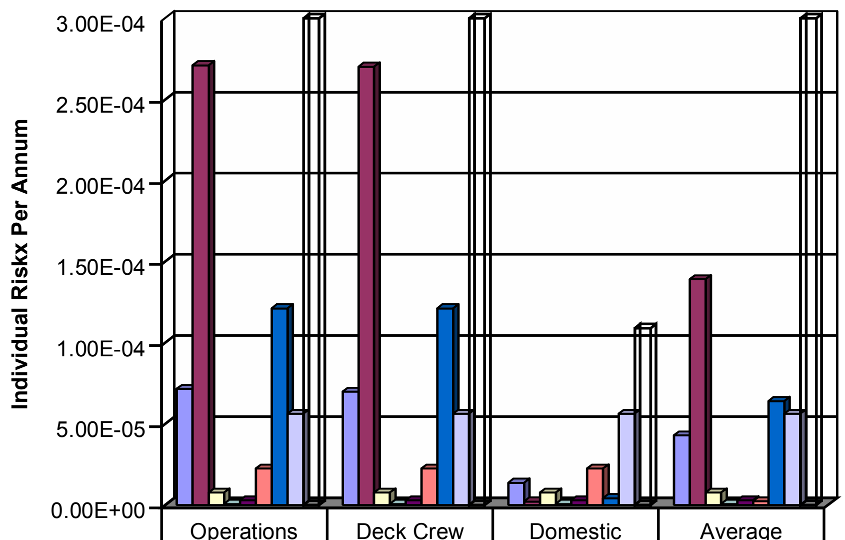


Figure 1-10: Risk Analysis Results - Average Manning Distribution (Hours Per Day)

TEAM	Position	No	Approx Outdoor Hours per person	M01 Hrs	Work Shop	M02 Hrs	M03 Hrs	M04 Hrs	M05 Hrs	T06 Hrs	T07 Hrs	Machine Space	Main Deck (equal Spread)	QC/DC Room	Total
Production	Prod	1	6	0.5	0	0.9	0.9	0.9	0.9	0.5	0.5	0	0.9	0	6
	Prod	2	4	0.25	0	0.9	2.5	0.9	0.9	0.5	0.9	0	0.9	0.42	8
	CCR	3	0	0	0	0	0	0	0	0	0	0	0	0	0
	Prod	1	2	0.3	0	0.3	0.3	0.3	0.3	0.3	0.3	0	0	0	2.1
Marine	Marine	1	4	0	0	1	0.5	0.5	0.5	0.5	1	0	0	0	4
	Marine	3	8	1	0	0	0	0	0	0	2	20	0	0	23
Maintenance	Maint	1	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0	0	0	4
	Maint	4	12	1	20	2	5	5	5	5	1	0	4	0	48
Service	Catering	7	0	0	0	0	0	0	0	0	0	0	0	0	0
	Service	1	4	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0	0	3.5
	Crane	1	2	0	0	0	1	0	0	1	0	0	0	0	2
	Deck	7	3.2	0.5	0	4	3	4	4	2	5	0	0	0	22.5
Total Man Hours in each				4.0	20.5	10.1	14.7	12.6	12.6	10.8	11.7	20.5	5.8	0.42	123.3

Figure 1-11 Distribution of Individual Risks



	Operations	Deck Crew	Domestic	Average
Risers	7.15E-05	6.97E-05	1.35E-05	4.28E-05
Process	2.71E-04	2.70E-04	2.08E-06	1.39E-04
COT fire / explosion	7.58E-06	7.58E-06	7.58E-06	7.58E-06
Iceberg collision	6.45E-07	6.45E-07	6.45E-07	6.45E-07
Ship / MODU collision	2.67E-06	2.67E-06	2.67E-06	2.67E-06
Structural / ballasting	2.22E-05	2.22E-05	2.22E-05	2.22E-06
Occupational	1.21E-04	1.21E-04	4.04E-06	6.39E-05
Helicopter	5.62E-05	5.62E-05	5.62E-05	5.62E-05
TOTAL	5.53E-04	5.50E-04	1.09E-04	3.15E-04

Figure 1-12 Contribution of Hazard to Average Risk

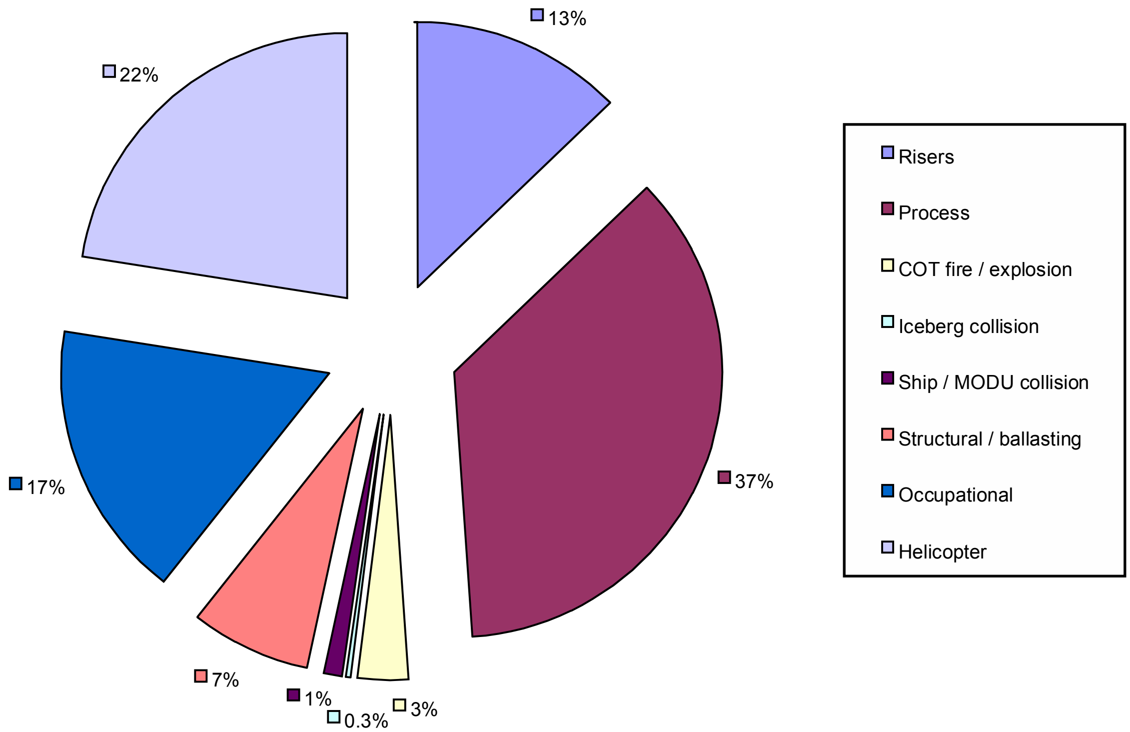
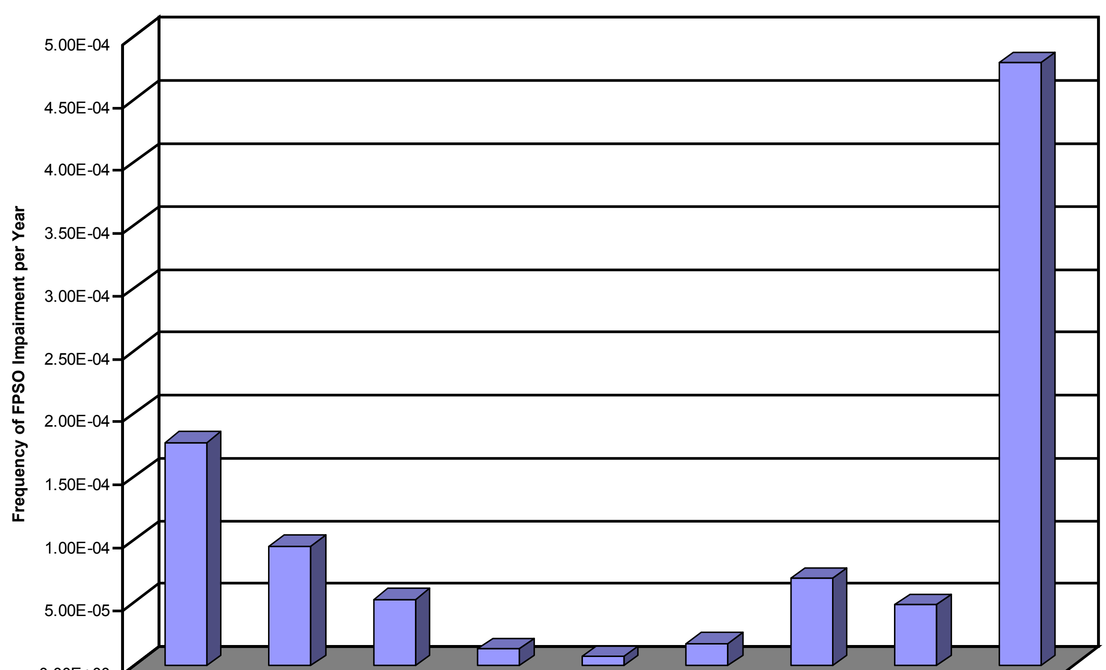


Figure 1-13 FPSO Integrity



	QCDC Room	Subsea	Gas Process	Oil Process	COT fire /explosion	Iceberg collision	Ship/MODU collision	Structural / ballasting	Total
FPSO Integrity	1.77E-04	9.49E-05	5.23E-05	1.31E-05	6.93E-06	1.75E-05	6.93E-05	4.80E-05	4.79E-04