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*Reliability of Offshore Operations:
Proceedings of an International Workshop*

Emil Simiu, Editor

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Reliability of Offshore Operations: Proceedings of an International Workshop

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NOTE: The views, conclusions, and recommendations expressed by participants in this Workshop are not necessarily those of the National Institute of Standards and Technology or the Minerals Management Service.

Glossary of Acronyms Used in These Proceedings

API-RP	American Petroleum Institute Recommended Practice
CAIRS	Computer Aided Inspection Reporting System
CCPS	Center for Chemical Process Safety
CIMAH	Control of Industrial Major Hazards
COGLA	Canada Oil and Gas Lands Administration
CPRA	Canada Petroleum Resources Act
CRBA	Cosr/Risk Benefit Assessment
CSE	Concept Safety Evaluation
DAE	Design Accidental Event
E&P	Exploration and Production
ERDA	European Reliability Database Association
FAA	Federal Aviation Administration
FAR	Fatal Accident Rates
FMECA	Failure Modes and Effects Criticality
FSA	Formal Safety Assessment
GOM	Gulf of Mexico
HAZAN	Hazard Analysis
HAZOP	Hazard and Operability Study
HC	High Consequence
HC	Hydrocarbon
HSE	Health and Safety Executive
IADC	International Association of Drilling Contractors
ISO	International Standards Organization
LC	Low Consequence
LQ	Living Quarters
LRFD	Load and Resistance Factor Design
MC	Moderate Consequence
MCAPS	Method for Comparison of Alternate Platform Systems
MMS	Minerals Management Service
MODU	Mobile Offshore Drilling Unit
MSRC	Marine Spill Response Corporation
NCS	Norwegian Continental Shelf
NHC	National Hurricane Center
NIST	National Institute of Standards and Technology
NPD	Norwegian Petroleum Directorate
OCS	Outer Continental Shelf
OHMSETT	Oil & Hazardous Material Simulated Environment Test Tank
OIM	Offshore Installation Manager
OOC	Offshore Operators' Committee
OREDA	Offshore Reliability Data
OSD	Offshore Safety Division
QA	Quality Assurance
QRA	Quantified Risk Assessment
PDQ	Production (or Processing), Drilling and Quarters
PM	Preventative Maintenance
PRA	Probabilistic Risk Assessment
RAE	Residual Accidental Event
RSR	Reserve Strength Ratio
SMS	Safety Management System

SOLAS	Safety of Life at Sea
TLP	Tension Leg Platform
TRA	Total Risk Analysis
TSR	Temporary Safe Refuge
UKOOA	U.K. Offshore Operators Association
WOAD	World Offshore Accidental Database

ABSTRACT

The proceedings of an International Workshop held at the National Institute of Standards and Technology on March 20, 21, and 22, 1991 are presented. The purpose of the Workshop was to examine new developments in the application of risk analysis in offshore oil and gas operations. The proceedings include: an executive summary, invited papers on current practice in the United States, Canada, the United Kingdom, and Norway, and summary reports and recommendations of six Working Groups: (1) Experience Data Bases and Case Study Analyses; (2) Risk Management Practices; (3) Structures: Risk and Reliability Issues; (4) Production Facilities; (5) Pipelines and Subsea Systems; and (6) Drilling Operations. Also included are Working Group theme papers.

Key words: Codes; drilling platforms; gas production; marine engineering; ocean engineering; offshore platforms; oil production; petroleum engineering; regulations; reliability; risk analysis; shipping; standards.



Proceedings of the International Workshop on

RELIABILITY OF OFFSHORE OPERATIONS

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EXECUTIVE SUMMARY

On March 20, 21 and 22, 1991 an International Workshop on Reliability of Offshore Operations was held at the National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, USA. The Workshop was organized by NIST and sponsored by the Minerals Management Service, U.S. Department of the Interior; Canada Oil and Gas Lands Administration; Offshore Safety Division, Health and Safety Executive, U.K.; NIST; and the American Society of Civil Engineers. It was attended by experts from the petroleum industry, consulting firms, government agencies, and academic and research institutions.

The purpose of the Workshop was to discuss current practice, progress, and future directions in the fields of risk management and safety/reliability analysis of offshore oil and gas operations. Recent experience and case studies were emphasized.

Invited papers on the safety of offshore installations and operations were presented by representatives of regulatory agencies in Canada and the U.K., a U.S. oil company and a U.K. industry group, and by consulting engineers active in the United States and Norway. The papers included, respectively:

- (1) An overview of the Canada Oil and Gas Lands Administration, its mandate and responsibilities, the legislative authority under which it has operated, and an explanation of the regulatory process, procedures and requirements it has formulated and implemented to provide for safety and environmental protection for offshore oil and gas operations in Canada.
- (2) A description of the Offshore Safety Division, Health and Safety Executive, U.K.; a discussion of the Piper Alpha disaster; a discussion of principles of risk and reliability and safety management; and considerations on the application of these principles offshore.
- (3) A description of the U.K. Offshore Industry's response to Lord Cullen's report on the Piper Alpha disaster, and a discussion of the centerpiece of the new U.K. approach to offshore safety, the Safety Case.
- (4) A discussion of Chevron Corporation's efforts in risk and reliability management, focused on Chevron's operations in the Gulf of Mexico.
- (5) A presentation of methods for characterizing loads and structural capacity, and of structural reliability methods and criteria, in the context of design and re-qualification of offshore platforms.
- (6) A discussion of the background to the introduction in 1981 of Norwegian Regulatory Guidelines for Concept Safety Evaluation, and of the current introduction of Norwegian Regulations for the Use of Risk Analysis in Petroleum Activities; and a discussion of the development of safety studies in Norway in the last decade.

In preparation for the Workshop co-chairmen and core groups were selected for six Working Groups: (1) Experience Data Bases and Case Study Analyses; (2) Risk Management Practices; (3) Structures: Risk and Reliability Issues; (4) Production

Facilities; (5) Pipelines and Subsea Systems; (6) Drilling Operations. Each Workshop participant joined the Working Group of her/his choice. The Working Groups discussed, in parallel sessions, preliminary reports prepared by the co-chairmen on the following issues: state of practice; problem areas; data acquisition and research needs; and opportunities for implementation and application. The Workshop Proceedings include final Working Group reports. These were prepared by the co-chairmen on the basis of the preliminary reports and the Working Group discussions. In the interest of time the final reports were not circulated to and reviewed by all Working Group participants; for this reason they should not necessarily be viewed as a definitive expression of all participants' views. The reports are summarized below.

Working Group #1. EXPERIENCE DATABASES AND CASE STUDY ANALYSES

The scope of this Working Group was defined as reviewing the potential use of existing offshore reliability and accident databases, establishing requirements and needs for future databases, and determining ways in which greater industry participation and acceptance can be accomplished. In addition to the preliminary report by the co-chairmen, the Working Group based its discussions on three theme papers. The first theme paper, presented by R. Visser and entitled "Offshore Accidents -- Lessons to Be Learned," reviewed major accidents that had a major influence on practices concerned with reliability of offshore operations. The second paper, presented by T. Gjerstad and entitled "Brief Review of the Oreda Project," discussed the results from the ongoing Oreda reliability data collection project. The third paper, also presented by T. Gjerstad and entitled "Data Collection of Hydrocarbon Leaks and Ignitions -- The E&P Forum Approach," discussed the planned approach for a new data collection project by the E&P Forum. The three theme papers are included in the Workshop Proceedings.

State of Practice. Experience databases are currently collected both by government agencies, which can ensure that the data collection is complete and from all operators, and by industry, which normally limits use of the data to participating companies and can direct data collection efforts on specific objectives of interest to participants.

Accident databases are maintained by the Minerals Management Service for federal waters in the Gulf of Mexico, the Institut Francais du Petrole for accidents worldwide, and by various individual companies for specialized statistics (e.g., mobile drilling unit failures, offshore worker fatalities).

Accident frequency databases (i.e., accident databases tied to population data) are maintained worldwide by Veritec.

Equipment reliability databases include the Oreda program, which now has several European and two U.S. participants, and the E&P Forum, the objectives of which are to develop data collection guidelines for hydrocarbon leak and emission events, and to set up an initial database of release data.

Structural platform inspection data have been collected by the Minerals Management Service since 1988, when reporting of the structural condition of the some 3700 platforms in the Gulf of Mexico became mandatory. (Inspections are

required every 5 years.)

Problem Areas. One possible problem is the misuse of information through misinterpretation, which could lead to favoring certain technological solutions or products, rather than seeking their improvement. A second problem is the restriction of data use to participating companies, as in the case of the Oreda data; without such restrictions those companies would normally not be prepared to engage in the data collection. A third problem is the lack of a standard methodology for data collection. A fourth problem is the possible misuse of data in liability court cases, especially in the United States. It was noted, however, that such legal difficulties do not appear to have arisen in the airline industry, which maintains extensive equipment failure databases.

Research Needs. To show the usefulness of data collection case analyses should be performed. These should use the data not only for quantitative risk estimates, but also to compare possible solutions to various safety problems in offshore operations. As far as the Minerals Management Service events file is concerned, it would be worthwhile tying the data in with population data. Since many databases exist that are not widely known, a directory of available databases should be compiled. When the E&P Forum database becomes available, its data should be calibrated and checked against Minerals Management Service events file data. Advantages of Oreda membership expansion should be considered. There is a need to separate clearly in databases those accidents due to organizational causes from those due to human error. Outside technical audits should be considered. These would concentrate on platform safety and life safety problems, reviewing systems, training and so forth, and would report to the highest management levels. A data collection conference that would seek to establish data collection standards could be useful.

Implementation and Application. An illustrative example was outlined of the possible implementation and application of databases in an offshore production organization. In that example data on release events and safety system failures were used in conjunction with fault trees to define frequencies of scenarios that could cause fatalities in safe haven facilities.

Working Group #2. RISK MANAGEMENT PRACTICES

The purpose of this Working Group was to review principles and practices of risk management in the regulation of the offshore oil and gas industry. The Working Group noted the significant progress made in the last decade in risk assessment and risk management practices. The Working Group report incorporates material from a theme paper presented by J. E. Vinnem and is based, in addition, on discussions by Working Group participants.

State of Practice. The report emphasizes the state of practice in Norway, the first country to adopt risk management principles in the regulation of offshore operations. In Norway the certifying authority operates on behalf of the government. Formerly, acceptance criteria were issued by the Norwegian Petroleum Directorate (NPD). More recently, regulation requires operators to set their own long term safety goals, rather than imposing a 10^{-4} /year criterion under all circumstances. The primary objective of risk assessments during planning and

design is the identification of Design Accidental Events (DAE), that is, events that the platform should be designed to sustain. Estimates are then made of the frequencies of Residual Accidental Events (RAE), i.e., events that the platform is assumed not to be capable of sustaining. These frequencies should be compared with the 10^{-4} /year cut-off limit per safety function and for each hazard type. The Concept Safety Evaluation (CSE) was formally required as of September 1, 1981 for production installations on the Norwegian Continental Shelf. Accident scenarios are identified by taking into account possible initiating events, possible failures of safety systems, and environmental conditions. DAE's are identified from among these scenarios. The 1981 Guidelines specify six DAE requirements, including the requirement that personnel outside the immediate vicinity not be injured, and that safe evacuation be possible. The use of Probabilistic Risk Assessment (PRA) techniques is viewed as an indispensable element in the implementation of the risk management approach inherent in Norwegian practice.

Brief sections are devoted to practice in the United Kingdom and the United States. In the U.K., the Safety Case requirement, recommended by the Cullen Report following the Piper Alpha disaster, dominates the approach to risk management. Its main feature is that the approval of safety is based on dedicated assessment of the specific conditions on each installation, rather than on meeting prescriptive standards or guidelines. The Safety Management System (SMS) should include a quantified risk analysis assessment, a fire risk analysis, and an evacuation, escape and rescue analysis. Regular audits are recommended, to be performed internally by the operator and by the regulatory body. In the United States risk assessment and risk management techniques are just beginning to be used. A recent application is the Methodology for Comparison of Alternate Platform Systems (MCAPS).

The application of risk management principles to offshore operations is illustrated in the report by a case study analysis of a recent development project on the Norwegian Outer Continental Shelf.

Problem Areas. Lack of data remains a main obstacle in the efficient use of risk management techniques. In Norway risk assessments are not used for verification of safety levels, but rather as a design tool. The possible fear on the part of industry that risk assessment tools could be used to require "proof" of an acceptably low risk level may inhibit their use. Thus it is necessary to emphasize that the process of risk assessment, rather than a set of numerical results, is of primary significance. Results should be viewed in a notional probability, rather than in an actuarial, sense. Finally, "exactness" in the physical model should not be carried too far, since it could render the analysis prohibitive without achieving significant improvements in the results.

Research Needs. Research is suggested on the expanded utilization of PRA for Cost/Risk/Benefit Assessments. The development of appropriate software also warrants additional effort. Continued attention should be given to the integration of risk assessment into the design process, keeping in mind that the risk assessment process itself has the highest value, while analytic (numerical) results are usually of minor importance; and that risk assessments can be used

without creating significant controversies.¹ It is suggested that PRAs are potentially useful in the context of life cycle cost optimization. Research is also warranted on integration of PRA's into operational planning, including maintenance and inspection planning and specification of equipment standards. Research is needed on the physical modeling of certain fire and explosion scenarios, and for the failure mechanisms of novel systems, e.g., flexible pipelines. Also needed are data on the reliability of safety systems, leaks, and ignition of oil and gas.

Implementation and Application. Major opportunities for implementation and application of risk management techniques include studies for the upgrading of first generation platforms, and studies of platforms in deeper waters.

Working Group #3. STRUCTURES: RISK AND RELIABILITY ISSUES

For the sake of efficiency, the discussions were focused around the following four issues: (1) Reassessment of Steel Jackets; (2) Optimization of Inspection, Maintenance and Repair; (3) Risk Management of Novel/High Consequence Systems; and (4) Design: Reliability-based Design, Design Norms (Standards), and Life-Cycle Design Optimization.

State of Practice. First generation structural-mechanical and structural reliability tools are available for use in the reassessment of steel jackets, but there is no consensus on how to use the results in decision making.

Reliability-based methods applicable to individual members have been developed and used successfully for inspection planning. Recent advances have coupled these member-oriented analyses with multiple deterministic push-over studies to identify the more critical members for inspection focus. Inspection was felt to be pertinent primarily to platform reassessment; for new platforms the first line of defense should not be inspection, but design allowing for sufficiently long fatigue lives.

The acceptance by industry and the likelihood of performing risk analyses of novel and/or high consequence systems have improved since 1984. However only relatively few operators and contractors have the requisite expertise; the receptivity to risk analyses on the part of regulators varies geographically; and there is a lack of standardized guidelines for decision making based on risk analyses. These factors, among others, still limit the application of risk/reliability analyses.

¹Some practitioners believe that safety decisions based on Probabilistic Risk Assessments (PRAs) are not significantly affected by uncertainties in the probability distributions used in the PRAs. However, there are indications that this belief is not warranted in general, even if PRA results are used in a notional and relative sense. The possible effect of such uncertainties on various types of safety decisions should therefore be viewed as an important research topic. (*Editor's note.*)

Much progress has been made since 1984 in the areas of reliability-based design, design norms, and life-cycle optimization. Reliability-based design norms with deterministic format (e.g., LRFD) are now being routinely developed in many parts of the world for various types of structure, including conventional jackets. A similar development is under way for tension leg platforms. Direct reliability-based design is feasible computationally if standard assumptions are used on the pertinent probability distributions. Interest on the part of industry would be needed for this capability to develop. This is also true of full-life-cycle, cost-risk benefit optimized designs.

Problem Areas. Push-over analyses appear not to provide a realistic basis for estimating reserve strength ratios for platform reassessment purposes. Work is needed to correct this state of affairs. In particular, this is true for damaged structures/members. Advanced analysis approaches (e.g., nonlinear finite elements analyses) are available to help in this regard.

Difficulties still remain with regard to assessing correctly (a) the probability of detecting defects given a particular device/operator combination and (b) the probability of sizing defects correctly. Probabilistic tools for inspection planning developed in Norway are based on various assumptions, such as initial flaw size, that need careful scrutiny. These tools require extensive efforts to produce requisite input data (e.g., structure-wide fatigue analyses). Finally, to date no adequate procedures for planning inspection appear to have been devised that account for such needs as marine growth or damage due to dropped objects.

Mechanisms for analyzing the uncertainties inherent in probabilistic assessments for novel types of structures are not widely agreed upon. Problems also exist with regard to the definition of target failure probabilities. The whole area of probabilistic design and assessment for novel types of structures is still in its infancy.

Where probability-based methods exist (e.g., for jacket platforms), there are wide discrepancies between approaches existing in different countries. This entails potentially difficult code calibration issues. The state of the art is still insufficiently developed in the area of reliability-based foundation design.

Although reliability-based codes are beginning to emerge for jack-up platforms and tension leg platforms, these are not usable in practice owing to calibration difficulties.

Design for ice forces in the Arctic is well suited for probabilistic treatment, but developing adequate models and databases remains a formidable task.

Life-cycle design optimization appears to be an unattainable goal at present owing to unavailability of sufficient probabilistic information. However, use of probabilistic methods for specific limited goals appears to be feasible in some cases (e.g., limiting downside risk if extended use is required).

Research Needs. These include: the establishment of agreed methods for performing system reliability analysis of complex or novel structural types and of

foundations; the development of acceptable methods for describing (a) joint occurrence of environmental loads and (b) uncertainties in all probabilistic estimates of concern; development of philosophies for setting performance goals and acceptance criteria; development of methods for transferring reliability analysis methods.

For jacket reassessment/re-qualification, it is necessary to: establish performance goals for reserve strength, robustness, consequences, ductility; develop techniques for assessing realistically material characteristics in an existing jacket (e.g., toughness, yield); model potential occurrence of sequential near failure loads and the resultant low-cycle degradation; evaluate repair techniques and their probabilistic implications; establish agreement on approaches to analyzing and defining ultimate capacities of structures, particularly under earthquake loading; develop methods for estimating reserve strength ratios from push-over analysis; collating databases for use in public domain.

For optimal inspection, maintenance and repair planning, it is necessary to develop: methods for quantifying probability of detection and correct sizing of defects; inspection planning tools linked to importance/criticality of component to be inspected; and approaches to foundation condition inspection and assessment.

For risk management of novel and/or high consequence systems, research is needed on: establishing relevant failure modes; developing system reliability tools to investigate sensitivity of overall reliability to failure modes that may be overlooked; assessment of human error effects during design and effects of accidental loads; incorporating uncertainties in system reliability analyses; establishing target risk levels that account for modeling uncertainties and damage tolerance measures; assessment of installation risks; establishing rationale for specifying environmental design criteria (e.g., 100-year, 1,000-year or 10,000-year load) and design factors; modeling of load effect combinations.

For reliability-based design, research is needed on: allowance to be made in codes for modeling errors; development of a code format for compliant/dynamic platforms; combinations of environmental effects for compliant/dynamic platforms; system redundancy/robustness factors in design codes; split-factor code design for foundation systems and for seismic loadings; probabilistic modeling of ice forces in the Arctic; approaches to limit "downside risk" following from decision to extend platform use; development of commonly agreed paradigms for developing reliability-based design codes.

Opportunities for Implementation. Probabilistic tools are already available for use in areas where the needs listed earlier exist. There are opportunities for implementation in each of these areas, provided that current impediments are overcome. To achieve this, the following are needed: firmer guidance in use of risk analysis results, broader dissemination of expertise and, when warranted, explaining to managers/regulators the need for and advantages of a probabilistic approach.

Working Group #4. PRODUCTION FACILITIES

In addition to the preliminary Working Group report by the co-chairmen, brief reports were presented on the following topics:

- (1) Arco practice for installations in the Gulf of Mexico and in the U.K.
- (2) Exxon practice for platforms in Australia
- (3) Mobil practice for platforms in Nigeria
- (4) Perspectives of a small operator in the Gulf of Mexico, presented by Paragon Engineering
- (5) Shell Oil practice for Gulf of Mexico installations

The discussions were focused on risk analysis. Although the participants kept in mind the general framework proposed for Working Group discussions, it was found more effective to organize the report around the following questions:

Do We Need to Adopt More Formal Risk Assessment Technologies for Offshore Production Facilities Design and Operation? It was noted that the application of risk assessments have been found useful both by authorities and oil companies. Simplified assessments are adequate where great detail and accuracy are not needed. The practice of risk assessment has been established in areas with much larger and more complex platforms than, e.g., in the Gulf of Mexico. Risk assessments can in some instances be useful even if they provide only qualitative information. Risk assessments may not be necessary for facilities that are similar to other facilities for which assessments have already been made, or for small and simple platforms.

Do We Need a Safety Case Similar to that Proposed by Lord Cullen for the British Offshore Industry? The Safety Case must demonstrate that the company's Safety Management System (SMS) and the installations are adequate for design and operation. The Working Group concluded that SMS's are needed and that API RP 750 provides adequate recommendations for such systems. Preparation of a Safety Case exactly as proposed by the Cullen Report is deemed not to be generally necessary.

What Techniques Should be Used to Identify Hazards in Offshore Facilities? No technique is a substitute for experience. Hazard identification requires proper definition and subdivision of facilities and activities. No hazard should be omitted because a part of a system was not considered, and no hazard should be counted twice. Typical techniques include Hazard and Operability Studies (HAZOP's), use of checklists, failure mode and effects analysis, and searches for possible unwanted energy releases. HAZOP's and checklists have the advantage of facilitating the involvement of designers and operation personnel into the risk analysis, but for new types of applications some appropriate guide-words may be missing and would have to be added. None of the techniques listed guarantees identification of all hazards, which requires a combination of techniques supplemented by experience and judgement.

What Tools Are Best Suited to Perform Consequence Analyses? Such tools include,

e.g., finite element capabilities, software, and so forth. To assist the risk analyst a system of certification of such tools -- especially software -- would be needed. Databases are needed for selected equipment which is common to most platforms and which is vital for safety. Better data are also needed on the reliability of human interventions and reactions in critical situations.

Should Frequencies of Incidents be Part of a Risk Assessment or a Safety Case? The analysis need not include detailed quantitative information on frequencies if decisions on alternatives do not require it. The Working Group was not in full agreement as to what this means in practice.

What Type of Risk Acceptance Criteria Should be Used? The Working Group concluded that acceptance criteria should preferably be qualitative. However, in cases where Quantified Risk Analyses have to be used, the criteria should be in the form of maximum allowable probability for loss of specified safety functions.

Should Regulations, including Risk Acceptance Criteria, be Prescriptive or Performance Oriented? In practice offshore regulations are basically prescriptive, but some classification societies accept the "equivalent safety principle," which allows deviations from prescriptive rules. The Working Group concluded that prescriptive regulations are desirable for simple platforms in well known environments; performance oriented regulations may be desirable in more complex situations; and the "equivalent safety principle" should always be included.

What Resources Should be Provided to Enhance Process Safety, and Which Organizations Should Take the Lead in Providing Them? Industry should cooperate to develop risk management and design guidelines on various aspects of design, operations, and hazard identification; failure rate databases on about 25 types of offshore production equipment and on human errors; structural design guidelines for accidental loading due to fire and explosion; exchange of accident data for production facilities; and better quality databases covering a broader range of accident severity. Industry and government agencies should cooperate to develop and/or accept models and corresponding parameters for use in accident consequence assessments.

Conclusions. Formal risk assessments may enhance the reliability of offshore facilities. However, preparation of a safety case on the model proposed by Lord Cullen was deemed unnecessary for facilities installed in the open atmosphere. Factors that influence the need for formal risk assessment include confinement within modules, and density of obstacles and of potential sources of release.

Working Group #5. PIPELINES AND SUBSEA SYSTEMS

The discussions were based in large part on recommendations of a report on this theme included in the Proceedings of the 1984 International Workshop on Application of Risk Analysis to Offshore Oil and Gas Operations held at the National Bureau of Standards, Gaithersburg, Maryland.

State of Practice. Different techniques are generally used for subsea systems on the one hand and for pipelines on the other. Techniques used for subsea systems

include: (i) Failure Mode and Hazard Identification Techniques (e.g., Check Lists; Failure Mode and Effects Criticality Analysis (FMECA); and Hazard and Operability Studies (HAZOPs)); (ii) System Evaluation Methods (e.g., Fault Trees; Event Trees; Network Analysis; Parts Counts/Parts Stress Method; Availability Modeling; Dropped Object Risk Assessments). For pipelines industry generally relies for safety on pipeline design standards. Internal and external inspection are used to remove doubts on the condition of a pipeline.

Problem Areas. For subsea systems hardware the need exists for definitive failure rate data for components; however, data on causes of failure do not appear to be necessary at this time. Current reliability prediction techniques at a systems level were viewed as adequate. Development of techniques for prediction of component reliability from first principles was considered impractical and largely unnecessary. However, methods for relating component reliability to design, quality assurance, or manufacturing practice would be useful to component manufacturers and for reliability specifications. For subsea operations the need for and the benefits of risk assessments for dropped objects was discussed. A code of practice for such assessment appears to be of interest particularly for North Sea operators. Research appears to be needed on models for trajectories and velocities of falling objects in water. For pipelines it was noted that although existing standards have served the industry well, they have a number of deficiencies, such as: (a) not dealing with certain failure modes, including those due to corrosion or other damage, or upheaval buckling in the North Sea and Arctic; (b) reliance on subjective stress safety indices, rather than on quantification of component or system reliability; (c) lack of guidance on inspection data accuracy and on how inspection data should be effectively used in risk/reliability assessments for maintenance and rehabilitation decisions. These deficiencies may be due to the assumption -- which may or may not be warranted -- that the reliability of pipelines is so high compared to that of subsea system components that it may be neglected as a factor in overall reliability analyses. There was general interest in use of risk and reliability assessment methods for existing pipelines, and some support for the gradual development of a code of practice. For both subsea systems and pipelines, the use of hazard analysis techniques is needed in the context of a total effort also involving topside facilities. Documented guidance in the form of a code of practice on the use of these techniques will be a useful and important step.

Opportunities for Implementation and Application. (1) Reliability, availability and hazard assessment tools should be developed in view of their importance for effective subsea technology implementation and application. (2) While those tools exist, there is a need for standards, guidelines, and recommended practices. (3) The development of a comprehensive reliability-based code of practice is desirable but not practical except as a gradual, long-term proposition. (4) In the short term recommended practices, reliability and event data requirements, and recommended data sources should be developed for subsea systems HAZOPs, FMECAs, Fault Trees, and Availability Analyses. (5) API and MMS would be the most appropriate bodies for generating recommended practices and codes. (6) Current lack of a generally available database for subsea operations is an obstacle to the application of quantitative reliability assessments techniques. (7) Given the sparsity of subsea reliability data and event data, it is recommended that an international joint industry-government program on collection of such data be initiated for subsea components, pipelines and systems.

Working Group #6. DRILLING OPERATIONS

State of Practice. Reliability analysis methods are not routinely used in drilling operations. To help understand their potential application the Working Group report briefly reviews the basic concepts used in this type of analysis, the way in which drilling operations are managed, and the primary hazards affecting them. It is noted that the overall drilling process does not lend itself to classical reliability analysis. Nevertheless, a number of offshore drilling sub-systems and processes are cited that have been studied using reliability analysis procedures.

Problem Areas. These include the absence of accurate data on failure modes and failure rates. The accurate modeling of human error becomes increasingly difficult as the complexity of the system increases and the amount of interaction required for system operation is larger. Various agencies have overlapping requirements. Internationally recognized standards are needed.

Research Needs. High priority should be given to: (1) rig automation, (2) escape and evacuation in harsh environments, (3) handling shallow gas flows, (4) optimum frequency of testing subsea blowout preventer equipment, and (5) safety margins in casing programs.

ACKNOWLEDGMENTS

The International Workshop on the Reliability of Offshore Operations was sponsored and supported by the Minerals Management Service, United States Department of the Interior. It was co-sponsored by the Canada Oil and Gas Lands Administration, which provided partial support, and by the U.K. Department of Energy, the National Institute of Standards and Technology, and the American Society of Civil Engineers.

Credit for initiating the Workshop goes to Mr. Charles E. Smith of the Minerals Management Service. Thanks are also due to the members of the Advisory Committee, the co-chairmen of the Working Groups, and the participants in the Working Groups. A fascinating talk given at the Workshop banquet by Dr. Edward Wenk Jr. on management of risk in technological megasystems was highly appreciated by the Workshop participants.

The success of the Workshop is due in no small measure to the organizing skills and the hard work of Ms. Kathleen Kilmer, Ms. Lori Phillips, and Ms. Sandra Auchmoody. The patient and careful review of the manuscript by Ms. Diana Todd, Dr. Felix Yokel and Mr. D. R. Harris of the National Institute of Standards and Technology is also acknowledged with thanks.

PURPOSE OF THE WORKSHOP

The purpose of the Workshop was to discuss current practice, progress, and future directions in the fields of risk management and safety/reliability analysis of offshore oil and gas operations. Recent experience and case studies were emphasized. Participants included representatives of the petroleum industry, consulting firms, government agencies, and academic and research institutions.

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WELCOMING REMARKS

Dr. Richard N. Wright
Director, Building and Fire Research Laboratory
National Institute of Standards and Technology

Representatives of the petroleum industry, consulting firms, government agencies, and academic and research institutions, from the United States, Canada, the United Kingdom, France and Norway are gathered here today in an effort to advance the state of the art in the fields of risk management and safety/reliability analysis of offshore oil and gas operations.

NIST is proud of its long history of contributions to the solution of technical problems related to offshore operations. For more than three decades designers of offshore platforms around the world have used wave loading criteria based on the dimensionless number named after Keulegan and Carpenter, two fluid dynamicists who performed their classic work at the National Bureau of Standards.

More recently, the Minerals Management Service, the principal co-sponsor of this Workshop, has supported NIST work on structural, fire, and materials problems involved in offshore operations. This work has included research on the dynamics and reliability of deep-water compliant platforms; arctic concrete structures; weldments of arctic structures; concrete punching shear; composite materials for deep-water structures; fitness-for-service fatigue criteria; containment of blow-out fires; promotion of burning of oil on water, and the study of the pollutants produced by such burning. Some of this work has subsequently developed into large joint industry projects, as in the case of the punching shear project.

Given this history, NIST is pleased to serve as a host and co-sponsor of this Workshop.

Our countries have a great stake in the development of procedures ensuring that offshore oil and gas operations are safe and pollution-free. It is the goal of this Workshop, of its distinguished speakers, of its Working Group Chairmen, and of its participants, to contribute to this development.

I wish you every success in your work toward this goal.

Thomas Gernhofer
Associate Director, Minerals Management Service
U. S. Department of the Interior

On behalf of Mr. Barry Williamson, the Director of the Minerals Management Service (MMS), welcome to the Workshop on the Reliability of Offshore Operations.

The new MMS 5-year lease plan emphasizes the development of natural gas. There are eight sales scheduled in the Alaska Region, two in the Atlantic Region, twelve in the Gulf of Mexico Region, and one in the Pacific Region.

As a result, operations on the Outer Continental Shelf will be moving into two new frontiers, deep water and arctic ice. The MMS is leasing tracts in water depths up to 3,000 m. Such water depths pose a technological challenge for exploration and development. The sale areas in Alaska include remote areas of the Beaufort and Chukchi Seas where ice conditions will make operations more difficult.

The offshore industry has a good safety record and the MMS will strive to ensure its preservation by expanding MMS requirements for safety, training, and environmental protection. The MMS is also considering a new inspection strategy for the Gulf of Mexico that includes increased numbers of unannounced oil spill drills and the reinstatement of civil penalties.

The MMS will also increase funding for oil spill containment and cleanup research and will reopen the Oil and Hazardous Material Simulated Environmental Test Tank (OHMSETT).

The MMS is actively pursuing establishing ties with foreign regulatory agencies and has cooperative agreements with the United Kingdom, Canada, and Australia for research purposes.

Finally, the MMS will continue to sponsor international workshops like this one. These have proven to be valuable to industry and government alike. Future workshops are planned for offshore pipeline safety, and seismic effects on platforms.

Thank you and have a successful workshop.

INVITED PAPERS

**SAFETY AND ENVIRONMENTAL PROTECTION
FOR OFFSHORE OIL AND GAS OPERATIONS
IN CANADA**

G.R. Yungblut
Director General, Engineering Branch
Canada Oil and Gas Lands Administration

ABSTRACT

This paper presents an overview of the Canada Oil and Gas Lands Administration (COGLA), its mandate and responsibilities, the legislative authority under which it has operated, and a fairly detailed explanation of the regulatory process, procedures and requirements it has formulated and implemented to provide for safety and environmental protection for offshore oil and gas operations in Canada.

1. Background and Responsibilities

For the past 10 years the Canada Oil and Gas Lands Administration has been the Federal Government's principal contact with the petroleum industry in matters relating to the management and regulation of oil and gas activities on what is technically known as Frontier Lands. COGLA was established in 1981 by a Memorandum of Understanding between the Minister of Energy, Mines and Resources and the Minister of Indian and Northern Affairs. It replaced the Resource Management Branch of EMR and the Northern Non-Renewable Resources Branch of DIAND who, at that time, were responsible for oil and gas matters on Canada Lands - the Resource Management Branch for those areas lying South of 60° and the Northern Non-Renewable Resources Branch for areas North of 60°. At that time, Frontier Lands included all offshore areas on both the East and the West Coasts, the Arctic Offshore, the Hudson Bay, the Arctic Islands, the Yukon Territory and the Northwest Territories.

Since then, agreements have been reached with the Newfoundland and the Nova Scotia Provincial Governments whereby the management and regulatory responsibilities on the East Coast have been assigned to offshore petroleum boards. At present, COGLA is responsible for the Arctic Offshore, the Hudson Bay, the West Coast, the Arctic Islands, the Yukon Territory and the Northwest Territories. However, agreements-in-principle are in the process of being negotiated which will eventually turn over the responsibilities for oil and gas activities in these regions to organizations that are structured similar to those that now exist in Nova Scotia and Newfoundland.

The prime responsibilities of COGLA are twofold. The first is to manage the oil and natural gas resources that lie within Frontier Lands. The second is to regulate the exploration for and the development and production of these hydrocarbon resources. To facilitate the carrying out of its mandate, COGLA is organized with five branches. These are: the Rights Management Branch, the Resource Evaluation Branch, the Policy Analysis and Coordination Branch, the Environmental Protection Branch and the Engineering Branch. Today, I will be

discussing mainly the work of the Engineering Branch and indirectly the support provided by the Resource Evaluation Branch and the Environmental Protection Branch.

The responsibility to manage the oil and gas resources involves acting as the property manager, on behalf of the Canadian public, of those resources on lands that are the direct responsibility of the Federal government. The authority to manage federally controlled lands is provided through the Canada Petroleum Resources Act. In performing this function, COGLA evaluates the potential of each geological basin and arranges for land sales whereby companies can acquire the right to explore for oil and gas. Tied to this exploration activity is the right of the company to produce whatever hydrocarbon resources are discovered.

Also instrumental to the management role of COGLA is its responsibility to ensure that resources are explored for, that they are developed in an appropriate time frame, and that the terms and conditions of any development and production activity are such that the government and the public will receive the best overall return from the resource. The return from the resource is not simply royalties but includes employment, creation of new skills, development of infrastructure in remote areas, meeting the security of Canada's supply needs, and many other associated benefits.

The responsibility to regulate oil and gas activities, which is provided through the Oil and Gas Production and Conservation Act, involves ensuring that the program of work is carried out in such a manner that the workers' safety is adequately protected, that the risk of pollution to the environment is minimized, that the hydrocarbon resources are not wasted through poor production practices, and that the exploration, production and transportation facilities that are to be used in connection with the program of work satisfactorily provide for the above. These concerns are regulated through a system of approvals based on a comprehensive assessment of a proposed project against the requirements and standards set out in regulations and guidelines. In addition, during the life of an exploration or production project, all facilities and operations are carefully monitored and regularly inspected to ensure that the facilities are being adequately maintained, that proper operating and safety procedures are being followed and that good resource management practices are being implemented.

COGLA presently administers three significant pieces of legislation. They are:

- The Canada Petroleum Resources Act;
- The Oil and Gas Production and Conservation Act; and
- Part II of the Canada Labour Code.

The first piece of legislation, the Canada Petroleum Resources Act (CPRA), provides for the granting to individuals or companies the right to search for, to develop and to produce petroleum resources. Its main features consist of:

- the process for granting rights and interests;
- establishing "exploration licenses";

- establishing "significant discovery licenses";
- requiring at least 50% Canadian ownership in the development of a field;
- authority to set and collect royalties;
- establishing the "environmental studies research fund";
- establishing processes for transfers, assignments and registration of interests; and
- generally provides for enforcement.

The second piece of legislation is the Oil and Gas Production and Conservation Act (OGPCA). The purpose of the Act is:

- to ensure the safety of workers;
- to prevent pollution;
- to prevent the waste of resources;
- to ensure proper facilities are used; and
- to encourage the use of Canadians.

This Act has incorporated several important features pertinent to the regulation of oil and gas activities. It:

- provides authority to make regulations;
- provides authority to regulate;
- establishes the requirement for an approved development plan;
- creates a "Chief Conservation Officer" to make decisions respecting safety, resource conservation, and pollution prevention - with the power to order activities to cease;
- creates "Conservation Engineers" to enforce the Act and its regulations - with the power to order activities to cease if a safety regulation is being violated;
- provides for forced unitization;
- creates "absolute liability" in regard to spills and debris;
- provides for prosecution where an operator contravenes the regulations or certain other parts of the Act, and stipulates the maximum penalties; and
- establishes the "Oil and Gas Committee" to hear appeals, to hold inquiries and to make orders in respect of resource conservation matters such as

water flood schemes, pressure maintenance, etc.

Amendments to this Act are presently in the process of being prepared. These amendments are primarily in response to the recommendations of the Royal Commission on the Ocean Ranger Disaster (Hickman Commission) and other work that was done around that disaster. The main purpose of the amendments is to further enhance the safety provisions of the Act. These will consist of:

- establishing the requirement that owners and operators provide a declaration that equipment and facilities are fit for the purpose for which they are to be used;
- establishing the requirement that operators obtain a "Certificate of Fitness" for certain facilities and installations from an approved "Certifying Authority";
- creating a "Chief Safety Officer" and "Safety Officers" who will have the power to order activities to cease if there is risk to the worker;
- creating a requirement for each offshore installation to have an "Installation Manager" who will have specific powers, similar to those of a ship's captain, and who will be required to have specific qualifications;
- creating an "Oil and Gas Administration Advisory Council" which will be tasked with ensuring consistency in the application of regulations amongst the various regulatory agencies;
- creating an "Offshore Oil and Gas Training Standards Advisory Board" which will be tasked with advising on the training requirements of offshore workers and on the adequacy of various training courses; and
- establishing the requirement for an independent investigation of all serious accidents or oil spills.

The third piece of legislation is the application of the "Canada Labour Code". COGLA was given the responsibility for enforcing it, through a Memorandum of Understanding with Labour Canada, in 1987.

The Labour Code's principle objective is to ensure a safe work place. Its main features consist of:

- the authority to make and enforce regulations;
- establishing an employee's right to know if a danger exists;
- establishing an employee's right to participate in matters involving safety;
- establishing an employee's right to refuse dangerous work;
- establishing the specific duties of the employee and employer with respect

to safety matters; and

- creates "Safety Officers" and "Regional Safety Officers".

COGLA enforces two sets of regulations under Part II of the Canada Labour Code. The first is the Oil and Gas Occupational Safety and Health Regulations (OSH). It deals primarily with:

- specifying the equipment and material that can or should be used;
- requiring and specifying how workers are to be given information on hazardous material to meet the Workplace, Hazardous Materials, Information System (WHMIS) requirements;
- ensuring accidents and dangerous situations are reported and investigated;
- requiring that safety procedures are in place; and
- requiring that workers be properly trained and informed about potential dangers.

The second set of regulations enforced by COGLA under Part II of the Canada Labour Code is the Safety and Health Committee and Representatives Regulations. These regulations establish the make-up of the "Safety and Health Committee" and how the Committee is to carry out its duties and responsibilities.

Several sets of regulations pertaining to safety, resource conservation and environmental protection have been drafted by COGLA pursuant to the Oil and Gas Production and Conservation Act. At present, five sets of regulations have been promulgated under this Act and five sets are in various stages of preparation. Special features of a few of the regulations presently administered by the Engineering Branch of COGLA will now be discussed.

The first set of regulations, the Drilling Regulations were promulgated in 1979 with minor amendments in 1988 and 1990. The Drilling Regulations feature two approvals:

- the Drilling Program Approval (DPA); and
- the Authority to Drill a Well (ADW).

These regulations contain:

- a requirement that the drilling unit, drilling systems and other related equipment meet specified standards;
- a requirement that the well design meets certain standards;
- a requirement to test and inspect equipment periodically;
- a requirement to have contingency plans;

- a requirements to dispose of waste materials in an approved way;
- a requirement to report daily to the Chief Conservation Officer;
- a requirement to test and evaluate the well;
- a requirement to take and keep samples;
- a requirement to have trained personnel and regular drills; and
- a requirement to keep and submit records.

The process for approving the drilling of a well involves two steps. First, the operator must apply for an approval for its drilling program, i.e. a Drilling Program Approval. The application for Drilling Program Approval is required to be submitted four months prior to the spud of the first well in the program and, where applicable, must provide details on the following:

- general information on the project including the geography, holders of interest in the exploration agreement, the number of wells to be drilled, and the duration of the drilling program;
- details on the construction of the drilling base (i.e. ice, berm or artificial island), if applicable, including the design, the construction plan, the source of material, the monitoring and instrumentation, etc.;
- results of pre-drilling site-specific seabed investigations;
- complete details on the drilling unit including:
 - plans, diagrams and specifications;
 - drilling and marine equipment, maintenance and operations manuals; and
 - personnel safety equipment and safety systems;
- details on the support crafts and systems including:
 - the standby and supply boats;
 - the supply base;
 - the aircraft support; and
 - the communications systems;
- details on the geology of the area and on the procedures to deal with potential problems or hazards such as:
 - overpressured formations, gas hydrates, slumping formations; and
 - casing, cementation and logging programs that will be used to control the problems;
- description of the physical environment including:
 - meteorological, oceanographic, ice and climatic data; and

- the weather and ice forecasting arrangements;
- a discussion of environmental concerns including:
 - impact of the operation on the environment;
 - the drilling unit response to extreme environmental or accidental events;
 - mud disposal, particularly any mud containing oil; and
 - sewage and waste treatment;
- and finally, complete contingency plans for all potential accidents or threats including:
 - serious injury or death;
 - a major fire;
 - loss or damage to a drilling unit or support craft;
 - oil spills;
 - collisions;
 - loss of well control (blowouts);
 - drilling of relief wells; and
 - rescue at sea.

COGLA carefully reviews and evaluates the information submitted in support of the application in consultation with experts in other departments and agencies. When COGLA is satisfied that the drilling program provides the framework for a safe, environmentally sound drilling project the Chief Conservation Officer approves the program.

The operator requires a second approval, an "Authority to Drill a Well", before drilling can actually commence. The application for an Authority to Drill a Well is required to be submitted at least 21 days prior to spud for each well in a drilling program and should include:

- general information including a wellsite project summary, the participants, and a survey plan;
- proof of adequate financial resources and insurance; and
- the specific well prognosis including:
 - the anticipated geological stratigraphy;
 - drilling plan - including casing setting depths and sizes, mud program, logging program, deviation control, etc.;
 - specific relief well arrangements;
 - specific environmental concerns at the location; and
 - any modifications to contingency plans for the specific location.

As with the Drilling Program application - this information is carefully reviewed and evaluated by COGLA in consultation with other departments and agencies with particular attention to the well design and to the procedures that will be used to combat potential hazards. When COGLA is satisfied that the plan for the drilling of that well provides for a safe, pollution-free operation, a

Conservation Engineer will approve the drilling of that particular well. The actual drilling operations are inspected regularly to ensure that the regulations are being complied with and that the approved program and specific wellsite plans are being followed.

Another very significant set of regulations, the Production and Conservation Regulations were promulgated in 1990. These regulations also feature two approvals, namely:

- a Development Plan Approval; and
- a Production Operations Authorization.

These Regulations stipulate that no approval for work that involves the development of a field is valid unless there is an approved development plan for that field. The approval process for the development of a large field, such as the Hibernia field, is extensive. As a first step, the operator must prepare a comprehensive development plan. The application for Development Plan Approval must describe in detail how it is intended to develop the field and must include:

- information on the scope, the purpose, the location, the timing and the nature of the proposed development, and the physical environmental conditions at the location;
- information on the production rate, on how the field was evaluated, on the estimated amounts of oil and gas expected to be recovered, the reserves, the recovery methods including secondary recovery, and the production monitoring procedures;
- information on the estimated cost of the development;
- information not only on the preferred production system but on any alternative production systems that could be used; and
- reports of all environmental, engineering feasibility and other studies necessary for a comprehensive review and evaluation of the proposed development.

On the environmental side, the development plan must include an "Environmental Impact Statement" that describes both the physical and biological environment, and the environmental impacts that are likely to arise from the project. This statement must include the mitigative measures that the operator will be prepared to take.

In addition to the environmental impact statement, the operator must provide, as part of the development plan, a "Benefits Plan" which sets out how the operator intends to ensure that Canadians and Canadian manufacturers will be given a full and fair opportunity to participate in the project.

When the development plan is submitted to COGLA, it is thoroughly studied and evaluated and where there are deficiencies, the operator is asked for more data and may be asked to undertake further work or studies. This comprehensive

assessment is undertaken in consultation with experts in other departments and agencies and, if necessary, COGLA will engage outside consultants to assist in the evaluation process.

When COGLA is satisfied that the development plan provides a framework within which an efficient, reliable, safe, pollution-free project can be carried out - the plan is approved. The operator can then commence with the detailed engineering design and construction activities. However, the operator must still comply with the relevant regulations under the Oil and Gas Production and Conservation Act as it carries out the project.

Coinciding with the development plan assessment there will likely be an environmental assessment and review, following the "EARP" process. This process independently assesses the environmental and socio-economic aspects and impacts of the project. In most cases, it will include a public review and public hearings. As recent court cases have demonstrated, EARP has become an essential part of the process for approving any project in which the federal government is involved, either as a regulator or as an interest holder.

The second approval connected with the Production and Conservation Regulations is the Production Operations Authorization. It is granted after the production installation has been constructed, put in place and is complete and ready to operate in the production mode. As a condition to that approval, the operator must comply with all other relevant provisions of the Production and Conservation Regulations and, if the installation is an offshore installation, must obtain a Certificate of Fitness for that installation.

Another important set of safety related regulations are the proposed Installations Regulations. Although these draft regulations contain no specific approvals, they do however contain numerous safety requirements pertaining to the structure and its facilities. These regulations:

- specify the analyses that must be done - i.e. structural analyses, fatigue analysis, safety analysis, etc.;
- specify the loads that must be considered and how they are to be determined;
- specify the materials acceptable for use;
- specify acceptable standards for design, construction and installation;
- specify requirements for the protection of the installation, i.e., against corrosion, collision and fire;
- specify the requirements for personnel protection, i.e., personnel safety devices, lifesaving equipment, firefighting systems;
- specify requirements for site-specific investigations;
- specify requirements for operations and maintenance manuals;

- specify requirements for monitoring and inspection during operations; and
- form the primary basis on which a Certificate of Fitness can be granted.

The last set of regulations I would like to draw to your attention are the proposed Certificate of Fitness Regulations. These regulations establish the criteria for a valid Certificate of Fitness and identifies who is authorized to issue a Certificate of Fitness. The four organizations that have been approved, to date, are:

- American Bureau of Shipping;
- Lloyd's Registry;
- Det norske Veritas; and
- Bureau Veritas.

These regulations also:

- specify the criteria that must be met in order that a valid Certificate of Fitness can be issued;
- specify that the Certifying Authority must carry out an approved scope of work;
- specify the circumstances under which the Certificate of Fitness becomes invalid and the consequences; and
- specify how a change of a Certifying Authority may take place.

To assist an operator in the use of certain Regulations made under the Oil and Gas Production and Conservation Act, COGLA has developed and issued several guidelines which provide pertinent information on the interpretation and procedures to be followed in complying with the requirements of the Regulations. These guidelines include:

- Geophysical and Geological Programs on Frontier Lands, Guidelines for Approval and Reports;
- Guidance Notes for the Canada Oil and Gas Drilling Regulations;
- Development Plan Application Guidelines;
- Offshore Waste Treatment Guidelines;
- Guidelines for the Use of Oil Based Drilling Muds; and
- Physical Environmental Guidelines for Drilling Programs in the Canadian Offshore.

2. Summary

In summary then, the regulations which have been developed and implemented by the Engineering Branch of COGLA have defined requirements, standards and criteria essential to the enhancement of safety and environmental protection for offshore oil and gas operations. These are applied through a process whereby each activity or project is thoroughly assessed to determine if the regulations and standards can be met through the life of the project followed by regular inspections to ensure that they continue to be met. In this regard, if methods and procedures to quantitatively assess the reliabilities and risks associated with each activity or project were available, this assessment would be even more definitive which would further enhance safety and environmental protection.

U.K. ENFORCEMENT OF RISK AND RELIABILITY MANAGEMENT OF OFFSHORE OIL AND GAS OPERATIONS

J. R. Petrie

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ABSTRACT

This paper briefly describes the Offshore Safety Division, Health and Safety Executive; discusses the Piper Alpha disaster; discusses principles of managing risk and reliability and safety; and concludes with considerations on how these principles might be applied offshore.

1. The Offshore Safety Division, Health and Safety Executive

The U.K. government agency charged with administering occupational health, safety and welfare law offshore is the Offshore Safety Division (OSD) of the Department of Energy. However we are in the process of transferring this Division to the Health and Safety Executive (HSE). This Division is responsible, amongst other things, for the making of regulations and guidance notes and monitoring and enforcing compliance with satisfactory health and safety standards.

2. The Piper Alpha Disaster

The year 1988 saw the Piper Alpha disaster in which 167 people lost their lives and a major oil production platform was destroyed as a result of a succession of fires and explosions fed from a very large fuel supply from a number of gas and oil pipelines. Piper Alpha was located in the North Sea approximately 125 miles northeast of Aberdeen on the Scottish mainland.

The most likely primary cause of the disaster was not related to hardware failures but was a consequence of human error. Both the Public Inquiry and my technical investigation concluded that the immediate cause was that condensate had been inadvertently admitted to an unsealed pipe end. The pipe end had been left in a non-gas tight condition as a result of incomplete maintenance work.

Persons on the subsequent shift, apparently unaware of the open state of this particular condensate line, opened valves so allowing considerable quantities of flammable gas to escape. The valves did not have any physical impediments in the way of secure mechanical isolation to prevent them from being activated.

Inevitably the condensate vaporized and was ignited. The source of ignition was never positively identified. Our main findings were that the ensuing explosions and fires rapidly escalated and pipelines were ruptured to such an extent that the escape routes for the installation personnel were cut off. The explosions and fires reached such a magnitude that the complete structure was destroyed.

The narrow causes of the disaster were the likely failure of maintenance personnel to effectively secure and prevent leakage of gas from a pipe end, and

the failure of the Permit-to-Work system and procedures to pass on information relating to the state of the plant. The wider causes were firmly linked to the ineffectiveness of management control. Notwithstanding the safety consciousness of the operators in the North Sea, it was clear that a new more stringent approach to the management of health and safety was required, wherein the operator has to demonstrate to the regulatory body that their safety assessments and management control of the offshore installation and all activities on it are adequate in both normal and emergency situations. This should provide for continued and progressive improvement in offshore safety.

For many years in the UK we have recognized the need for health and safety to be managed and to be subject to quality assurance procedures in the same way and with the same vigor as commercial activities. This line of thinking underpins our Mineral Workings (Offshore Installations) Act 1971 and the Health and Safety at Work Act 1974 which both apply to offshore activities. The Mineral Workings Act places health and safety duties on two critical points in the management chain so recognizing the connection between management and health and safety standards. The Health and Safety at Work Act places duties on employers to safeguard, as far as is reasonably practicable, the health, safety and welfare of their employees. There are requirements for the provision and maintenance of safe plant and systems of work, and the provision of information, instruction training and supervision. Employers have to prepare a written statement of their policy, organization and arrangements for health and safety, which again serves to emphasize that health and safety has to be managed. The crucial importance of the role of management, including that at board room level, has been reinforced by inquiries into a number of recent disasters in the UK such as the capsizing of The Herald of Free Enterprise and the London Kings Cross underground transport fire. Worldwide there are other prominent examples such as Three Mile Island, Alexander Kielland, Challenger, Bantry Bay, Bhopal, etc. All of these demonstrate the axiom that accidents are not matters of chance, but are subject to management control, and if management so determines, can be eliminated.

3. Principle of Proportionality

Another fundamental precept of the UK approach is that there should be proportionality between industrial risks and the measures taken for their control. When applying this principle offshore, because of the difficulties of escape in the event of a major incident, the precautions against catastrophic happenings must be greater and wider than those which would be required for the equivalent operation onshore.

4. Piper Alpha Recommendations

Returning to the Piper Alpha disaster, the inquiry recommended that operators should demonstrate to themselves and to a single regulatory authority, the OSD, the safety of their activities using the combined mechanism of Safety Management Systems, risk assessments and emergency rescue analysis, which together form the Offshore Safety Case.

- The Offshore Safety Case should, amongst other things, demonstrate that certain objectives have been met including:
 - (i) that the safety management system of the company and that of the installation are adequate to ensure the design and operation of the installation and its equipment are safe;
 - (ii) that the potential major hazards of the installation and the risks to personnel therein have been identified and appropriate control provided; and
 - (iii) that adequate provision is made for ensuring, in the event of a major emergency affecting the installation, a temporary safe refuge for personnel on the installation and their safe and full evacuation, escape and rescue.
- The operator should be required to satisfy itself, by means of regular audits, that the Safety Management System is being adhered to.

5. Offshore Safety Cases

Offshore Safety Cases will be required to demonstrate that the hazards have been identified and assessed, and that exposure of personnel to the hazards has been minimized.

They should be prepared primarily by the operator's own staff, although the use of consultants, particularly in the field of design and constructional integrity, will be admissible.

Our detailed thinking is still being developed, but we will be requiring the submission of an Offshore Safety Case for every installation within UK designated areas. The submissions for particular installations should extend to all related activities including diving, pipelines, the provision and conduct of standby vessels, etc. They should at least address whether or not an installation has been designed so that it is fit for its purpose and can be constructed, operated and eventually demolished safely. Many issues need to be considered under this heading. Ones that have particular relevance include:

- The location of accommodation facilities in respect of the main hazards.
- Escape routes.
- The provision of temporary safety refuges and their protection.
- The provision of Permit-to-Work systems.
- An assessment of the risks including quantified risk assessments for the major hazards.

- A statement of the Corporate Safety Policy and how this links into the overall company strategy.
- The system for implementing the Safety Policy and for managing health and safety.
- Methods to be adopted for controlling the risks including physical and management techniques.
- Procedures for keeping the Offshore Safety Case current.
- Revision dates.

6. Principles of Management

The basic concepts of management are the same no matter what activity is being undertaken. The main ingredients of any management scheme are:

- setting and agreeing on measurable objectives;
- preparing an operating plan with identifiable milestones on which progress can be measured;
- establishing mechanisms for achieving the plan and meeting the objectives;
- monitoring progress towards meeting the plan;
- making adjustments to the objectives, the plan or the mechanisms in the event of progress veering from the plan;
- carrying out further monitoring and adjustments.

7. Managing Health and Safety

The principles involved in managing health and safety are no different to those outlined above. Objectives have to be set and progress monitored to ensure that these are realistic and are being achieved. Just as for other management areas, applying the principles in the health and safety field is no easy matter and much effort and commitment are required at all levels within an organization.

Promoting acceptable health and safety standards depends upon having a clear policy that starts with a corporate acceptance of responsibilities which aims to cultivate positive management attitudes towards improving standards. A good starting premise is that all accidents and incidents of industrial ill health are avoidable and all are the responsibility of management. The policy should then go on to specify objectives that align with the overall company strategy and define the organization to meet these objectives. These should include the responsibility for the protection of people, plant and the environment. It is sometimes suggested that these can be pursued separately, but all form part of a coherent whole. Specific postholders should be named together with their

health and safety duties. At least some of the objectives should be in a measurable form, e.g., reductions in accident rates, lost time accidents and dangerous occurrences, carrying out a set number of safety audits each year. However, for major injury accidents, fatal accidents and disasters, it must be recognized that numbers are too small to be of statistical significance. In these areas the aims have to be couched in terms of reducing their long-term probabilities. To be successful, the policy has to have the positive support of the main board.

The management structure for implementing safety policies should include:

- Corporate Commitment - Perhaps the most important element in managing health and safety is that the most senior level of management and the most senior individuals make time and effort to demonstrate that health and safety performance is an important issue for the company concerned. Too often companies are willing to spend much money on developing schemes but do not give them sufficient status to allow them a chance of success. How many chief executives make time to get involved in safety presentations?
- Line of Accountability - A line of accountability for health and safety performance must extend from the board room to the lowest level of supervision within an organization. This should embrace the activities of contractors. Circumstances offshore demand that operators, in their dealings with contractors, reserve overall control to themselves. Therefore it is necessary for the accountability line to extend into the organizational structure of contracting bodies. Success is felt on rigorous application of management control, and each level of management should be held accountable for health and safety performance. How many annual performance reports have a relevant section on a person's achievements in the field of safety? Particular attention should be paid to the links between the management elements based ashore and those that are installation based, and to the problems of handovers at crew changes and shift changes.
- Safety Procedures - Details of the safety procedures to be followed will depend upon the identified hazards, and will include procedures for the control of safety critical activities. It goes without saying that Permit-to-Work Schemes should cater for secure isolation of equipment, for situations where more than one task is being carried out on one piece of equipment, and for shift change handovers. A more difficult question to address is when should they be used. Certainly they should be used to control all nonroutine work activities, but there may be some routine activities where the degree of risk warrants the formalized control afforded by a Permit-to-Work Scheme.
- Competence of Staff - The management system should align the competence and temperaments of individuals to the tasks which they are being expected to perform. Information, training and supervision needs to be according to the individual requirements.
- Communications - Attention should be given to establishing clear communication systems wherever these would be of benefit to health and

safety. Special care should be taken with the links between shifts and between operators, their contractors and other contractors. Also the benefits of having a command center that can be used in emergencies should be considered.

- Emergencies - The operators' formal command organization which is to function in the event of an emergency should be defined and well understood by all concerned. Emergency drills should be undertaken periodically.
- Monitoring - It is not sufficient to have written safety procedures that deal with every conceivable set of circumstances. Arrangements must be made to monitor their implementation and to report back any shortcomings to the line manager concerned and to senior management. Senior managers need to know, and should be very interested in whether or not their safety policies are being implemented. Unfortunately there is no easy calculus that can be applied to measuring health and safety standards. In lots of situations the objective is to reduce what is already a very low level of residual risk. There are a number of proprietary audit schemes on the market which can help with this task, but there is no reason why a company cannot generate its own system. A home-grown solution with all its shortcomings, but with which people can readily identify can often be more acceptable than an expensive system imported from outside. Any system should incorporate some elements that compare what actually happens on the ground with what is expected to happen. Periodic thorough scrutinies of plant and operations can help identify shortcomings.

8. Summary

Managing health and safety costs time and money. However, operators should make realistic appraisals of the costs that are avoided and the other benefits that accrue by ensuring good standards. Apart from the tragic loss of life, not much was left of the Piper Alpha platform following the disaster. There is growing evidence to show that health and safety not only makes good social sense, but also good commercial sense. This becomes particularly clear when the property damage costs that usually accompany accidents are added into the equation. Firm control over health and safety equates to control over other matters such as quality, wastages, manpower deployment, and so forth, and perception of control of these issues by outsiders can result in improved business opportunities. There is much truth in the adage that good business is safe business and safe business is good business.

LORD CULLEN'S REPORT ON PIPER ALPHA: THE U.K. OFFSHORE INDUSTRY'S RESPONSE

Dr. Harold Hughes OBE
Director-General, U.K. Offshore Operators Association

ABSTRACT

This paper describes the offshore industry's response in the U.K. to Lord Cullen's report. The centerpiece of the new approach to offshore safety will be the Safety Case, which will cover not only hardware but human aspects as well. Lord Cullen's recommendations will be implemented by the operating companies. The U.K. Offshore Operators Association will monitor progress and coordinate the industry studies necessary to support them.

1. Introduction

The 6th of July 1988 is a date ever to be remembered by those in the offshore oil and gas industry, certainly in the U.K., but probably worldwide, too. The Piper Alpha disaster (the world's most serious offshore fire) started at about 10 pm that night. One hundred sixty seven men died, many others were injured, and survivors still suffer the after-effects of having lived through it.

The subsequent Public Inquiry, set up immediately afterwards by Government and headed by Lord Cullen, produced an extremely thorough analysis of the events of that night and what preceded it, and (in its second part) a review of then current offshore safety organization and approaches, and, very importantly, Recommendations for the future. The Government agencies and the offshore industry itself came under the latter scrutiny; the United Kingdom Offshore Operators Association Ltd. (UKOOA) played the major role in this second part of the Inquiry, presenting 37 of the 64 papers taken as evidence.

This paper describes the offshore industry's response in the U.K. to Lord Cullen's report. The Recommendations of the report, when fully enacted, will represent quite a sea-change, particularly in the regulation of safety, and the organization within the U.K. Government of that activity. I am afraid that I have had to refer, in this paper, to these Government agencies and indeed I could not consider the changes that Lord Cullen's report will engender without referring to their changed rules and responsibilities. I think therefore I feel some need to apologize for getting into this detail about the U.K. Government organization, but it is a necessary component of my paper.

UKOOA is the industry body which represents all (currently 36) Member Companies who explore for and produce oil and gas in the North Sea and other U.K. territorial waters.

All UKOOA's Member Companies have now welcomed Lord Cullen's Report, published in November 1990, as signposting ahead a very clear path for the further improvement of the offshore safety regime in the UK. The major change will be in the way in which platform operators will have to take much more responsibility

themselves for demonstrating, to a new Government authority, the safety measures they have provided on their platforms.

The centerpiece of the new approach will be the Safety Case, a formal submission to be made by each Operator, for each platform, updated regularly and as platform hardware and procedures are changed. This Safety Case will not only cover hardware (such things as platform layout, provision of firewalls, escape routes, temporary safe refuges and the like) but human aspects such as the capability, experience, and training of management and workforce teams, the written operational and emergency procedures and exercises to ensure competence in their use, and the safety support systems such as onshore procedures, helicopter availability round the clock, standby boats and radio communications. The Safety Cases, to be developed for new and (as soon as possible) for existing installations will be assessed and approved by a new single offshore authority - a new specialized Division to be created within the existing national Health and Safety Executive. The Chief Executive of the new Division, Mr. Tony Barrell, has already been appointed and will work in the Department of Energy (the existing Government authority principally concerned) until transfer of responsibility is effected, probably during April 1991. (This transfer has now been effected.)

In parallel with the move to the Safety Case approach, there will be fundamental change in the form of the Regulations governing offshore working and safety. The current form of these has evolved over the years, from a basis in the Mineral Workings Act, and amendments and additions have largely followed experience; generally the form has been prescriptive, with the Department of Energy or other Government Departments laying down in often quite detailed form how provisions shall be made. This has led now to offshore operations being governed by 17 Acts of Parliament, 43 Statutory Regulations, 63 Operators' Notices, 148 Safety Notices and 171 Diving Safety Memoranda; not all these have statutory force, but are usually taken so. This general approach led to a process of exemption, because the approach could not keep up with the emerging technology of new platforms; worse, Operators were tempted to believe that if they complied with all these sets of rules, their platforms were necessarily safe.

All this is now to be swept aside in favor of the Safety Case, supported by a new limited range of Regulations which instead of being prescriptive will be objective-setting. In other words, they will set safety goals. It will be up to Operators, through their Safety Cases, to demonstrate how these goals are being achieved for each platform. A very small number of prescriptive rules will remain but only in narrowly defined areas, such as the numbers of lifeboats to be provided. This path, to goal-setting regulation, is one already being followed by the Norwegian offshore safety authority, and it parallels the approach used since 1984 onshore in the U.K., although the Safety Case approach recommended by Lord Cullen goes somewhat beyond those onshore requirements.

UKOOA welcomes these developments - indeed they correspond with the recommendations UKOOA made in its evidence to Lord Cullen's Public Inquiry. But before the Inquiry had even started, Member Companies had commenced to analyze for themselves the first lessons of the awful tragedy and had started the engineering of hardware improvements which were largely completed offshore in the weather-windows of the summers of 1989 and 1990. A dreadful component of the tragedy was the burning of pipeline inventory on the Piper Alpha platform, and

so the industry has spent about \$500 million repositioning over 150 emergency shut-off valves on platforms, and some \$700 million providing further sub-sea remote shut-off valves in carefully selected instances. On Piper Alpha, smoke was clearly an even greater hazard to escape than had been thought, and the industry has spent about \$500 million improving emergency walkways and their lighting and signing, and on preventing the entry of smoke into accommodation units used as temporary refuges.

This expenditure has gone a long way to meeting in advance some of Lord Cullen's 106 Recommendations, but clearly much has to be done both by Government and the industry over the next 2-3 years to enact them fully. Safety Case approaches are already in use in UKOOA's major companies but their use has to be made universal, and the inventory of over 150 existing platforms subjected to this rigorous approach. Availability of skilled technical resources will be a limiting factor, and UKOOA's Member Companies will have to undertake training programs to ensure these Safety Cases can be done where they need to be done - in house.

Other Recommendations, dealing with the design and capability of standby boats and the standards applying on contract drilling rigs, for example, will necessitate close cooperation with other sectors of the industry and these contacts are already being strengthened.

The world's worst offshore tragedy seems now likely to lead to the development of an offshore safety regime which will be a model for the development of new offshore production regimes the world over.

This, then, is effectively a summary of the overall position that the industry has taken up following the publication of the Report. I should like now, as time permits, to go into somewhat more detail concerning some of the specific Recommendations and related matters.

1.1. Emergency Shutdown Valves

Fire and explosion are major hazards offshore and if an accident does happen which results in a fire, the first priority is to contain its impact by shutting off the supply of fuel. Even before Piper Alpha, pipelines were fitted with emergency shutdown valves which isolated the pipeline contents in the event of fire, but as I have said, the experience of Piper Alpha showed that the precise location of a valve can be critical. A properly located and protected emergency shutdown valve provides a secure first line defense against the uncontrolled release of the pipeline contents. The advantage of an emergency shutdown valve located above the water is that it remains accessible for inspection, testing and maintenance.

In the last two years, companies have checked the location of over 400 emergency shutdown valves and have repositioned over 150 of them. Where appropriate, additional protection from fire and falling debris is being provided.

1.2 Subsea Isolation Systems

In special circumstances, for example where large diameter gas pipelines are present, the installation of subsea isolation systems can provide protection

against the failure of the platform emergency shutdown valve or of the pipeline riser itself. This double protection would ensure that an accident on the platform, which is severe enough to damage the platform emergency shutdown valve or the pipeline riser, does not escalate.

Prior to Piper Alpha, 10 subsea isolation systems had been installed in the North Sea. Since Piper Alpha, operators have been carrying out safety assessments to determine priorities for the installation of further subsea isolation systems. As a result of these assessments a further 67 systems have been installed at a cost of over \$700 million.

1.3 Smoke Hazard

Smoke proved to be a major hazard on Piper Alpha and Operators have been and are looking closely at how smoke could hinder evacuation and how its effects could be mitigated. Smoke is inevitably formed during a hydrocarbon fire but its ingress into the accommodation module can be prevented and additional personnel protection provided. For example, where they are not already provided, companies are fitting smoke detectors in the air intake ducts of accommodation modules to ensure that the smoke dampers shut automatically as soon as smoke is detected.

Offshore installation fire fighting teams are trained in the use of breathing apparatus, but in addition, consideration is being given to the provision of easily portable smoke hoods for all offshore personnel. These could provide protection for a vital few minutes in smoke conditions. In December 1989, UKOOA and the Department of Energy commissioned a joint study at Aberdeen University to develop a standard for smokehoods suitable for use offshore. We expect this standard to be available in 1991. A number of companies have provided currently available smokehoods as an interim measure; others are waiting until the offshore standard is available.

1.4 Evacuation and Escape

If, as a last resort, a platform has to be evacuated, reliable means to do so safely must be readily available.

Helicopters are the most convenient way of evacuating an installation but in addition every platform has its own dedicated evacuation system which is completely independent of external help. The platform lifeboats provide the primary means of evacuation. They are totally enclosed and self-propelled to assist them to clear the platform safely after launching.

Escape routes are provided from every part of the platform to the helideck and the lifeboats. The main requirement for escape routes is that there must be more than one way of escape available from any particular part of the platform. Companies are providing further improvements, for example the installation of heat shielding and improved lighting which is self contained and needs no external power supply. More use is being made of floor level photoluminescent strips which remain visible in poor light.

Piper Alpha has also made the industry more aware of the need for secondary evacuation systems to cope with the situation where some personnel may not be

able to get to the helideck or lifeboats. The industry uses a range of devices, including knotted ropes, ladders, extending steps, nets and abseiling equipment. Every installation is different and new ideas which are emerging must be tested to make sure that they do not create new problems in use.

Information on these new methods of escape is exchanged between Member Companies at the UKOOA Safety Committee meetings which are held monthly, and the joint UKOOA/Department of Energy Emergency Evacuation Committee reviews new methods on behalf of the industry.

It is difficult to determine exactly how much all these general safety enhancements will cost, because they normally form an integral part of the detailed engineering of the platform equipment, but, using information obtained from Member Companies, it is estimated that offshore operators have spent nearly \$2,000 million on safety related hardware including emergency shutdown valves and subsea isolation systems.

1.5 Permit to Work System

The Permit to Work System (PTW) is one of the foundations of safe working and accident prevention and is employed throughout the petroleum industry, both onshore and offshore. Individual operators design their own PTW systems based on Guidelines published by the Oil Industry Advisory Committee (OIAC) which comprises representatives from the oil industry, the Health & Safety Executive, the Department of Energy, and the Trades Unions.

The OIAC Guidelines are being revised following Piper Alpha to incorporate the lessons learned and UKOOA Member Companies have increased their efforts to audit their PTW procedures to check that they comply with the best industry practice and are being followed on all occasions.

2. Formal Safety Assessment (FSA)

What I have said so far represents a conscientious and rapid response by a responsible industry to a major disaster. Our objective is to create and maintain a safe environment offshore, recognizing the hazardous nature of our business. But there is a risk that this reaction to experience, however thoroughly carried out, will result in a piecemeal rather than comprehensive improvement in safety. If we are to convince ourselves in the industry, and those outside it, that the likelihood of another major disaster has really been reduced to an acceptable level then something more is required.

In its recommendations to Lord Cullen, UKOOA reaffirmed its previously held conviction that the prime responsibility for the safety of an offshore installation must remain with the operating company. UKOOA proposed that the present prescriptive regulations, promulgated under the Minerals Workings (Offshore Installations) Act 1971, should be gradually phased out and replaced with objective goal-setting regulations, which would require Operators to demonstrate the safety of each installation by carrying out a Formal Safety Assessment (FSA) similar to that required for onshore installations under the Control of Industrial Major Hazards Regulations (CIMAH). UKOOA believes, and has

for some time, that the introduction and use of FSA represents the best way forward for the offshore industry to enhance safety and prevent disasters like Piper Alpha.

FSA has many advantages compared with the current regulatory regime. It is flexible and can take account of different types of installation. There are over 150 existing offshore installations, fixed and floating, extending from the shallow waters of the southern North Sea to the deeper water found in the central and northern North Sea. Some produce gas, some oil and some oil and gas. Some are small, with only a handful of personnel or even not normally manned, others are large with hundreds of personnel on board. Prescriptive regulations cannot adequately cover this diversity of installations, except by a legal exemption process used at the discretion of the Secretary of State.

By its very nature, FSA encourages management thought, innovation and the introduction of improved safety techniques. Rigid regulation tends to lock safety into yesterday's technology. For example, free-fall lifeboats do not meet the requirements of current UK regulations.

FSA does not dictate to the Operator how safety should be achieved, for example, by specifying the strength of fire walls or the amounts of fire water to be deployed. Therefore the most appropriate provisions for each individual installation can be used rather than the detailed and wholesale requirements prescribed in the current form of regulations.

FSA puts the spotlight on the Operator. It focuses on his responsibility to create and maintain a safe place of work. Prescriptive regulations provide the wrong sort of prop for the Operator - if he complies with the regulation he may feel that he is "legally safe".

3. The Safety Case

UKOOA is committed to the Safety Case approach. Most of the new installations designed in the 1980's have used safety case methods. The UKOOA procedure on Formal Safety Assessment, which has been issued to every company, will assist in harmonizing the scope of the safety cases prepared for all installations including existing ones. The preparation of safety cases for all prior existing installations is an enormous challenge and will take time to implement.

When CIMAH (Control of Major Industrial Accident Hazards) Regulations were introduced in the U.K. onshore in 1984, the Health & Safety Executive allowed 5 years for their implementation. UKOOA believes that, taking into account the work done already, the task offshore should be completed in 2 to 3 years. One advantage of the safety case is that it enables major hazards to be identified early and therefore priorities can be established for remedial actions. This means that any safety improvements can be implemented while the safety case is being completed.

To the extent that the preparation of the safety case will require the use of quantitative risk assessment techniques, UKOOA has recognized that updated and improved data bases will be an essential prerequisite of the assessment. As a

first step in upgrading the information available to the industry, UKOOA commissioned a study "The Update of Loss of Containment Data for Offshore Pipelines" which is expected to be published by HMSO in 1991. The data base covers subsea pipelines and associated incidents through the North Sea up to the end of 1989 and was compiled with the assistance of operating companies and the regulatory authorities' departments with North Sea oil and gas interests. We are now going on to develop a database on incidents involving offshore cranes.

An essential ingredient of a safety case is the company's Safety Management System (SMS). According to Lord Cullen, the safety case should demonstrate that the SMS of the company and that of the installation are adequate to ensure that (a) the design, and (b) the operation of the installation and its equipment are safe. The SMS should be in respect of (a) the design (both conceptual and detailed) of the Operator's installations; and (b) the procedures (both operational and emergency) of those installations. In the case of existing installations the SMS in respect of design should be directed to its review and upgrading so far as that is reasonably practicable.

The SMS should set out the safety objectives, the system by which these objectives are to be achieved, the performance standards which are to be met and the means by which adherence to these standards is to be monitored. UKOOA endorses Lord Cullen's recommendation that in the formulation of their SMS, Operators should draw on the principles of quality assurance similar to those contained in the British Standard BS 5750 and International Standards Organization 150 9000.

To implement successfully these fundamental changes in the way offshore safety is to be administered and managed will require a dedicated and concerted effort by the Government, the Health & Safety Executive and the offshore industry all working together. UKOOA is keen and ready to play a full part in this challenging future.

4. Safety Committees and Safety Representatives

Above all, offshore safety is about the people who work offshore. Whether they are employed by contractors or by oil companies, whether they belong to trades unions or not, it is essential that the whole workforce is committed to and involved in safe operations.

UKOOA believes that each individual has a vital role to play in safeguarding himself or herself, and others. There is no place for artificial distinctions between contractors and oil company employees.

All must be trained to work safely, to understand their responsibilities and to be confident that they will be listened to when they raise a safety issue either directly with their management or through their safety committee.

The Offshore Installations (Safety Representatives & Safety Committees) Regulations 1989 stipulate that every employee offshore has the right to freely elect (or to be elected as) a safety representative. This is different from the situation onshore in the U.K. where safety representatives are appointed by a

recognized trades union. Lord Cullen recognized the merit and democratic basis of the present offshore regulations and endorsed the intention to review them after two years' experience.

UKOOA accepts Lord Cullen's recommendations that the training of safety representatives should be determined by and paid for by the Operator. This should further enhance the effectiveness of offshore safety committees.

5. Command in Emergencies

Lord Cullen highlighted the need for a formal emergency command organization which should form part of the Safety Management System (SMS). In the U.K. the Offshore Installation Manager (OIM) is in charge of his installation and is responsible for taking control of an emergency. The Operator's criteria for selection of OIMs, and in particular their command ability, will form part of the SMS. UKOOA is working with the Offshore Petroleum Industry Training Organization (OPITO) to determine competency criteria for OIMs. It is recognized that greater attention will have to be given to determining selection criteria and appropriate leadership and management training for OIMs.

Lord Cullen recommended that there should be a system of emergency exercises which provides OIMs with practice in decision making in emergency situations, including decisions on evacuation. OIMs and their deputies should participate regularly in such exercises. We are also looking at the transfer of naval experience to the industry to improve its command-in-emergency response.

6. Conclusions

In conclusion, UKOOA reaffirms that safety remains the first priority. Lord Cullen's recommendations will be implemented by the operating companies. UKOOA will monitor progress and coordinate the industry studies needed to support them. There is no doubt, however, that Lord Cullen's report will influence offshore safety throughout the world.

RISK AND RELIABILITY MANAGEMENT IN U.S. OFFSHORE OIL AND GAS OPERATIONS

R. L. McGannon
Vice President, Chevron Corporation

ABSTRACT

Chevron Corporation's efforts in risk and reliability management are discussed. The first task is to understand the risks to people, the environment, and facilities. Management of the risks involves efforts in the areas of training, contingency measures, operating procedures, design, inspection, and maintenance/repair. Future directions are then outlined. These include the development and application of quality improvement strategies and tools, the application and evaluation of formalized risk management procedures, including Hazard and Operability Studies, quantitative risk assessments, and comparative risk assessments for the evaluation of alternative concepts and systems for deep-water development. The discussion is focused on Chevron's operations in the Gulf of Mexico.

1. Introduction

The entire industry has a responsibility to continuously improve its offshore safety record. At Chevron our highest priority is the safety of our employees, the public, and the environment. Workshops such as this provide good opportunities for representatives from industry and government to share experience and exchange information.

I appreciate this opportunity to discuss some of Chevron's efforts in risk and reliability management. Today I will be focusing on Chevron's operations in the Gulf of Mexico (GOM) rather than the United States industry in general.

We appreciate the guidance and working relationships with governmental agencies such as the Minerals Management Service (MMS), the U.S. Coast Guard, the Canada Oil and Gas Lands Administration, and the Petroleum Division of the U.K. Department of Energy to improve safety offshore.

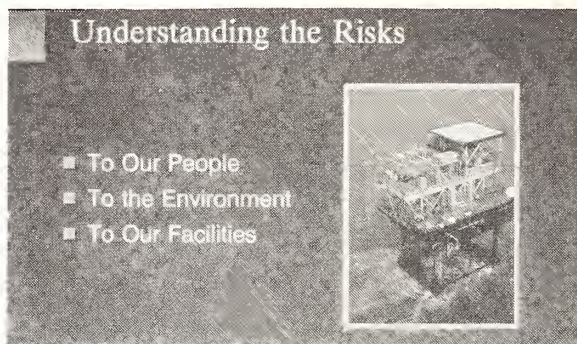
We shouldn't forget that the offshore industry is a vital part of the overall U.S. petroleum production. In fact, oil is literally the life blood of our economy: more than 75 percent of all our nation's energy comes from oil and gas, and the transportation section is 97 percent dependent on oil. I'm sure you are aware that one out of every two barrels of oil this nation needs comes from foreign sources. So, that's why safe, environmentally sensitive exploration and development — especially in the offshore — is so very critical to our nation's economic security.

Chevron has offshore operations worldwide, in Indonesia, Africa, China, and the North Sea, in addition to our domestic operations. Our total offshore operated production is about 900,000 barrels per day of oil and condensate, and about 3 billion cubic feet of gas per day. We are the largest offshore operator in U.S.

waters, producing about 200,000 barrels of oil and condensate, and 2 billion cubic feet of gas per day from 1200 offshore installations in the Gulf of Mexico. That's about 19% of total GOM production.

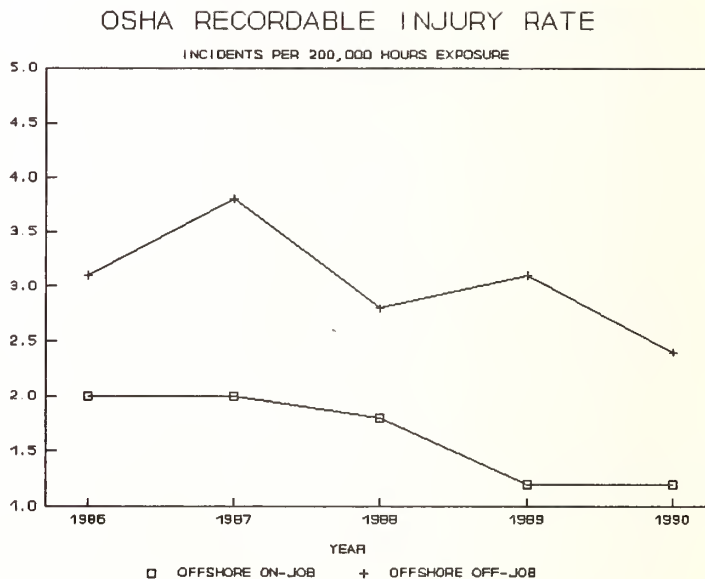
2.0 Understanding the Risks

Offshore production involves risks to our people, to the environment, and to our facilities. I will spend a little time putting each of these in perspective.



2.1 Risks to our People

There are many inherent risks associated with offshore operations. Helicopter and boat transportation is necessary; cranes are in frequent use; there are numerous stairs, ladders and metal decks; and we work with heavy equipment, high pressure wells and process equipment, and flammable fluids.



1990 was our best safety year since we began Gulf of Mexico operations. We received 15 American Petroleum Institute (API) Accident Prevention Awards for a combined total of 14.5 million hours without a lost-time injury. The MMS awarded Chevron USA its Safety Award for Excellence for "outstanding production operations" on eight platforms in Ship Shoal Blocks 107/108. We reduced our on-the-job Occupational Safety and Health Administration (OSHA) recordable injury rate to 1.2 incidents per 200,000 hours worked, and our off-the-job rate to 2.4.

This excellent performance attests to the dedication and commitment of all our people. Safety is an integral part of every job. Our people watch out for each other and take great pride in their significant safety accomplishments. We

continuously strive to improve our record.

A drug and alcohol program is applicable to our offshore employees. As part of this program, employees must submit to random testing. Our employees are highly supportive of this program.

2.2 Risks to the Environment

As an industry we are making a concerted effort to reduce the risk of spills, and to be able to better respond should one occur. The oil industry sponsored Marine Spill Response Corporation (MSRC) will spend about \$800 million over the next five years, purchasing response vessels and barges, providing training, supporting R&D, and employing about 400 people. This will improve our effectiveness in dealing with oil spills.

Beyond our participation in MSRC, Chevron assembled an in-house Oil Spill Response Task Force to enhance our prevention, preparedness, and response capabilities. Through this effort we determined the two most likely causes of an offshore oil spill are, first, corrosion and erosion in hydrocarbon handling equipment and pipelines, and, second, human error. We are working to strengthen programs in both areas.

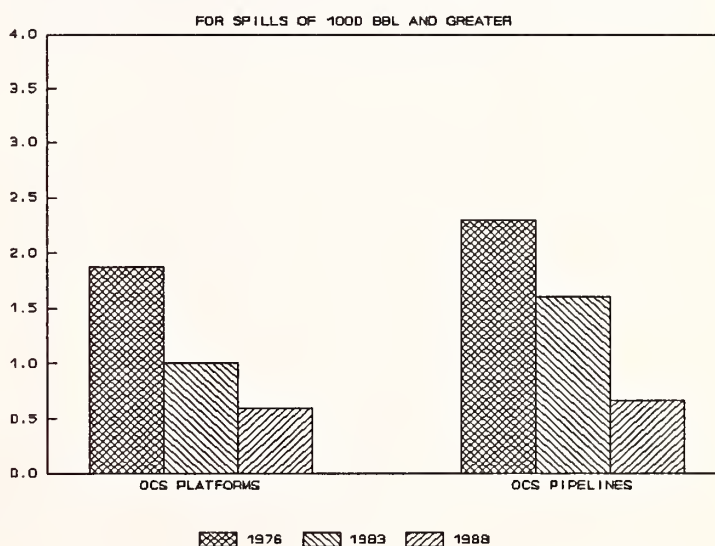
This task force effort involved over 100 employees from 30 different operating companies and staff organizations. At the 1991 International Oil Spill Conference, held in San Diego earlier this month, Chevron presented the programs developed and actions taken by our Oil Spill Response Task Force.

A recent study by C.M. Anderson and R.P. LaBelle¹ of the MMS shows that since the mid-70s the industry has been steadily improving its spill prevention performance for platforms and pipelines. The industry's current spill occurrence rates, for significant spills, have dropped by about 70% since 1976. On average, the industry now produces and transports about 1.5 billion barrels between significant spills.

2.3 Risks to our Facilities

One of the risks to the industry's offshore facilities in the GOM is hurricanes. To date, 38 platforms have failed due to storm loading². Platform evacuations have averted both fatalities and severe injuries. Approximately 15,000 barrels of oil have been spilled as a result of platform failures, compared to more than 7 billion barrels produced between 1964 and 1987³. The next figure shows the percentage of failures due to hurricanes between 1955 and 1990.

SPILLS PER BILLION BBL OF OIL HANDLED



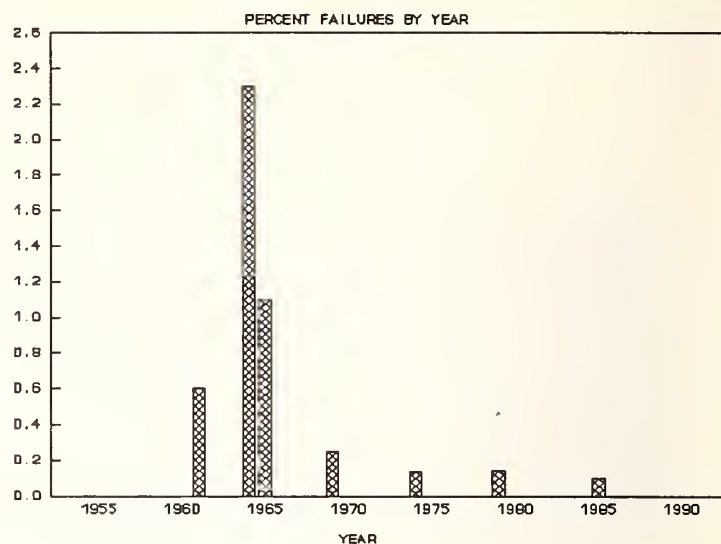
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We have a good idea why the platforms failed. Prior to 1966 most platforms were designed for 25 year return period waves. Following fourteen platform losses from hurricane Hilda in 1964, and eight more from Betsy in 1965, operators began using the more stringent 100 year storm design condition.

In 1969, the first recommended practice for design was published (API RP 2A). By that time most operators used the 100 year design condition. Since then, most, if not all storm induced failures, appear to have been due to either

conditions not accounted for in design (such as mud slides), poor maintenance, or the inadequacies of the 25 year storm design platforms.

PLATFORM FAILURE RATE DUE TO HURRICANES



Chevron has traditionally favored conservative designs for offshore platforms. Fortunately, during our early days offshore we had a highly capable, far-sighted manager of offshore design and construction who accounted for risk in his platform designs. Let me quote from a paper he wrote: "Many industries would, and do, willingly pay more than 3% of the cost of an investment for insurance against hazards of smaller magnitude and better known mathematical probability than those encountered in hurricanes in the Gulf of Mexico. For this reason, Chevron structures have been designed to withstand greater wave and wind loads than most other operators assume in the design of structures for the Gulf of Mexico....If any structures can survive the full brunt of a hurricane, I feel confident that Chevron's structures will be among them."⁴

That was written in 1952...nearly four decades ago...by Paul Besse. He was right. None of the 38 platforms that failed were Chevron platforms.

3. Managing the Risks

Now I would like to move from understanding to managing risk. It is hard to devise a satisfactory breakdown of risk management methods. One such breakdown is given in API RP 750 - Management of Process Hazards, which includes items such as management of change, investigation of process related incidents, and audit of process hazards management systems.

These are valid procedures, but we will consider them to fall under the six broad headings listed here. Training, contingency measures, operating procedures, design, inspection, and maintenance. These are the methods we rely on to control risk.

In the time available today it is not possible to do any more than provide illustrative examples of how risk is managed in each of these categories.

3.1 Training

We regard effective personnel training to be the most important method to manage risk. At our Gulf of Mexico Training Center in Lafayette, LA, our production personnel receive hands-on training in all aspects of production operations. The facility includes a production platform simulator utilizing typical production equipment, including two wellheads complete with operative surface-controlled subsurface safety valves, test and bulk separators and oil and gas measuring devices.

Eighteen months ago we started a program for our newly hired operations and mechanical personnel. The 30-month program contains three phases: classroom training, on-the-job training, and independent study.

We begin with five weeks of classroom training at the Lafayette facility, scheduled at intervals during the employee's first 15 months with Chevron. The first week deals with safety issues; subsequent classes teach basic job skills.

Then, during on-the-job training, experienced offshore instructors re-teach the classroom material in the work environment.

The last phase — independent study — is also done on the job. Employees are provided manuals and two hours per day to master skills needed for qualification under MMS training requirements. This certifies them for positions of operating responsibility on Outer Continental Shelf (OCS) leases.

One of the functions of Chevron's Drilling Technology Center is to certify its drilling representatives and engineers in well control under MMS guidelines. Our classroom instruction time exceeds the minimum required by the MMS to fully equip Chevron personnel to handle all types of well-control problems.

Managing the Risks

- Training
- Contingency Measures
- Operating Procedures
- Design
- Inspection
- Maintenance/Repair



Managing the Risks

- Training
- Contingency Measures
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- Inspection
- Maintenance/Repair



At the Drilling Technology Center, we give personnel a fundamental understanding of what causes kicks and teach them specific procedures for controlling wells. Our people receive considerable training on state-of-the-art, computer-based well-control simulators. They also have the opportunity to circulate a nitrogen gas bubble from an existing well at the center using the conventional land drilling rig shown here.



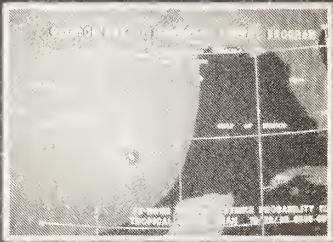
3.2 Contingency Measures

One of the ways we control risk to personnel and to the environment is by evacuating platforms and shutting-in production in the event of hurricanes. For Chevron's GOM operations, this means evacuating about 2,600 employees and contractors. To make timely, appropriate evacuation decisions, we need the best hurricane information available.

To get this, we worked with a contractor to expand a Navy model for hurricane risk prediction. The model permits Chevron to generate plots, showing the earliest time to expect winds of a specified magnitude, and giving a particular confidence level. This is important because we wish to avoid flying helicopters in winds over 45 knots during hurricane evacuation.

Managing the Risks

- Training
- Contingency Measures
- Operating Procedures
- Design
- Inspection
- Maintenance/Repair



The program uses both a historical hurricane database and a forecast error database along with a forecast simulation program and the real-time National Hurricane Center (NHC) forecast. This way we can supplement the vital information supplied by the NHC with past forecasting experience.

The decision to evacuate remains a judgment call, but we find that the program provides good confirmation of that judgment.

While the use of helicopters for hurricane evacuation is an important safety precaution, we must recognize that helicopter transportation brings its own risks. Chevron Aircraft Operations has an outstanding safety record. Our Federal Aviation Administration (FAA) recordable incident rate for the last five years is less than one for every one million departures. The Gulf Coast average of about six per million compares very favorably with the U.S. helicopter average of about 26. Since 1988, our Aircraft Operations has received six API Accident Prevention



Awards and two FAA Spirit of Safety Awards.

We attribute our success to our safety precautions, maintenance operations, management support, and, most importantly, our people.

3.3 Operating Procedures

Several years ago Chevron suffered a brief series of unfortunate crane and rigging accidents. During a broad review of Coast Guard, MMS, and industry reports, we found (in an MMS industry-wide report) that in 50 reported crane accidents from 1971-1983 there were 37 fatalities and 26 serious injuries⁵. Just one of these 50 accidents involved Chevron personnel.

Chevron organized an employee task force to examine crane and rigging operations and develop guidelines for improving our performance. The task force made recommendations regarding crane operations and rigging, crane inspection and maintenance, crane equipment, and training.

Chevron's Crane and Rigging Program has been in place since February 1987, and we have not had one reportable crane-related injury since that time.

3.4 Design


Proper design is essential to reducing risk. There are primarily two ways in which we control risk through design: design codes and Chevron standards.

Many major operating companies take an active role in developing and revising API recommended practices related to offshore production facilities. This is a natural outgrowth of the research and development activities funded by major oil companies.

I could use any one of a number of API recommended practices as examples, but I selected API RP 14C because it is considered highly successful in controlling production facility risk. For those unfamiliar with 14C, it is the Recommended

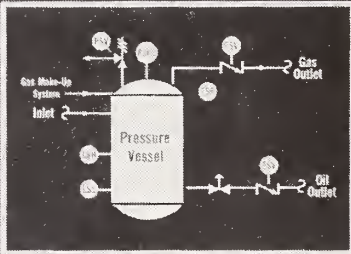
Managing the Risks

- Training
- Contingency Measures
- Operating Procedures
- Design
- Inspection
- Maintenance/Repair



Managing the Risks

- Training
- Contingency Measures
- Operating Procedures
- Design
- Inspection
- Maintenance/Repair



Practice for Analysis, Design, Installation and Testing of Basic Surface Safety Systems for Offshore Production Platforms. This figure is taken from 14C showing recommended safety devices for a pressure vessel.

In a paper presented at the Offshore Development Conference in 1989, it was shown that no fatality or even reportable incident could be attributed to safety devices that meet API RP 14C guidelines⁶, first published in 1974.

The API RP 14C Safety Analysis Checklist details all the safety devices required to protect individual process components, as well as the specific component combinations required to eliminate devices. Our operating people like this. They also appreciate the simplicity and the thoroughness of the 14C SAFE charts that document the design in a straightforward manner.

There are instances where Chevron standards exceed industry design codes. Using 14C as an example, we require all outgoing lines to have shut-down valves, in addition to all incoming lines. We require two relief devices per high pressure vessel rather than one. Also, we believe in "blowing down" the pressurized system during an Emergency Shut Down.

3.5 Inspection

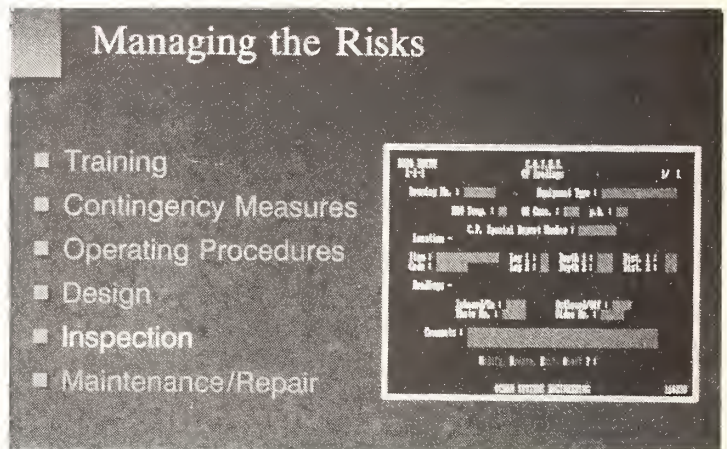
Even with well designed structures, it pays to inspect. Before inspections were required by the MMS, we performed routine inspections on our platforms.

We operate 581 platform installations and 621 caissons in the GOM. To control inspection, maintenance and repair activities, we developed — with the help of an outside contractor — Chevron's Computer Aided Inspection Reporting System (CAIRS). This system

standardizes inspection reporting for all structures, links inspection data to the original structure design, and permits computer manipulation of inspection data⁷.

3.6 Maintenance

Inspection occasionally reveals defects such as that shown here. This was a platform acquired from another company. It had not been properly maintained. An in depth investigation was conducted by Chevron Research and Technology Company, in conjunction with Chevron Oil Field Research Company.





Managing the Risks

- Training
- Contingency Measures
- Operating Procedures
- Design
- Inspection
- Maintenance/Repair

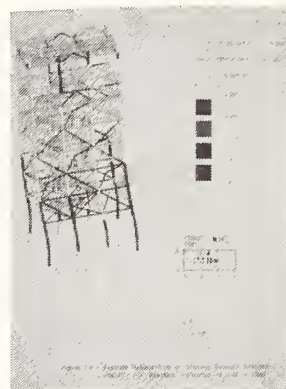


When it was determined that no information was available regarding the buckling capacity of tubular members with hole, Chevron conducted 90 experimental small scale tests as shown here⁸. Results were confirmed by detailed, nonlinear finite element analyses.

We were able to estimate the loss in member strength from the holes and dents found during inspection, and then conduct an ultimate strength analysis of the platform as a whole.

This slide shows which members would be most highly loaded and which ones would buckle when the platform reaches its ultimate capacity. Typically, this capacity is about 1.5 to 2.5 times greater than the loads associated with the 100 year storm.

Despite significant member strength loss, the holes and dents had minimal effect on overall platform strength. This was due to the location of the damaged members on the structure, and to the redundancy present in the design⁹.



3.7 Summary

So what have we learned about managing risk? First, human error is of greatest importance. Training and active management support can significantly reduce this risk. Second, API's approach, based on industry participation, has been remarkably successful in developing safe, cost effective design practices. And third, learn from the past. Examine your performance and find ways to improve it.

4. Future Directions

Where are we headed regarding risk management in U.S. waters? Certainly we will continue with the proven, traditional techniques I discussed earlier.

Further activity will probably stem from the present focus on quality. Like many other companies, Chevron has been actively developing and applying quality improvement strategies and tools. For example, we used this approach as part of our Oil Spill Task Force effort.

Future Directions

- Quality Improvement Strategies
- Formalized Risk Management Procedures
- Comparative Risk Studies

Formalized risk management procedures will be applied and evaluated, such as those outlined in API RP 750. Hazard and Operability studies (HAZOP) will be conducted. Quantitative risk assessments will likely increase.

Comparative risk assessments will be conducted to evaluate alternative concepts and systems for deep-water development.

There is one more thing that we can say about the future effective management of risk, and it is the main point I hope you take away with you.

The advanced technology, the probabilistic risk assessments, the well planned contingency operations -- all these depend upon people to make them effective. It is through our people that we will attain our goal of safe and pollution free operations. Experience has shown that when we motivate, train, equip, and empower our people, they will respond to the challenges facing them. And they will succeed.



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STRUCTURAL RELIABILITY: DESIGN AND RE-QUALIFICATION OF OFFSHORE PLATFORMS

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ABSTRACT

During the last 25 years, structural reliability methods have found increasing applications in the design and re-qualification of offshore platforms. Recent experience with development of platform environmental loading and capacity characterizations and definition of reliability targets are discussed in this paper in the context of design and re-qualification of offshore platforms. Reliability based design criteria developments include specified reserve strength analyses of the intact and damaged structure; these analyses are intended to demonstrate that the structure has adequate capacity, ductility, reserve strength, and damage tolerance. Reliability based re-qualification criteria developments include definition of guidelines to assist judgements of platform suitability for service. It is concluded that the insights that can be provided by experienced applications of structural reliability methods can help improve judgements concerning design and re-qualification of offshore platforms. Additional education, experience, and development of reliability applications guidelines are needed to allow increased realization of the potentials of this technology.

1. Introduction

It has been five years since the last International Workshop on Application of Risk Analysis to Offshore Oil and Gas Operations was held (Yokel, Simiu 1985). At that time, the American Petroleum Institute (API) was well along with its efforts to develop a reliability based Load and Resistance Factor Design (LRFD) format guideline for design of offshore platforms. The Norwegian Petroleum Directorate (NPD) had initiated its efforts to implement such a format in design of structures for Norwegian waters and the NPD was advocating the use of risk analysis techniques to perform full-scope, life-cycle evaluations of proposed offshore structures.

The workshop explored applications of reliability methods to a wide variety of segments concerned with offshore platforms including drilling and production operations, design, concept development, and construction. In general, the workshop seemed to conclude that the technology was still very immature. There was a general fear that risk analysis techniques could be used to the detriment of the objective of obtaining and maintaining reliability in offshore platforms and their operations.

How much further have we come in the last five years? The API has issued the first draft LRFD guidelines. The NPD has issued substantial revisions to its

guidelines. The United Kingdom (U.K.) has undertaken development of LRFD guidelines similar to those of API. The Canadian Standards Association (CSA) has issued draft Limit State Design (LSD) guidelines that contain specific target reliabilities for different classes of structures. Development of a worldwide design code for offshore platforms is under discussion. Full-scope, life-cycle applications of risk analyses recently have found exploratory applications in studies of innovative structures for U.S. waters.

Reliability technology has seen substantial developments during this same time period. There have been major improvements in reliability methods for evaluation of structural systems, for evaluation of environmental loadings, and for definitions of inspections and maintenance strategies. Software has been developed and implemented that helps relieve analysts of much of the drudgery of reliability calculations.

To illustrate application of some of the progress that has been made, the remainder of this paper will be devoted to two applications of structural reliability methods. The first is development of structural design criteria for a major production, drilling, and quarters (PDQ) platform located on the Northwest Shelf of Australia. The second is development of re-qualification criteria for an existing production and drilling (PD) platform in the Gulf of Mexico.

2. Design Criteria

2.1 Background

The example that will be discussed in this section is development of structural design criteria for a PDQ platform to be located on the Northwest Shelf of Australia. The platform will be a conventional, steel, 8-leg, template-type, pile supported platform sited in a water depth of 135 m (443 ft) [Fig. 1]. This is an area that is frequented by intense tropical cyclones; approximately five such storms pass in the vicinity of the platform each year.

The platform owner and operator specified that the basic structural design should be performed according to the working stress design (WSD) format contained in the current American Petroleum Institute (API) Guidelines [API RP 2A] (American Petroleum Institute 1989).

The platform owner and operator also specified that the platform was to remain in operation during tropical cyclones. Thus, the platform would not be de-manned in advance of intense storms.

In the context of the proposed structure configuration and operation, the design criteria were to address four key issues:

- 1) The required reserve strength, ductility, and residual strength,
- 2) The design wave height and period (current and wind) and force formulation to be used in conjunction with the API based WSD design process,

- 3) Definition of the elevations of the lower production decks, and
- 4) Definition of a design approach to assure adequate damage tolerance in the substructure.

2.2 Long-Term Wave Environment

An extensive investigation of the oceanographic environment had been conducted by the platform operator. This included five years of measurements of tropical cyclone winds, waves, and currents, development and verification of a sophisticated storm hindcasting model, and the use of this model to define and evaluate the expected annual maximum winds, waves, and currents expected at the platform location.

This work indicated a 100-year expected annual maximum wave height, H_m , of 20 m (65.6 ft) [Fig. 2]. This wave was associated with a period of 12 s [steepness of 1/12]. A directional spreading ($\cos^2 \theta$) exponent $s = 1$ [range $s = 0.5$ to $s = 2$] was estimated for the extreme wave conditions.

The current, U_c , associated with the time and direction of occurrence of the 100-year H_m was estimated to be 1.2 m/s (3.9 fps) at the surface and 0.8 m/s (2.6 fps) at the sea floor. The wind speed [1 min] at an elevation of 50 m (164 ft) was estimated to be 75 m/s (168 mph).

The expected annual maximum wave heights and current speeds were well characterized with lognormal distributions [Fig. 2]. The probability distribution of the logarithms of the expected annual H_m has a standard deviation, $s_H = 0.27$. The median expected annual maximum wave height, \bar{H} is 10.5 m (34.4 ft).

2.3 Global Storm Forces

Analyses of hydrodynamic forces developed on the platform by various combinations of wave heights, periods, and forces indicated that the global forces (base shear, overturning moment) varied approximately with the square of the wave height. Thus:

$$S_{Hm} = K_d K_u H_m^2 \quad (1)$$

where K_d is a force constant that embodies the hydrodynamic force coefficient (drag force dominated), the water density, and the projected area properties of the structure; and K_u is a constant that embodies the procedure used to calculate the wave and current kinematics and their integration over the structure (Bea 1990a).

The forces were computed using traditional long-crested, unidirectional waves that had a steepness of 1/12, current speeds consistent with the occurrence of the maximum wave height, and the Morison force formulation with a drag coefficient, $C_d = 0.7$ and inertia coefficient = 2.0.

The 100-year cyclone conditions produced a maximum total lateral force of 84 MN (18,900 kips), and an overturning moment at the sea floor of 9,546 MN-m (7.0 x 10⁶ ft-kips). The currents accounted for 25 to 30 percent of the total maximum

forces. The wind forces accounted for 10 to 15 percent of the total maximum forces.

The maximum lateral forces, S_m , defined as a function of H_m , and the probability distribution of annual H_m were used to define the probability distribution of the expected annual maximum total lateral force acting on the proposed platform. The probability distribution of the logs of the annual S_m had a standard deviation, $\sigma_{S_m} = 0.56$ and coefficient of variation, $V_{S_m} = 61$ percent. This figure reflects only inherent variability [Type I, natural randomness] in the expected annual maximum wave heights. Modeling uncertainties [Type II] associated with the prediction of the expected annual maximum storm conditions and with the prediction of forces were also assessed and integrated with the Type I uncertainties.

2.4 Wave Height Uncertainties

The evaluation of Type II uncertainties in the predicted storm conditions was developed by comparing hindcast and measured conditions in severe tropical cyclones (Bea 1990a). In the case of the comparisons of hindcast and measured maximum wave heights, the data indicated a median bias (measured/predicted) of $B_{IIH_m} = 1.0$ and a $V_{IIH_m} = 0.10$.

2.5 Wave and Current Force Uncertainties

Turning to the hydrodynamic forces, there are two paths that could be followed to evaluate uncertainties (Bea 1990a). One would be to evaluate each of the components contributing to forces uncertainties; kinematics and force calculations, conditional on specification of the cyclone waves and currents.

A second approach would be to use measured global wave force data measured on prototype platforms in tropical cyclones, avoiding the explicit evaluation of kinematics uncertainties. The second approach will be discussed here. Both approaches produced very similar results (Bea 1990a).

The evaluation of wave and current force uncertainties was based on wind, wave, and current force measurements from the Conoco Test Structure (Bea, Pawsey, Litton 1991). The data (Block 6, characteristic of the wave conditions close to the center of tropical cyclones) indicated a median bias $B_{IIF_m} = 0.83$ ($C_d = 0.7$) and $V_{IIF_m} = 0.34$ [Fig. 3]. The uncertainty associated with calculation of the hydrodynamic forces is $\sigma_F = 0.32$. The resultant Type I and Type II uncertainty in the forces was estimated as $\sigma_S = 0.66$.

Due principally to the lack of recognition of directional spreading in the calculation of wave kinematics (and other errors in the force calculation process) a conservative "bias" is introduced into the wave forces. In the criteria development, this bias was eliminated through the introduction of a directional spreading factor [$\epsilon = 0.9$] to correct the long-crested wave kinematics (Bea, Pawsey, Litton 1991).

2.6 Structure Capacity Characteristics

The platform owner specified that the structural elements that comprised the platform would be designed according to API RP 2A WSD guidelines. These guidelines address how the elements of the structure should be proportioned, but not how the assembled elements or structure system should perform. For this criteria development, the performance of the platform structure system was specified with the Reserve Strength Ratio (RSR) (Lloyd, Clawson 1983; Titus, Banon 1988; Bea 1990b). The RSR is the ratio of the ultimate lateral capacity of the platform structure system, R_u , to the design lateral loading, S_D [Fig. 4].

The design criteria specified that after the primary design analyses were complete, the structure system should be analyzed using nonlinear, static push-over analyses. Based on the results of these analyses, the structure was to be capable of developing minimum nominal RSRs = 2.0.

The bias associated with the static push-over analysis, B_{as} , was estimated as the product of a ductility factor, F_v , and a structural analysis bias, B_{ss} [$RSR = RSRs \times B_{as}$; $B_{as} = F_v \times B_{ss}$]. The ductility factor is a function of the type of loading, the displacement capacity of the structure, and the residual strength capacity of the structure [Fig. 4].

The displacement capacity of the structure was expressed as the ductility ratio, μ , of the maximum lateral displacement at which the structure could retain its equilibrium, Δ_p , to the displacement at which the structure first exhibited significant inelastic behavior, Δ_e [$\mu = \Delta_p/\Delta_e$]. The residual strength was expressed as the ratio, α , of the residual capacity, R_r , at a displacement of Δ_p to the maximum lateral capacity, R_u [$\alpha = R_r/R_u$]. The design criteria specified that the platform should be capable of developing a minimum ductility of $\mu = 3.0$ and a residual strength ratio of $\alpha = 1.0$ (Bea 1990b).

Study of wave loadings acting on simplified nonlinear systems [Fig. 5] indicated that the ductility factor was governed primarily by the ratio of the duration of the peak wave loading on the platform, t_d , [approximately half the wave period] to the natural period of the platform, T_n . For this structure this ratio was approximately 2.0; thus, $F_v = 1.25$.

Mill tests on the steels proposed for use in the construction of the platform indicated a Type I bias in the steel strength (true/nominal) of $B_{ss_I} = 1.1$. Evaluation of the analytical models that would be used to evaluate the ultimate capacity of the platform braces that governed lateral capacity indicated a Type II bias of $B_{ss_{II}} = 1.1$. The resultant bias was estimated as $B_{as} = 1.5$.

The platform capacity probability distribution was assumed to be lognormal. Evaluations of the Type I and Type II uncertainties associated with the evaluations of the platform capacity characteristics were found to be $\sigma_{RI} = 0.10$ and $\sigma_{RII} = 0.10$. Thus, $\sigma_R = 0.14$.

The resultant uncertainties in the logarithms of the maximum loadings and capacities were estimated as follows:

$$\sigma^2 = \sigma_S^2 + \sigma_R^2 - 2(\rho_{SR}\sigma_S\sigma_R) \quad (2)$$

where ρ_{SR} is the correlation coefficient of the resistance and loading variables, S and R. It is generally assumed that there is no correlation between the capacity and the loading $\rho_{SR} = 0.0$. In some cases, (e.g. high levels of cyclic loadings acting on brace and foundation elements) the capacity is inversely proportional to the intensity of the loading [$\rho_{SR} \approx -1$]. In these cases, correlation of the loading and capacity can have important ramifications in the characterization of reliability.

For this development, the loading and capacity were assumed to be uncorrelated [$\rho_{SR} = 0.0$], and the resultant standard deviation of the logarithms of the loading and capacity computed as $\sigma = 0.67$. It is noteworthy that the uncertainty in the maximum loadings dominates the resultant uncertainty.

2.7 Required Reliability

The acceptable (tolerable, desirable) or target reliability for the structure was evaluated using two approaches (Bea 1990b; Bea 1991). The first approach is termed the "historical" approach. It is based on statistics of the performance characteristics of a wide variety of engineered structures, including offshore platforms comparable with this structure. The premise of this approach is that over time and with experience, the industry and the societies that it serves have determined "acceptable" and "marginal" balances between the likelihoods of failure, Pf, and the consequences of the failures, C [Fig. 6].

The two lines labeled "acceptable" and "marginal" [Fig. 6] can be expressed analytically as follows:

$$Pf(\text{acceptable}) = 10^{-(0.74 \log CF + 1.12)} \quad (3)$$

$$Pf(\text{marginal}) = 10^{-(0.6 \log CF + 0.95)} \quad (4)$$

The total costs of failure, CF, are expressed in millions of 1990 U.S. dollars. Note that an alternative measure of the costs of failure are the average number of fatalities associated with the failures.

The second approach is termed the "expected cost minimization" approach. This approach is based on an evaluation of the expected initial and future costs associated with the platform structure performance. The premise of this approach is a minimization of the total expected costs (initial and future) associated with alternative platform design characteristics.

Initial costs include all first costs for the development alternative. Future costs include all costs associated with operation and maintenance, and in particular the risk costs. The risk costs are the costs associated with productivity (expected losses due to deferred production), property (expected salvage and replacement costs), environmental damage (pollution abatement, clean-up, and restoration), costs associated with injuries and fatalities, and costs associated with the resource development (lost production costs).

Given that the costs associated with a development alternative can be reasonably related linearly to the logarithm of the likelihood of failure, Pf, [Fig 7] then it can be shown that the probability of failure associated with the minimum total

cost is (Bea 1991):

$$P_{fo} = 0.435/[R_c f] \quad (5)$$

where R_c is a cost ratio. The cost ratio is the ratio of the expected cost of the platform loss of serviceability ("Cost of Failure", CF) to the cost needed to decrease the annual likelihood of the platform loss of serviceability by a factor of 10. In the case of future costs, the potential future risk costs need to be discounted to present values with a present value discounting function, f . In the case of a continuous replacement based operation that has an exposure period, L , and a net discount rate, r , f can be expressed as:

$$f = [1 - (1 + r)^{-L}]/r \quad (6)$$

For long life structures and continuous replacement of failed structures $f = 1/r$.

For the cases of non-replacement of the structure after failure, and deferred revenues considerations, more complex present value discount functions need to be considered (Stahl 1986).

The value of P_f determined on the basis of the foregoing approaches refers to the reliability associated with all aspects of the operations. Experience with permanent, bottom-supported drilling and production platforms indicates that 70 to 80 percent of accidents that develop "failure" [significant damage or losses of serviceability] in these structures are due to causes other than the structure and the environment (e.g. fires, explosions, blowouts, collisions, etc.) [Fig 8] (Bea 1991). This can be expressed as:

$$P_f = P_{fs} + P_{fo} \quad (7)$$

where P_f is the total probability of failure, P_{fs} is the probability of failure associated with the structure and P_{fo} is the probability of failure due to operational hazards. Thus:

$$P_{fs} = P_f [1 - P_{fo}/P_f] \quad (8)$$

Consideration of the operations for the proposed platform (no oil production, gas production transported directly to shore based facilities) indicated that operating hazards could be assumed to contribute 60 to 70 percent of the total likelihood of failure. Thus, $P_{fs} = 0.3 P_f$.

Evaluation of the total costs associated with failure of the platform indicated $CF = \$500$ million. Substitution of this value into Eq. 3 gives $P_f = 7.6 \times 10^{-4}$ per year. Allocating 30 percent of P_f to the tropical cyclone hazard would indicate $P_{fs} = 2.3 \times 10^{-4}$ per year. In the case of operations based on evacuation of personnel in advance of severe tropical cyclones, CF is estimated as \$300 million. Again substituting this value into Eq. 3 gives $P_f = 1.1 \times 10^{-3}$ per year; thus, $P_{fs} = 3.3 \times 10^{-4}$ per year.

Evaluating the platform using the cost minimization approach, and based on $CF = \$500$ millions, $f = 10$, and $R_c = 50$, gives $P_f = 8.7 \times 10^{-4}$ per year. Allocating 30 percent of P_f to the storm hazard gives $P_{fs} = 2.6 \times 10^{-4}$ per year. In the case

of operations based on evacuation of personnel in advance of severe tropical cyclones, $R_c = 30$, $P_f = 1.4 \times 10^{-3}$ per year, and $P_{fs} = 4.2 \times 10^{-4}$ per year

Thus, the range of P_{fs} indicated by the historical and cost minimization approaches is from 2.3 to 2.6×10^{-4} per year for manned operations and from 1.1×10^{-3} to 4.3×10^{-4} per year for unmanned operations.

These values are in good agreement with those developed in studies of comparable platform operations in the North Sea [manned] (Offshore Certification Bureau 1988), and in the Gulf of Mexico (evacuated in advance of hurricanes) (Bea 1990).

These P_{fs} are equivalent to structural Safety Indices of $\beta = 3.6$ for manned operations and $\beta = 3.3$ for unmanned operations [$P_f \approx 10^{-\beta}$; $P_f = 0.475 \exp(-\beta^{1.6})$, $1 \leq \beta \leq 3$].

2.8 Design Wave Height

Given lognormally distributed expected annual maximum tropical cyclone loadings (S) and platform capacities (R), the Safety Index, β , is computed as follows:

$$\beta = [\ln(R/S)/(\sigma_R^2 + \sigma_S^2)]^{1/2} = \ln(R/S)/\sigma \quad (9)$$

where R and S are the median (50-percentile) ultimate capacity and expected annual maximum loadings, respectively. σ_R and σ_S are the standard deviations of the logarithms of the platform capacity and expected annual maximum loadings, respectively.

Given the foregoing developments, the design wave height for the WSD design can be expressed as:

$$H_D = (H^2/RSR)[\exp(\beta\sigma)]^{1/2} \quad (10)$$

Thus:

$$H_D = [(10.5^2 \text{ m}^2/3) \exp(3.6 \times 0.67)]^{0.5} = 20 \text{ meters} \quad (11)$$

This design wave height would have an average return period of 100 years [Fig. 2]. The wind speed and current speed conditional on the time and direction of occurrence of the 100-year return period wave height would be used in the design criteria formulation. The design wave height would be assumed to have a height to length ratio of $1/12$ [range $1/10$ to $1/13$].

2.9 Design Deck Elevation

The design deck elevation was determined based on the elevation required to clear the forceful portion of the crest of the expected annual maximum wave that would bring the platform to its ultimate limit state [$RSR = 1.0$]. Allowing for subsidence, water depth tolerance, storm and astronomical tides, the deck clearance elevation [above mean sea level], E_D , was based on the following relationship:

$$E_D = 0.6 [(H^2 \exp(\beta\sigma)]^{1/2} \quad (12)$$

Thus:

$$E_D = 0.6 [10.5^2 \exp(3.6 \times 0.67)] 0.5 = +21 \text{ m} = +70 \text{ ft} \quad (13)$$

The expected annual maximum wave height associated with this crest elevation had an average return period in excess of 10,000 years [Fig. 2].

2.10 Design RSR For Damaged Conditions

The design nominal RSRs for platform damaged conditions was based on the strength of the platform that would implicate de-manned platform operations. The nominal RSRs was estimated from:

$$\text{RSRs} = [H^2 / (B_{as} \times H_D^2)] \exp(\beta\sigma) \quad (14)$$

Thus:

$$\text{RSRs} = [10.5^2 / 1.5 \times 20^2] \exp(3.6 \times 0.67) = 1.6 \quad (15)$$

2.11 Intact Push-Over Analyses

Following completion of the WSD API RP 2A based design of the platform structure, the structure was subjected to a series of static, nonlinear push-over analyses to demonstrate that it possessed adequate reserve strength, ductility, and residual strength (Piermattei, Ronalds, Stock 1990).

The analyses indicated that modifications to the primary diagonal braces and joints (added approximately 1,000 tonnes of steel) were required. In addition, the design factors-of-safety used to define the axial capacity of the clustered corner piles for storm and operational loadings were increased to 3.0. In addition, spare pile sleeves were included at the corners to allow the foundation capacity to be supplemented if pile installation difficulties were encountered. With these modifications, the structure was able to demonstrate acceptable performance characteristics [Fig. 9].

2.12 Design Damage Conditions

One of the primary objectives of this part of the design criteria was to develop a structure that would possess sufficient robustness or tolerance to damage. The design for damage was based on damage experience with similar platforms and for the proposed operations of this specific platform.

Of importance in this regard, was the decision by the platform owner not to allow supply boat operations in the vicinity of the platform during severe weather conditions. Special stand-off, tie-up buoys and deck cranes with sufficiently long booms and capacity were provided to allow remote boat resupply operations. Mooring and boat operations in the vicinity of the platform were restricted to specified maximum sea conditions. These sea conditions became the basis for evaluation of boat inflicted damage.

The damage conditions were based on definition of the high probability damage and consequence (to strength) members (e. g. legs, diagonal braces) [Fig.10]. The high consequence members were identified based on the results of the intact structure analyses. Missing member analyses were performed involving diagonal and horizontal braces. Six damage scenarios were defined based on dropped objects. Boat collisions with the corner and interior legs were also investigated. Damage inflicted by the collisions and dropped objects was evaluated and the member properties adjusted to reflect the extent of damage.

The study identified the need to add additional steel in the areas of some damaged members. Approximately 120 tonnes of steel had to be added to the jacket to allow the structure to develop RSRs equal to 1.6 [Fig. 10] (Piermattei, Ronalds, and Stock 1990).

2.13 Summary

Structural reliability methods were used to develop advanced design criteria for a major PDQ platform, all within the context of traditional WSD methods. The primary design analyses of the structure were conducted using conventional methods with little disruption to the normal design process. Reliability methods were used to define the basis for the design tropical cyclone forces, and for nonlinear push-over verification analyses intended to demonstrate that the platform possessed sufficient reserve strength, ductility, and residual strength in its intact condition. These methods were extended to define damage conditions and analyses for the structure to assure that it possessed adequate robustness or damage tolerance.

3. Re-qualification Criteria

3.1 Background

There are about 6,000 major platforms located on the World's Continental Shelves. Approximately 3,000 of these are located in the Gulf of Mexico. Many of these platforms have experienced the compounding effects of aging including corrosion, degradation of joints due to fatigue, damage due to collisions and dropped objects, insufficient maintenance, and, technical obsolescence (early generation design criteria and construction methods). Many of these structures are being called upon for extended lives, in some cases of the order of twice the original design life. The industry is developing sophisticated approaches for the re-qualification of these structures (Skarr, et al. 1991).

This section will deal with one such platform, a PD platform located offshore the Louisiana coast in 150 ft (45.7 m) of water (Bea, Puskar, Smith, Spencer 1988). The platform is a 5-leg, fixed drilling platform that was installed in 1962 [Fig. 11]. It was originally designed for a 46 ft (14 m) 25-year return period wave height. Nine gas wells were completed on the platform. It is unmanned. Based on present production estimates and profitability guidelines, the platform is proposed for a 10-year remaining life.

Underwater inspections disclosed a wide variety of structural defects and damage [Fig. 11] that range from missing diagonal braces to cracked joints.

The basic objective of this work is to find a combination of structural and operational measures that will allow re-qualification of the structure for another 10-years life. A principal objective is to develop structural reliability based re-qualification criteria to determine the suitability for service of this structure and its proposed operations.

3.2 Hurricane Loadings

Advanced oceanographic studies were conducted to identify site specific hurricane wind, wave, and current conditions [Fig. 12]. The evaluations indicate that the platform has experienced several hurricanes that have developed wave heights close to the design wave height. One of the storms [Hurricane Hilda in 1964] developed wave heights that inundated the lower decks. This same storm caused failures of some 13 other platforms.

Evaluations of the forces exerted on the platform were based on the guideline minimum wave force approach defined in API RP 2A [Section 2,3,4 g. Forces. $C_d = 0.6$]. The total maximum lateral hurricane loading as a function of the return period associated with the predicted expected maximum wave heights indicated that waves begin to impact the deck at wave heights having average return periods of approximately 35 years [Fig. 13]. The dramatic increase in loadings (vertical and horizontal) is caused by the combination of the large exposed deck areas and the high water particle velocities near the crest of the wave.

For a 100-year return period wave height, the lateral loading based on the API guideline minimum wave force approach [with deck in wave crest] indicates a load of approximately 2,000 kips (8.9 MN). With the decks raised, the 100-year conditions loading is reduced to approximately 1,200 kips (5.3 MN).

3.3 Platform Capacities

Evaluations of the platform capacity was made using nonlinear, static push-over analyses of the structure and foundation system [Fig. 14]. The structure and foundation element capacity characteristics were defined appropriate for the early design characteristics of the platform. Because there are no joint reinforcing cans and the leg - pile is ungrouted, punching problems at the joints often controlled the brace load carrying capacity; thus, the brace capacity was modified to account for premature punching or tearing of the leg joints. The capacity of the damaged elements were modeled according to results from recently completed laboratory investigations.

The steel used in the platform was A36 with a nominal yield stress of 36 ksi (248 MPa). Based on mill certification specifications which were located for this platform, the nominal value was increased by 14 percent to account for the difference between the mean and the nominal strength. An additional 10 percent increase was recognized based on the difference between the low rate of strain used in the mill tension tests as compared with the wave loading strain rates.

The low natural period of this platform ($T_n = 0.5$ s) combined with the duration of the peak wave loading ($t_d = 5$ to 6 s), indicated very small ductility corrections to the static push-over results ($F_v \approx 1.0$).

In its present condition, the platform indicated an expected maximum capacity $R_u = 1,000$ kips (4.4 MN), and a $RSR = 1,000 \text{ kips} / 2,000 \text{ kips} = 0.5$.

Three alternatives were considered for rehabilitation of the structure [Fig. 14]. These included:

- a) repairing the damage and returning the platform to the as-designed condition;
- b) repairing the damage and grouting the legs to the piles to strengthen the joints, and
- c) repairing the damage and raising the deck 15 feet above the 100-year expected maximum crest elevation.

The RSR was evaluated for each of the alternatives [Fig. 14]. The RSR ranged from 0.55 [repaired] to 1.25 [repaired, raised decks].

3.4 Acceptable RSR

In this development, it will be assumed that for communication and decision making purposes it will be desirable to characterize the risks associated with a particular platform into three general categories: Low Consequences (LC), Moderate Consequences (MC), and High Consequences (HC). Such general qualitative categories can be very useful in public and regulatory communications of risks, and judgements concerning structure suitability for service [Skarr, et al. 1991].

A LC category platform would be one that would pose no or little risks to the environment, resource, productivity, life, or property. For example, an unmanned, well-jacket (small platform that supports a few wells) whose wells were equipped with reliable down-hole subsurface safety valves, and whose risers were equipped with emergency shut-downs and back-flow prevention valves could be placed in this general category. In terms of cost-benefit analyses, the consequences could be expressed as $C = R_c \times f$. A low consequence category could be assumed to have $C = 1$ to 10.

An HC category would be a platform that would pose significant or major risks. Platforms that supported large drilling and production operations and that were manned with a large number of personnel could be placed in this general category. A high consequence category could be assumed to have $C = 100$ to 1,000.

An MC category would be a platform that would pose risks that would fall in between these two extremes. Manned platforms that were evacuated in advance of extreme storms could be placed in this category. An MC category could be assumed to have $C = 10$ to 100.

Given that the platform demands (loads) and capacities are modeled with lognormal distributions, then the RSR can be related to the Safety Index, β , as follows (Bea, Puskas, Smith, Spencer 1988):

$$RSR = R_F \exp(\beta\sigma) \quad (16)$$

where R_F is the ratio of the median expected annual maximum force, \underline{S} , to the reference level design force, S_D . When S_D is defined on the basis of the 100-year design force,

$$R_F = \exp (2.33\sigma_S) \quad (17)$$

For this example, and based on the results developed by Bea (1990) and Bea, Puskas, Smith and Spencer (1988), $\sigma_S = 0.75$, and $R_F = 0.17$. The uncertainty associated with the platform capacity was evaluated to be $\sigma_R = 0.25$ [reflects additional uncertainties associated with damaged and repaired conditions]. The resultant uncertainty in capacity and loadings is $\sigma = 0.79$. Both Type I and Type II uncertainties have been included in these figures.

While the assumed total uncertainty might be appropriate for some platforms in the Gulf of Mexico, it could be an inappropriate estimate for other platforms. Data gathering, proof loadings by previous severe environmental events, and other similar sources of experience could lead to reductions in the uncertainties. In addition, there may be different loading and capacity uncertainties associated with other deep and shallow water locations (e.g. truncation of wave heights due to wave breaking in shallow water). The definition of the appropriate reserve strength ratios would need to reflect these potential effects on the probability characterizations (Aggarwal, Bea, Gerwick, Ibbs, Reimer, Lee 1990).

Based on an expected cost minimization analysis [Fig. 7] (Bea 1991), an "acceptable" Safety Index can be expressed as:

$$\beta_a = \{-\ln[0.915/(fR_c)]\}^{0.625} \quad \beta(18)$$

If it were assumed that the criterion to define the marginal Pf was the point on the expected total cost of failure curve where a slope equal to that of the initial cost curve was developed (investment to reduce risk = reduction in expected total costs), then the "marginal" Safety Index could be defined as:

$$\beta_m = \{-\ln[1.83/(fR_c)]\}^{0.625} \quad (19)$$

For the purpose of this development, it will be assumed that there are five major safety hazards that the platform must confront: fires, explosions, blowouts, collisions, and storms. It will be assumed that the storms will be allocated one-fifth of the total probability of failure deemed acceptable and marginal for the platform; thus, $P_{f \text{ storms}} = 0.2 P_f$.

Fig. 15 summarizes the results for the cost minimization approach to define acceptable and marginal combinations of consequences, C [$C = C_f \times f$], and RSR.

Alternatively, the history based approach for determining the Safety Index could be used [Fig. 6]. It is important to note that the experience based and utility based measures of consequences are not the same. This is because the experience based measure is expressed directly by the monetary costs associated with failure, CF, while the utility based measure reflects not only the monetary costs associated with failure, but as well, the costs associated with improving the reliability of the structure, and the present value discount function.

Fig. 16 summarizes the results for the experience based combinations of consequences and RSR. Comparisons of the RSR indicated by the three categories of consequences in Fig. 15 and Fig. 16 indicates reasonable agreement.

3.5 Observations

These results indicate that the platform will not qualify in its present condition. Further, repair of the platform and restoring it to its original as-designed condition will not qualify the structure. Only in the case of repairing the platform and raising the decks will the structure qualify for service.

Given that a particular platform repair and operations program would not meet the minimum RSR indicated by the utility and experienced based approaches, a variety of options should be investigated including:

- a) reducing potential consequences (through improved controls on life, resource, pollution, and property losses),
- b) increasing the platform strength (repairs or other strengthening measures),
- c) decreasing the platform reference force (removal of marine growth, removal of unnecessary appurtenances),
- d) decreasing the proportion of safety that must be allocated to non-storm related hazards (decreased likelihoods of collisions, blowouts, fires, explosions), and
- e) decreasing the uncertainties in loadings and capacities (implement data and information gathering programs and improved analyses).

If none of these measures are effective or can be justified economically, then the implication is that the structure should be removed from service.

4. Conclusions

4.1 General Observations

During the last thirty plus years, engineers have been developing and implementing structural reliability methods in design and re-qualification of offshore platforms. Researchers have developed an imposing storehouse of reliability technology.

There has been generally good experience with applications of structural reliability methods to special problems, and with code and guideline developments. It has taken much longer to develop acceptance by the practitioners than it has taken to develop the basic technology and background.

In the main, the practicing structural engineers (designers) still remain largely insulated from reliability technology. Reliability based design code

developments have developed relatively few converts to the theology of reliability.

Why is this? The answers are varied. Education of practicing structural engineers is a primary hurdle. As well, important limitations in what has been developed is another primary problem.

The education challenge goes in several directions. First, practicing engineers need to learn about what has been developed and how it can help them. Second, researchers need to learn about what problems need to be solved before the technology can be implemented in a mature way. Third, managers need to learn how to understand and interpret the results, and participate in supplying information that facilitates the decision making processes that can lead to applications and support for high priority research and development.

4.2 Limitations

What about the limitations? We seem to be struggling with a large variety of important problems such as:

- a) Defining practical approaches and processes that can lead to characterization and definition of desirable, acceptable, or tolerable reliability of structural systems.
- b) Defining, characterizing, and analyzing uncertainties including inherent randomness; modeling, measurement, and data uncertainties, and human-organizational actions uncertainties.
- c) Defining practical methods for realistic characterization of the reliability of structural systems (assemblies of elements) including the effects of the environment, design, construction, and operations processes.
- d) Defining practical methods for realistic characterization of loadings and demands placed on structural systems including those from construction and operations.
- e) Defining methods, analyses, and implementation frameworks to assist in the management of the organizational and human error aspects that play such an important role in the reliability of structural systems.
- e) Defining effective design code and special problem structural reliability analysis formats that will allow information sensitive, full-scope, life-cycle reliability methods to be implemented in design of new structural systems, and re-qualification and rehabilitation of such systems.

Perhaps application and implementation of reliability methods have been slow because the technology is still incomplete in some very important details, and suffers from many significant limitations. Also, perhaps the motivations for the practicing engineer to learn and apply the technology have been lacking or slow to develop.

It would appear that we still have a long way to go before we can claim maturity in applications. The research and engineering communities have much to do and learn.

4.3 Prospects

The prospects for the applications of structural reliability methods in design and re-qualification of offshore platforms is very encouraging. These methods have proven to be a valuable asset in helping address unusual problems associated with design of offshore platforms [Bea, Moore, Lee 1991].

The direct application of reliability technology in the general structural design process seems to be well beyond our current capabilities. Design for explicit reliability targets or resource optimized reliability seems to be in the very distant future. This is not so much because of the reliability technology limitations, but because of more basic technology and political limitations.

Performing realistic ultimate limit state analyses of complex structural systems severely stretches our current practice capabilities. Competent and workable analytical models for the behavior of new, defective, and repaired steel, concrete, composite, and foundation elements need development. This seems to be much more of a basic mechanics problem than a reliability problem.

Performing realistic fatigue analyses of complex structural systems that can realistically reflect ultimate limit state and serviceability limit state effects is still farther from our reach. This is particularly true when one attempts to recognize potential design, construction, and operations flaws, complex environmental-operational loadings, dynamic responses, and the effects of inspection, maintenance, and repair intervention programs.

But, if this is the state of affairs, why all of the optimism about prospects? Because we practicing structural engineers badly need the help that this technology can provide, even in its present state of development.

Our problems are rapidly becoming more complex. We have accelerated the development of innovative structures that are frequently placed in very hazardous or sensitive environments. We are working in a very complex mixture of political-social-economic environments. The engineer is being forced to form a partnership between nature and society.

In developed areas, we are faced with an aging infrastructure that we can not afford to throw away and replace. We must find out how to work with what we have, and not compromise technical, economics, and risks standards.

In developing areas, we are faced with severe economic, environmental, technical and social-political constraints. Again, we must find out how to work with what we have and not compromise appropriate standards.

4.4 Challenges

The first primary challenge is education. We need to define more effective methods of transferring research into practice. We need to relieve the engineer

of the burdens of complex reliability analyses, and have him focus on development of high quality input information, and performing high quality evaluations and applications. At this time, our problem is not so much one of developing new technology as it is applying the existing technology in a meaningful way.

We also need to define more effective methods of transferring practice problems back to research. The researcher needs to become more sensitized to the problems of the practitioner, and develop practical solutions to these problems. We need to provide sufficient support for researchers to address these problems.

Lastly, we need to reach managers and decision makers with this technology. This technology must be placed in the contexts of their problems, organizations, and means of making decisions. The general public is one component of the decision making framework, and it must be included in the education process.

The second major challenge is implementation. We need to further develop how reliability methods can be implemented within codes and guidelines, addressing conventional and unconventional structural systems. Definitive guidelines on how to perform structural reliability analyses are badly needed. Reliability based developments need to provide incentives for the practicing engineer to apply the technology, such as information sensitive formats.

The developments need to be founded on a practical and yet advanced system of analytical capabilities that take full advantage of computers and communication systems. The developments need to be directed toward full-scope, life-cycle reliability management of structural systems. The developments need to address both new and existing structural systems.

The third primary challenge is further research and development of reliability technology to address the practical problems of future implementations. We need to develop methods to define and realistically evaluate uncertainties in demands developed in structural systems and the performance of these systems.

We need to develop methods that will assist in engineering the management of the dominant threat to the reliability of structural systems: human and organization errors (Pate-Cornell 1990, Bea, Moore 1991). An analytical framework needs to be developed that will address the limitations, flaws, and frailties of humans, organizations, and societies. We need to develop methods that will allow us to evaluate practical and effective means of designing people and their activities into our structural systems, just as we design steel, concrete, and foundation elements. These methods need to address full-scope, and life-cycle aspects of structural systems.

Lastly, we need to further develop methods, approaches, and guidelines to define desirable, acceptable, or tolerable reliability. These methods need to address a full range of potential impacts including human injuries, injuries to the environment, resource development, property, and productivity. Methods need to be developed to assist in resolution of evaluation conflicts.

We have come a long way in developing and implementing reliability methods in engineering structural systems. We still have a long way to go before we can realize maturity of this technology. We should embrace this technology if we are

to dramatically improve the consistency and quality of our engineering. It is needed to allow us to examine a broad range of issues and consider a broad range of solutions to the increasingly difficult problems associated with maintaining our existing infrastructures and building new structures.

This technology can increase our creativity in solving engineering problems in a way that will form strong partnerships between the societies we serve and the environment in which we live.

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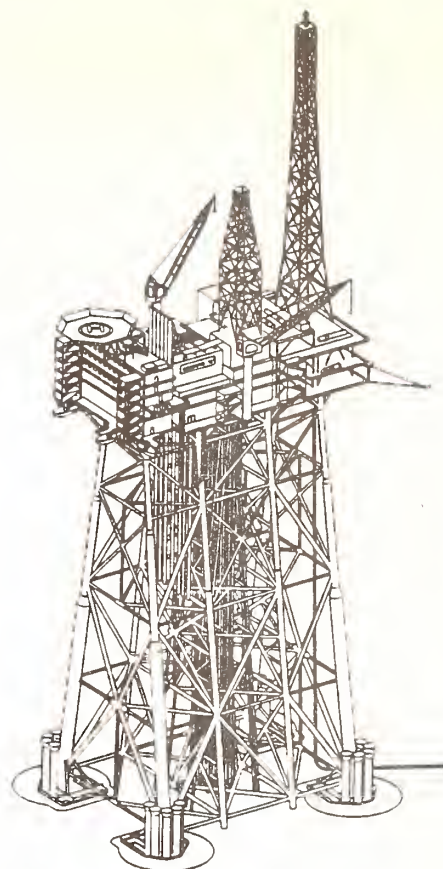


FIG. 1 Eight Legged Production, Drilling, and Quarters Platform

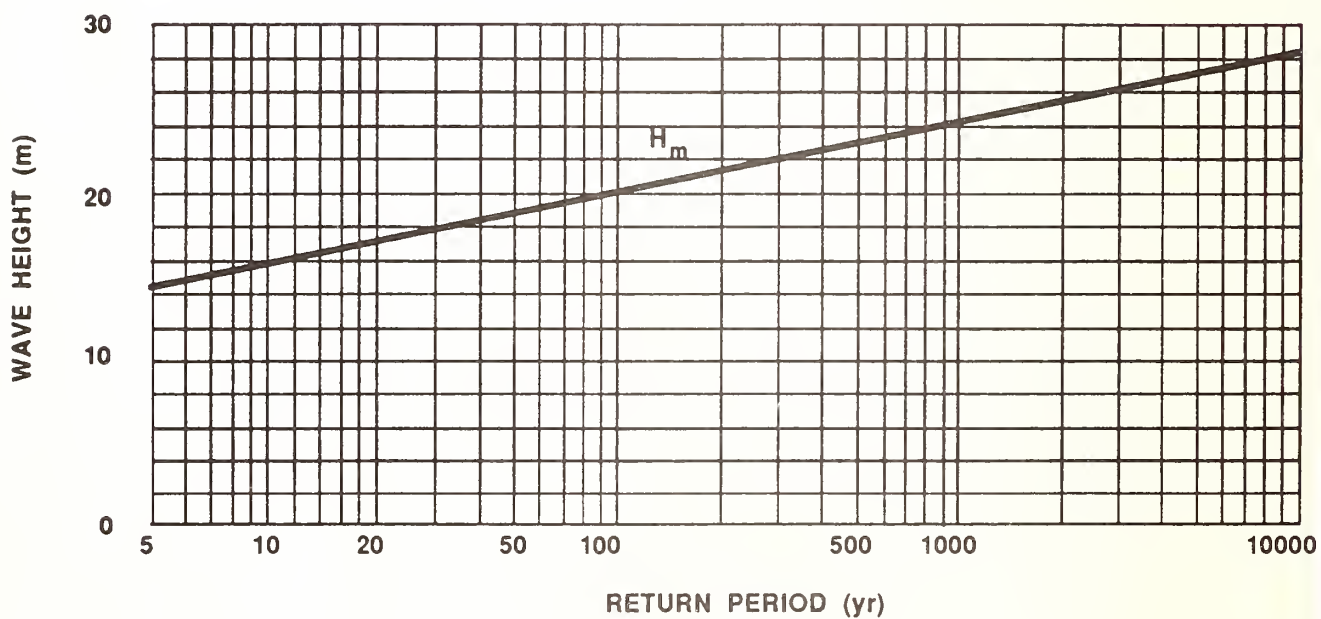


FIG. 2 Expected Maximum Wave Heights Versus Average Return Periods at the Platform Site, Northwest Shelf, Australia

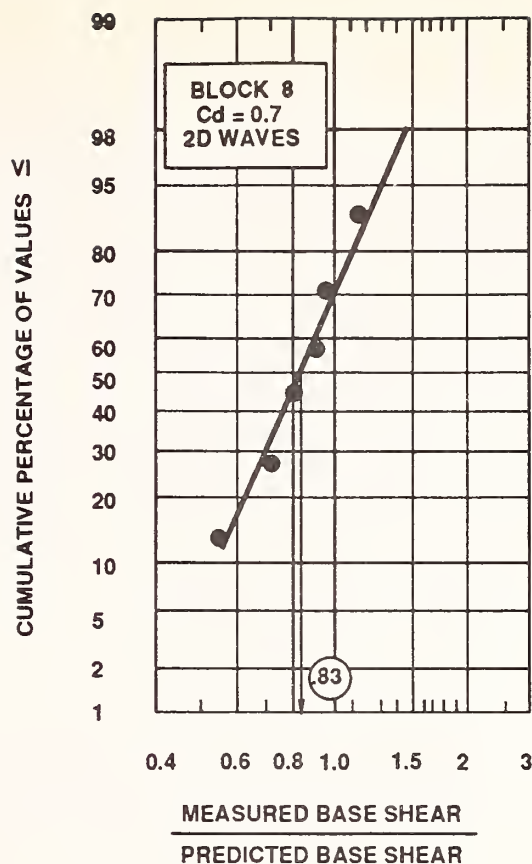


FIG. 3 Uncertainty and Bias in Predicted Total Maximum Hydrodynamic Forces Developed on the Platform in Intense Tropical Cyclones

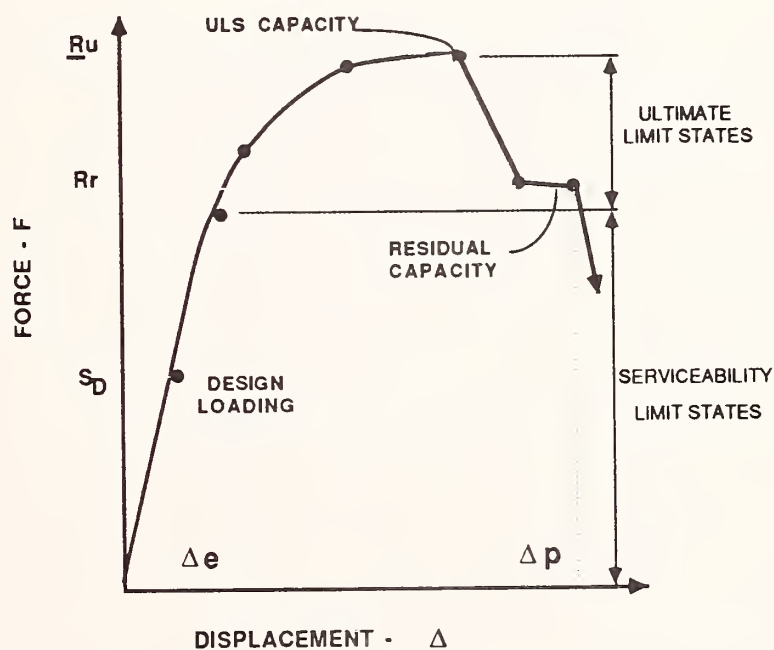


FIG. 4 Ultimate Limit States and Serviceability Limit States Load Capacity and Displacement Characteristics

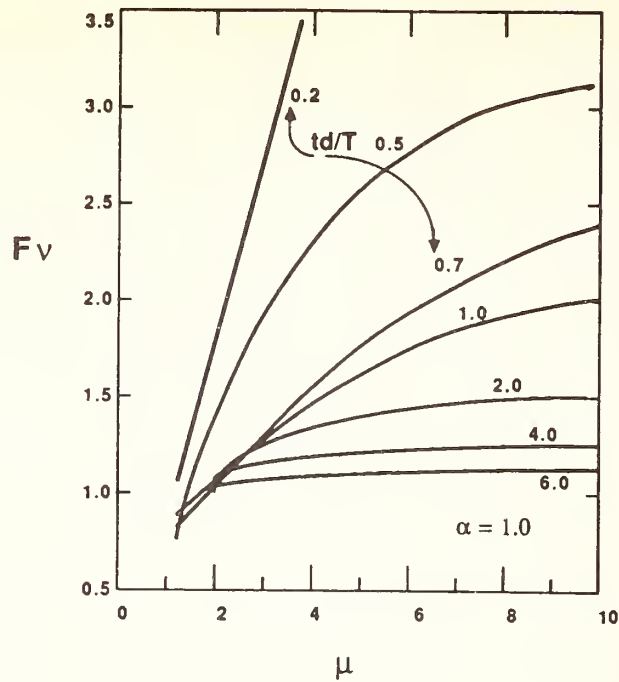


FIG. 5 Influence of Platform Ductility ($\mu = \Delta p / \Delta e$) and Wave Loading Duration - Platform Natural Period Ratio (t_d / T_n) on Correction to Static Push Over Capacity For A Residual Strength Ratio ($\alpha = R_r / R_u$) = 1.0

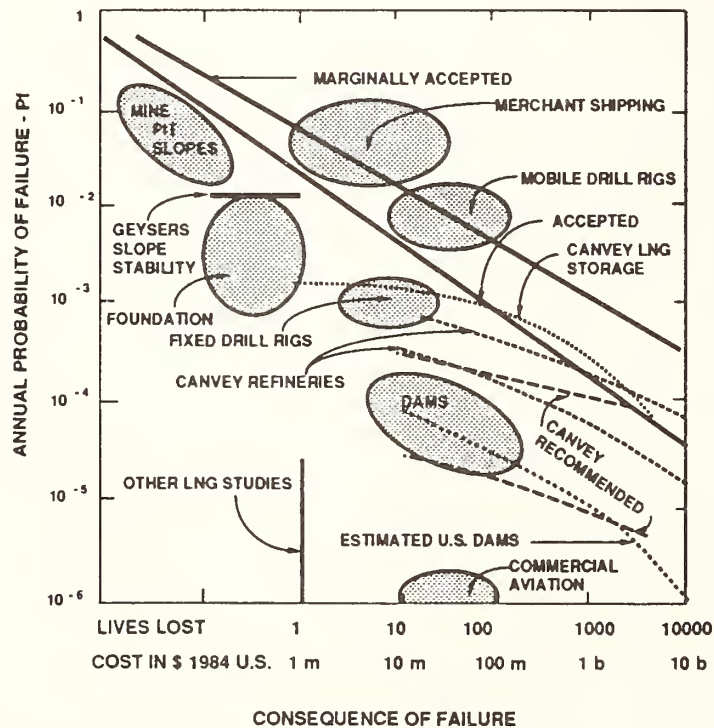


FIG. 6 Historical Relationship of Risks and Consequences for Engineered Structures

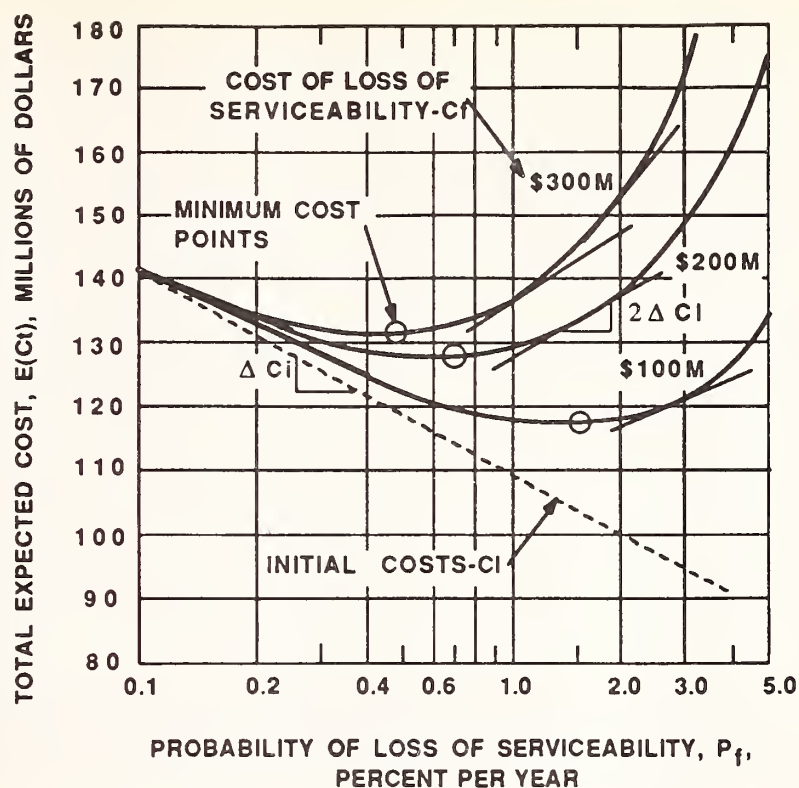


FIG. 7 Minimization of Expected Initial and Future Costs To Define Probability of Loss of Serviceability of the Platform

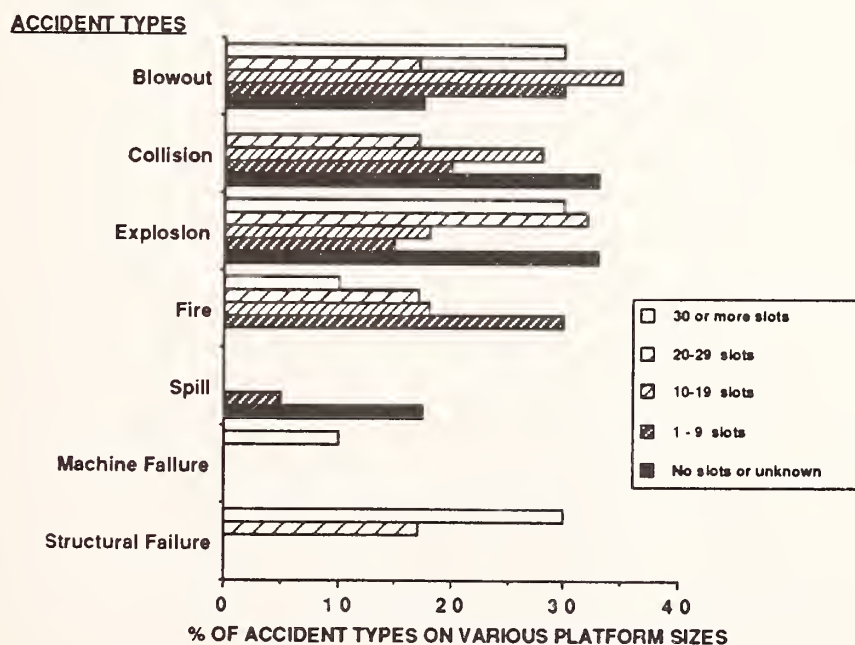


FIG. 8 Causes and Frequencies of Accidents on Major Offshore Drilling and Production Platforms

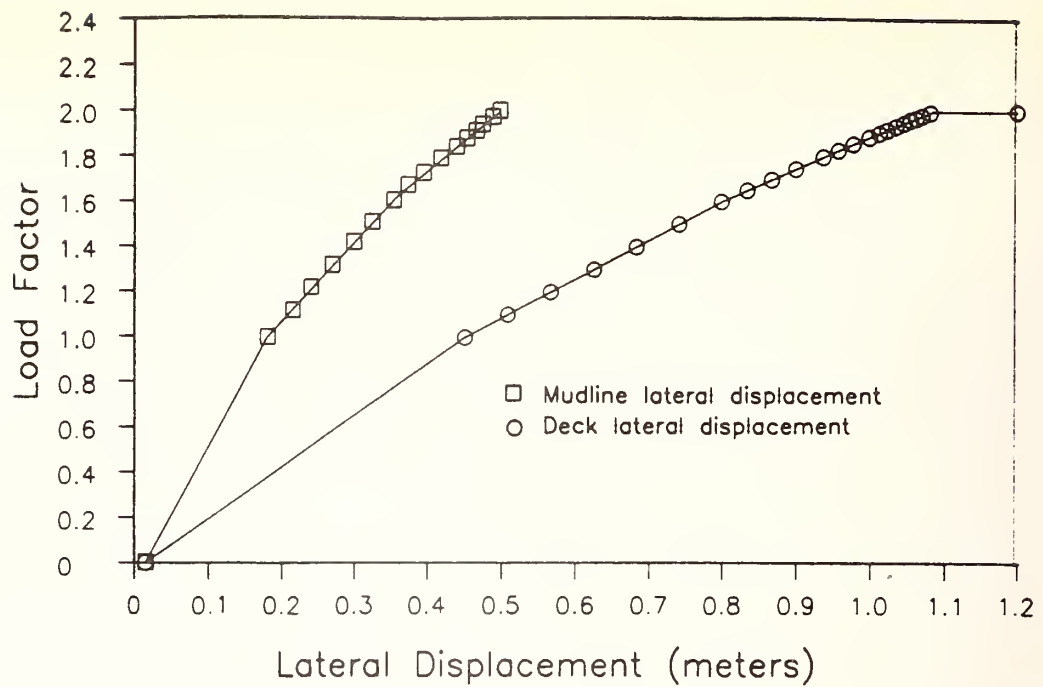


FIG. 9 Nonlinear Static Push Over Analysis Results for Platform After Brace, Joint, and Foundation Modifications To Achieve Target Reserve Strength Ratio (Load Factor), Ductility, and Residual Strength (After Piermattei, et al. 1990)

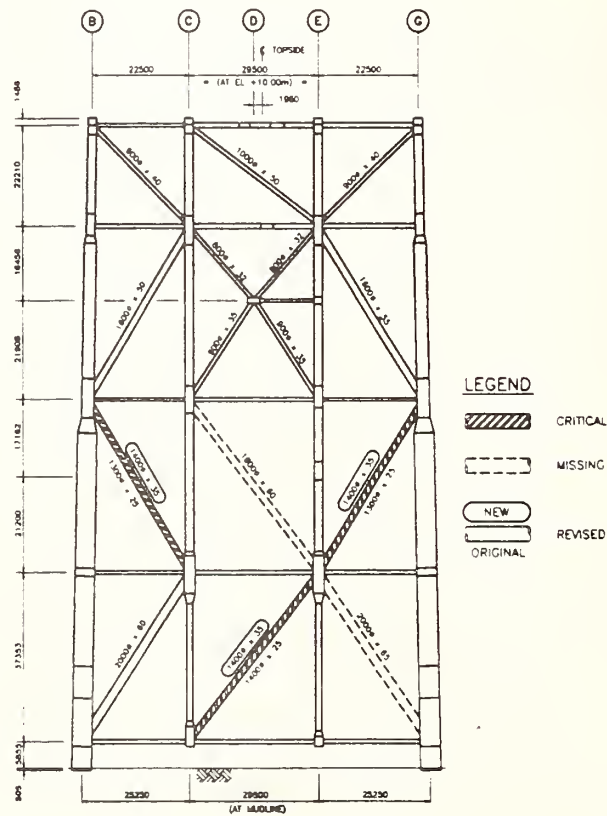


FIG. 10 Critical, Missing, and Revised Members Defined As A Result of the Damaged Structure Analyses (After Piermattei, et al. 1990)

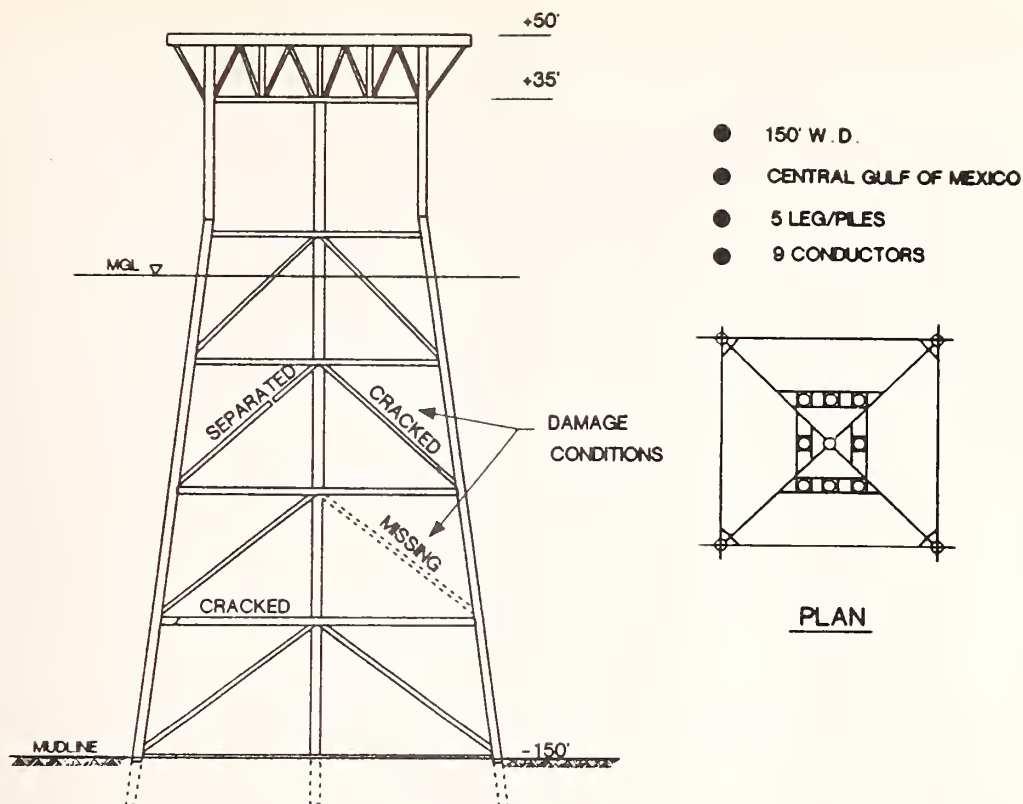


FIG.11 Gulf of Mexico Production and Drilling Platform to be Re-qualified For Extended Service

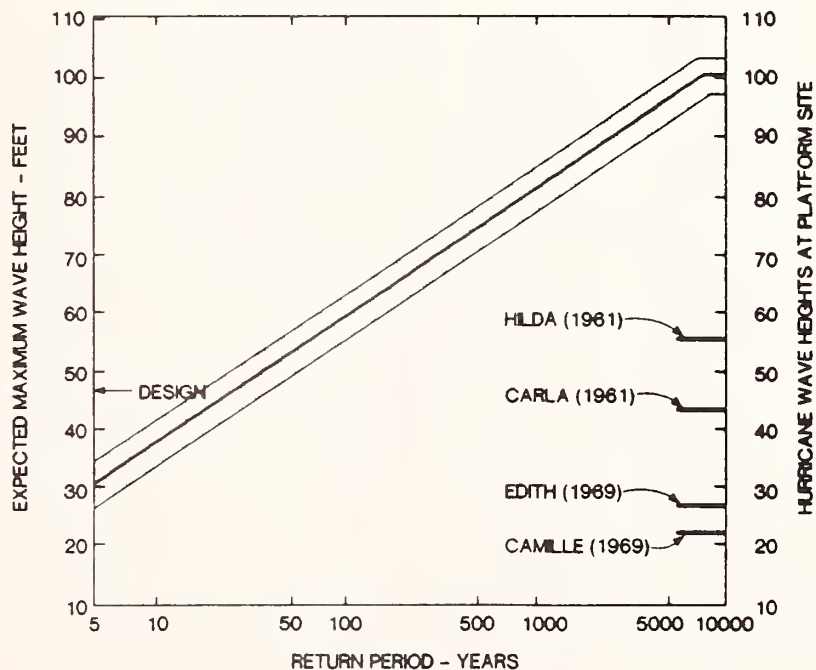


FIG. 12 Expected Maximum Wave Height Versus Average Return Period at the Platform Site

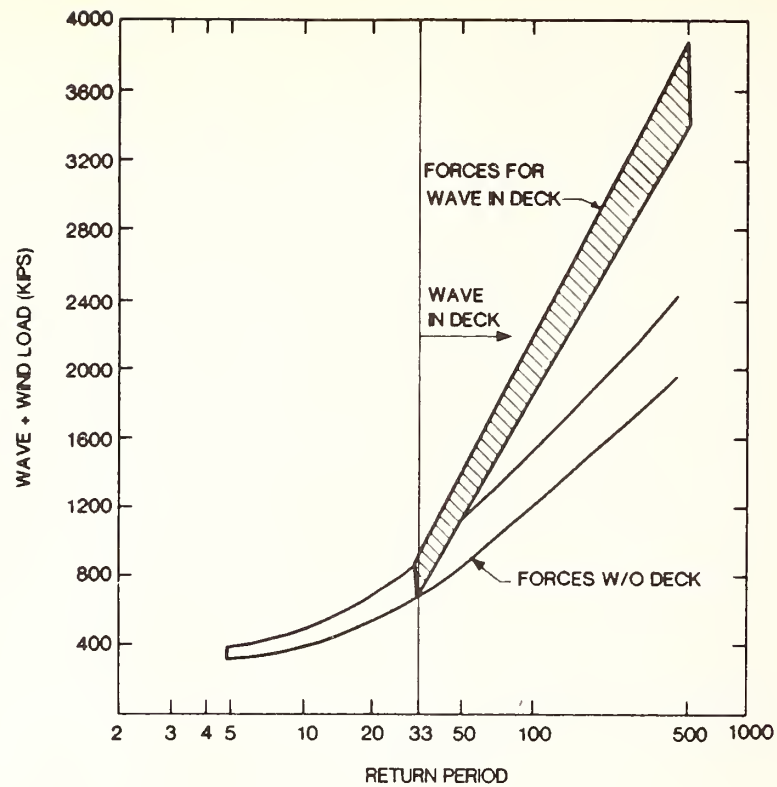


FIG. 13 Total Maximum Lateral Loading Developed on the Platform Versus Average Return Period

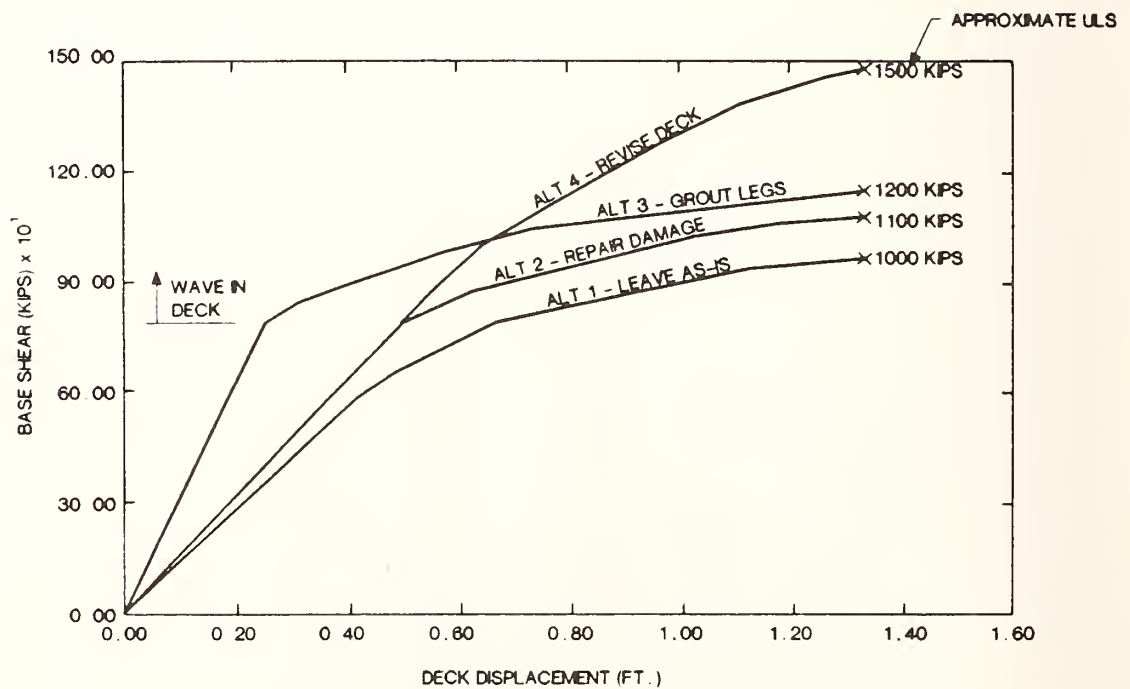


FIG. 14 Nonlinear Static Push Over Analysis Results for the Platform in its Present Condition, Repaired, and With Raised Decks

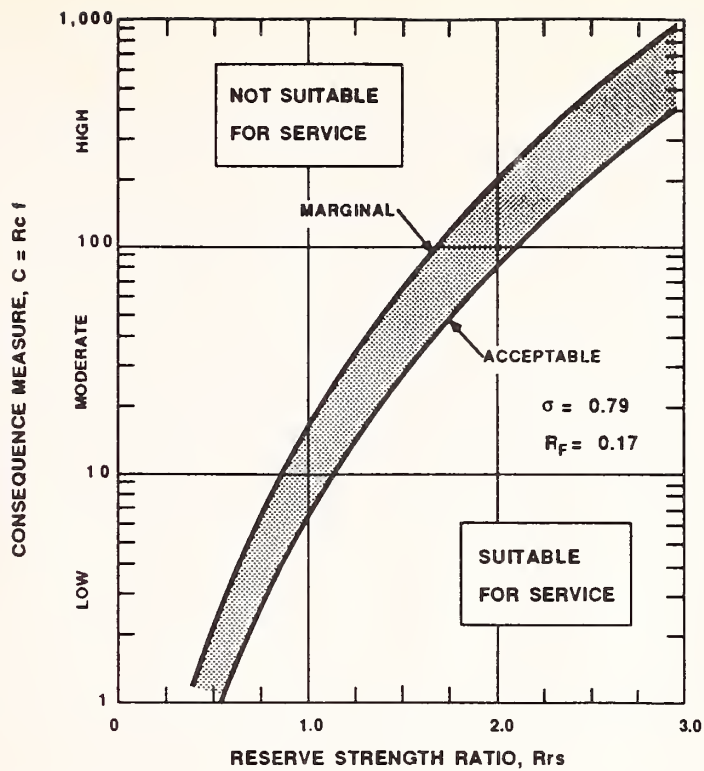


FIG. 15 Suitability for Service Evaluation Based on Expected Minimum Total Cost

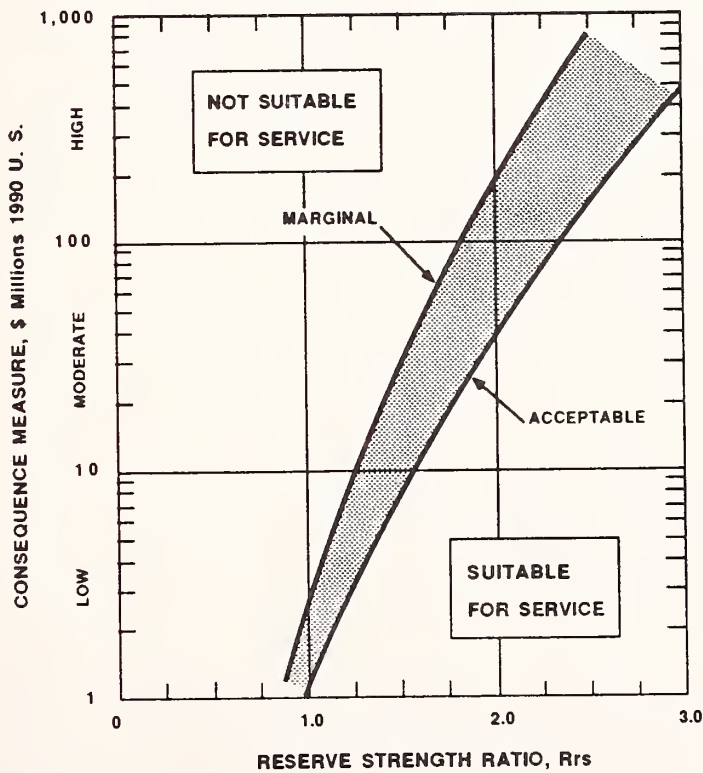


FIG. 16 Suitability for Service Evaluation Based on Historic Data Based Acceptable and Marginal Risks

SAFETY EVALUATION OF OFFSHORE INSTALLATIONS AND OPERATIONS: THE NORWEGIAN EXPERIENCE

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ABSTRACT

Regulatory Guidelines for Concept Safety Evaluation (CSE) studies were introduced in 1981 in Norway. This paper explains the background to this move by Norwegian authorities, and discusses the development of safety studies during these eight years. The current introduction of Regulations for the Use of Risk Analysis in Petroleum Activities is also addressed.

1. The Early Years (1969-1980)

Drilling for oil and gas on the Norwegian Continental Shelf (NCS) started in 1965, but it was not until 1969 that the first major field was discovered at Ekofisk. Two years later the Frigg Field was found, and these two fields dominated the early developments in the Norwegian sector. They were both developed using the same basic concept: separate wellhead platforms tied into major field centres for processing and export of oil and gas. The living quarters (LQ) were separated from the main processing areas, i.e. both Frigg and Ekofisk have stand-alone jackets for the LQ.

Three main events were to shape the way in which Norwegian authorities regulate major hazards in the offshore industry:

- | | | |
|-----------------------|---|--|
| Ekofisk Alpha, 1975 | : | The failure of a riser caused an explosion and following fire. In the course of evacuating the platform, three men lost their lives when the escape capsule accidentally dropped to the sea. |
| Ekofisk Bravo, 1977 | : | An unignited blowout occurred during a workover. No lives were lost. |
| Statfjord Alpha, 1979 | : | First integrated Processing, Drilling and Quarters (PDQ) platform comes into production. The Norwegian Petroleum Directorate (NPD) tells the operator that similar designs will not be accepted in the future. |

The two events at Ekofisk had demonstrated the major hazards potential of offshore installations, putting safety firmly on the public agenda in Norway. The Statfjord A platform was designed in this period. It represented a departure from the Ekofisk and Frigg concepts: It is a PDQ platform with mechanical ventilation in many hydrocarbon areas.

At this time, the NPD preferred separate LQ platforms, and they were concerned about the Statfjord A design from a major hazards point of view. The operator at the time (Mobil) intended to copy this design for the B and C platforms on Statfjord. They were instructed, however, by the NPD to reconsider the design, which resulted in the new design with longer decks in order to provide better separation of the LQ from HC areas. This design change was considered very costly, and the NPD was much criticised at the time for demanding the change.

Also today's NPD Regulations (for Production Systems) states a preference for the separated concept:

Consideration should be given in each design to the necessity to separate the activities of drilling, production and quartering on separate platforms.

NPD wanted to avoid for the future the kind of conflict which Statfjord A had caused. A major criticism against NPD had been that their objections regarding the design had arrived at a stage when the platform design had been "frozen". They therefore initiated a project to develop a Guideline which would lead operators to consider major hazards in a systematic way at the early stages of design. In 1980, draft Guidelines for "Safety Evaluation of Platform Conceptual Design" were issued to the industry. The response was by and large negative.

2. Application of Risk Analysis (1980-1990)

The CSE Guidelines were formally issued in September 1981. They represent an alternative way of doing risk analysis of industrial plant, in that they call for probabilistic methods to be used in defining design loads. Previous experience from the nuclear and chemical industries were more focused on the estimation of fatal risk.

The Guidelines do this by concentrating on three main safety functions:

- escapeways
- shelter area
- support structure.

The basic philosophy is that if these three safety functions remain intact during an accident, people outside the immediate vicinity of the accident will be able to escape to the shelter area (normally the LQ), which the platform structure will support until safe evacuation can take place.

It should be noted that the main objective of a CSE study should be to define Design Accidental Events (DAE), i.e. the accidental loads which the three safety functions should be able to withstand. The DAE is expressed in terms of heat loads, explosion overpressures and impact energies.

Yet, many CSE studies fail to define the DAEs in a proper way, but concentrates on the frequencies of Residual Accidental Events (RAE), i.e. those events that the safety functions cannot withstand. The result may be that the CSE study turns into a numbers game, something it is certainly not meant to be.

The probability per year that a safety function is impaired by a given type of accident (blowout, fire & explosion, collisions, etc.) is 10^{-4} . Since there are nine types of accidents listed by NPD, one may in theory end up with a total probability per year of 9×10^{-4} for each of the safety functions. Most platforms concepts end up in the order of 5×10^{-4} .

Many people question what such a number means in practice. It is only by considering a larger platform population that we may see more clearly what kind of risk level it implies. Let us for example consider 150 installations in the North Sea, and assume that the average platform would have a total probability of safety function impairment of 5×10^{-4} per year. Hence, the total probability per year for this population would be 0.075, i.e. once every 13 years. This kind of accident is very severe, but not necessarily as catastrophic as the Piper Alpha accident.

The data base from which probability estimates can be derived is today fairly good in many areas. Databanks such as the Worldwide Offshore Accident Databank (WOAD) and the Offshore Reliability Data (OREDA) Handbook provide reasonable data. Some operators and consultants have set up special data bases on e.g. blowout statistics, platform leak frequencies, dropped objects, etc. Some information is also available from four data bases operated by the NPD on drilling, personnel injury, pipelines & risers and on platform shutdowns.

There will, however, always be a continuing need to improve the data bases. It seems reasonable to suggest that the offshore industry should cooperate more extensively in this area. After all, an accident very often affects everybody in the industry, not only the operator or contractor which happens to own the installation on which the accident occurs. Sharing your experience on accidents and near-misses with others is therefore of mutual benefit, and the industry should seek ways of overcoming confidentiality problems (as was done in the OREDA Project).

As an example of the benefit from undertaking a CSE study, we may consider a riser on a gas platform. This platform was one of the first to be analyzed using the CSE approach, eight years before the Piper Alpha accident. The proposed design had the pipeline ESD valve located on the upper deck of the platform, close to the pig launcher. The CSE study identified the significance of knock-on effects from the process area below, and proposed to move the ESD valve to a lower location inside the Module Support Frame.

2.1 Other Types of Safety Assessment

The CSE study is the main vehicle for demonstrating safe conceptual design. Most operators on the NCS do also use other types of safety assessments at various stages of design and operation. The most common ones are listed below:

HAZOP : Hazard and Operability studies are in practice mandatory. The process HAZOP is usually performed in the detail engineering phase.

Technica has pioneered the use of Drillers' HAZOP on special drilling and well intervention operations. The

technique is commonly applied to operations involving simultaneous activities. More recently, the HAZOP technique has also been successfully applied to evaluate the reliability of safety systems.

- Total Risk Analysis : Some operators have conducted a risk analysis aimed at complete quantification of risk to personnel, environment and installations. The TRA study is useful for establishing the total risk profile of the installations, thereby enabling decisions regarding safety to reflect the importance of various hazards.
- Evacuation Studies : Evacuation studies are used to assess the process of getting off the installation in more detail than is usually done in the CSE. It is becoming a requirement today for the operator to base the emergency response system on the specific accident and evacuation scenarios of the installation.
- Production Regularity : Most operators today perform simulation studies to assess the production regularity of the installations and transport network. Although not a safety study, these studies link with the CSE or TRA when it comes to assessing accidental risk of production interruption.

3. Risk Acceptance Criteria

The use of Quantified Risk Assessment (QRA) assumes that the risk result be compared with some defined target or acceptance criterion, in order to decide whether the calculated risk level is deemed acceptable, or whether risk-reducing measures should be implemented.

Who is the legitimate decision-maker for risk acceptance criteria? It used to be that this was not an issue, when regulation was based on detailed technical and operational requirements, and the acceptable risk level was not stated explicitly. The regulatory bodies would then decide the requirements, and implicitly also the risk level.

When NPD issued their CSE Guidelines in 1981, the acceptance criteria stated were of a qualitative nature, basically requiring safe escape for anybody who would be outside the "immediate vicinity" of an accident. It was, however, recognised that the most unlikely events would have to be excluded from consideration, and NPD therefore made reference to a probabilistic target in the methodology section of the Guidelines. This target (10^{-4}) has since been widely referred to as the acceptance criterion for platform concept safety, and it may be argued that this is indicative of the industry's need to work against common, well-established risk acceptance criteria.

NPD is aiming to change the way in which oil companies go about their acceptable risk decision-making. In the 1991 Risk Analysis Regulations, no acceptance target

is stated, and the oil companies will be required by law to establish their own acceptance criteria. This is somewhat in contrast to earlier statements from NPD that all installations should be "equally safe". The main reason given by NPD for this change is that the setting of acceptance criteria by the oil companies themselves will elevate the decision-making to an appropriate level in the organisation, involving senior management input. There is obviously a chance that different oil companies will generate different risk acceptance levels, but NPD claim they would be in a position to moderate any outliers.

The NPD approach is in contrast to the Cullen Report's recommendation #5 concerning acceptance standards for risk: "For the time being, it should be the regulatory body which sets these standards".

How prepared the Norwegian offshore industry is to prepare their own risk acceptance criteria is probably premature to judge. It is going to be interesting to see how NPD will deal in practice with differences in the criteria. It will be a requirement to communicate risk results to the work force, and it would seem unlikely that safety representatives and the unions would accept higher risk levels on their installation(s) compared with other installations. The industry is afraid the setting of acceptance criteria could turn into some kind of a competition between the oil companies, in which the authorities could play one company against others.

The Norwegian Oil Industry Association (OLF) is therefore putting together a working group on risk acceptance criteria. Some operators are performing in-house studies to establish the feasibility of proposed criteria, by doing pilot studies of various offshore installations concepts. It should be recognised that arriving at practical risk criteria is a challenging task, most often requiring iterations before reasonable criteria can be fixed. It is therefore mandatory that NPD will allow these iterations to take place, probably over several years, even though the new Regulations require the risk criteria to be fixed in advance of the QRA study.

The common trap is to be too ambitious when establishing criteria, or to state some criteria without considering in detail the practical necessity and technicalities of meeting the criteria. An example is simultaneous drilling and production operations, where a number of operators have laid down a criterion stating that no risk increase should result from such operations compared with carrying out the operations in sequence. Even though lay-out, design, and operational measures may eliminate the risk of one operation affecting the other, there will still be risk increase: the drilling crew will be exposed to production risks and vice versa. Such a criterion is therefore likely to be impossible to meet.

It is important to keep in mind that acceptance criteria, risk analysis methodology and data input go hand in hand. Due to uncertainties in the modelling and the statistical failure frequency data, one may end up accepting or rejecting a design or operation, depending on the method being applied. It is therefore worthwhile for an oil company and perhaps the industry as a whole to consider agreeing to some standardised tools for offshore risk analysis. This has been quite common with some companies e.g. when evaluating the need for subsea isolation valves.

4. Risk Analysis Methodology

Risk analysis is a means for communication. It is an inter-discipline activity which requires input and participation from several parties in order to achieve the best results. Key areas include communications with

- project disciplines
- project and operations management
- offshore supervisors
- offshore personnel and safety representatives
- authorities

The methods we use and the way risk analyses are documented and communicated must reflect the communication function. I think it is generally true that many risk analysis studies and reports do not provide the maximum possible benefit to the users, because the analyst fails to explain the work done and the results in a format which is readily accessible and useful. This could typically relate to "black-box" methodologies (in which the user will have little faith), lack of traceability, failure to transform recommendations into "what-to-do" items, etc. Most risk analysts would do themselves and the users a favour by spending more of the time available on interpreting results, and less time on calculations.

Communicating risk results to operations personnel, safety representatives and unions is going to be a challenging area. The new NPD Regulations make this an explicit requirement (Section 14): "Results from risk analyses shall be communicated to the employees.....". This puts added emphasis on the need for transparent, clear and practical approaches to risk analysis, and is hopefully going to advance the benefit from undertaking such studies.

Some methodologies for risk analysis lend themselves quite well to communication by themselves. The ideal example is the HAZOP (Hazard and Operability) study technique, pioneered by ICI for systematic review of process design and operation. The same principle has since been adopted for review of drilling operations (Lewis & Østebø, 1989). It is very encouraging that simple (yet systematic) techniques combined with inter-discipline participation generate very practical and immediate results.

The hazard identification part of any risk analysis is critical, since both consequence and probability assessment rely on the assumption that all significant hazards have been found, and hence can be analysed. Hazard identification is the starting point where co-operation with design engineers and operating personnel can be very crucial. It is my experience that more attention should be paid to this activity, particularly since analysts trained in this area have an inclination towards concentrating on the consequence and/or probability aspects. Achieving excellence in hazard identification is strongly experience-based, and it is therefore more difficult to train analysts for this purpose. The application of artificial intelligence technology should therefore be considered as a means to accumulate knowhow and making it available to risk analysts.

When developing and selecting techniques for consequence and probability assessments, two key features must be considered:

Realism: The modelling should be able to reflect realistically design features which definitely affect the level of risk. Examples of such features include ESV location (hydrocarbon inventory), number of gas detectors, etc. This may sound like an obvious requirement, yet many risk analyses fail to reflect such aspects, with resulting frustration and lack of credibility with the decision-maker.

Data Matching: The level of detail in the modelling must match the availability and quality of experience data. It is of very limited use to develop models for e.g. gas cloud ignition which incorporates delayed ignition events, if little or no data can be found to estimate the fraction of ignitions which are delayed, and for how long the delay is likely to last.

The two above aspects are sometimes contradicting each other, since a high degree of realism may require data inputs which are virtually non-existent. It is nevertheless the duty of industry, authorities, research institutions and consultants to constantly strive for improved realism in the risk analyses, by devoting adequate resources and creativity into this area.

Fairly good databases have developed over the last decade for offshore risk analysis use. The industry co-operation in the OREDA Project since 1983 is an excellent example in this respect. Commercial databases like WOAD by Veritec and BLOWOUT by Technica provide unique data input to many users. Currently, the E&P Forum is launching an initiative to improve the failure frequency data for offshore QRA. The industry has come to believe that co-operation in this area is a must, since no single oil company can accumulate enough experience on rare events by themselves. Confidentiality issues should not be allowed to sabotage exchange and use of the best possible data base, since lack of quality data can only harm the industry. Overestimating or underestimating the risks are equally bad in the long run.

The regulatory bodies may have a role to play in establishing good data bases. The NPD have 4 different, computerised data bases for personnel injuries, drilling operations, production upsets and pipelines & risers. Up till now, very limited information has been available to outside parties from these data sources, partly because of confidentiality issues, and partly because of differences of opinion as to whether it is the function of a regulatory body to disseminate this kind of information. There are, however, signs that the situation is changing, and that more data may become available from NPD. It is interesting to note that the Cullen Report recommends a regulatory initiative in this area (recommendation #39):

The regulatory body should be responsible for maintaining a database with regard to hydrocarbon leaks, spills and ignition in the industry and for the benefit of the industry. The regulatory body should:

- (i) discuss and agree with the industry the method of collection and use of the data.

- (ii) regularly assess the data to determine the existence of any trends and report them to the industry, and
- (iii) provide operators with a means of obtaining access to the data, particularly for the purpose of carrying out quantified risk assessment.

Another aspect to consider concerning risk analysis methodology is the need for updating the studies. The Cullen Report recognises the need for updates every 3-5 years (recommendation #10). The new NPD Regulations require risk analyses to be updated "to follow the progress of the activities" (Section 15). The aim should be to ensure the risk analysis is maintained to provide a relevant basis for decision-making, reflecting the status of the installation. Experience indicate that updating 3-5 year old risk analyses requires a major effort, and a computerised tool and model would certainly help in making such updating feasible and efficient to carry out.

5. Risk Analysis Contracts

Most offshore risk analyses are performed by consultants. It is a general observation that the quality and practical benefit from such studies will be enhanced whenever the client has some in-house expertise to define, co-ordinate and follow-up such studies. Oil companies should therefore train some of their staff to take on this role, in order to make the best possible use of consultants by putting forward demands which aim at excellence and contribute to progressing state-of-the-art in risk analysis technology. An important role for the co-ordinator is to enable good communications between the risk team and the engineering or operations people. Having some in-house expertise is also going to provide a better opportunity for ensuring practical implementation of results and updating of the risk analyses.

Competition between risk analysis consultants is very healthy. It challenges creativity and stimulates excellence by those who intend to stay in the risk analysis consultancy market. Competing on the combination of quality and price is obviously something no professional consultancy would object to. There is, however, a risk that consultants end up "competing" on behalf of the client's level of ambition. It is after all difficult to write a risk analysis scope of work to a level of detail and clarity which enables consultants to arrive at the same understanding of what is wanted. Hence, consultants may end up squeezing the ambitions, e.g. by lowering the level of detail of the risk analysis, in order to arrive at a price which is not significantly above that of competitors. Only the more experienced users of risk analysis may be able to identify the significance of a difference in approach, methodology and man-hour input. There is evidence in the Norwegian Sector that this "squeezing effect" has lowered the efforts put into e.g. CSE studies. These studies used to require in the order of 2000 man-hours, and it is today not uncommon to spend as little as 4-500 manhours. The total difference is not attributable to improved efficiency in undertaking the study.

A practice which is not uncommon in Norway is to parcel out risk analysis contracts, commissioning several small studies one at the time. This is in my

view a practice which does not benefit any party from a commercial point of view, and which also most likely deteriorates the practical benefit from undertaking risk analysis studies. The total efforts spent on risk analysis studies is after all quite modest compared with the total engineering efforts. An offshore development project may typically spend 10,000 man-hours on risk and safety studies. It would therefore seem like a good idea to establish one consultancy contract for all of these studies. This would enable stiffer competition on price, and enable better continuity and coordination between the studies. Part of the contract could involve secondment of personnel to the client organisation, which would improve relations, communications and understanding of the client's needs. Better planning and resourcing, with less risk of extreme time pressure (a not uncommon feature) would also result.

6. Using Risk Analysis

A key challenge for any user of risk analysis is to identify (in a timely manner) when one can benefit from doing a study, and to define a scope of work which is tailored to the decision-making context. Risk analyses should always link to a decision problem, i.e. it is a decision support tool. It follows that one most likely does not need a risk analysis if no reasonably well-defined decision problem is on the table, and we have on more than one occasion advised our client not to undertake a proposed study.

Risk analysis very much originated in the nuclear industry, where acceptable risk problems dominate the discussion. Risk analysis in the offshore industry has become more of a design tool, aimed at defining design accidental loads. Nobody should be satisfied with risk analyses which concentrate on highlighting problem areas, but fall short of coming up with solutions to these problems.

It is important we remind ourselves that risk analysis in itself does not improve safety. Only practical measures aimed at technical, procedural and organisational improvements will do this. It is therefore important to incorporate human factors in risk and safety studies, and to acknowledge the importance of human error not only when reviewing experience data, but also when analyzing safety and reliability.

It is furthermore vital that planned, systematic follow-up takes place, in order to ensure that recommendations and assumptions made are implemented in real life. This is a bit like "fitting the terrain to the map", i.e. to make sure the installation as built and operated conforms with the model (drawings, P&IDs, etc.) on which the risk analysis was made. If this is not the case, then the risk results and the decisions that followed may be irrelevant. One way to help accomplish this is to establish a computerised risk accounting system, which contains all recommendations and critical assumptions made in risk and reliability studies. The system should reference where the recommendations and assumptions arise from, and define the person/discipline responsible for follow-up. Lists may then be generated per discipline (with deadlines), making practical follow-up feasible. The risk accounting system should be transferred to the operations division once the engineering and construction periods are completed. A typical risk accounting system could hold some 3-500 items, and is very valuable when updating risk analyses. The system should also be used for recording implementation (e.g. by reference to an engineering drawing),

alternatively to record why a recommendation was not implemented, and on what basis this decision was made.

In the early days of performing CSE studies in the Norwegian Sector, it was common practice to submit the study report to NPD without much comment from the operator. This practice has now ended, with NPD placing firm emphasis on the principle of internal control (operator's safety management system), wanting to know from the operator:

- does he support the methods and data used?
- does he agree with the conclusions?
- who defined the acceptance criteria?
- which recommendations will be implemented?
- what system is in place for follow-up?

Primary emphasis is thus put on how risk analysis has influenced design and operations, i.e. on practical results. Nothing else matters much.

7. Conclusion

Risk analysis have been actively used in the Norwegian offshore industry during the last ten years. From a start where the industry was largely skeptical to probabilistic assessment, the use of risk analysis is today widely accepted as a practical tool for design purposes and decision-making.

The UK and Norwegian sectors of the North Sea now have very common regulatory requirements for offshore risk analysis. Quantitative risk analysis has been recognised as a practical tool for improved decision-making. A key challenge facing the regulatory bodies and the industry is to develop reasonable risk acceptance criteria, and to provide risk analysis methodologies which allow realistic modelling which reflect platform-specific features in design and operation. Cooperation will be needed to establish robust data bases, and it is important to recognise that the perhaps most difficult job starts when the risk analysis is finished: practical implementation of results.

9. 8. References

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WORKING GROUP REPORTS

REPORT OF WORKING GROUP #1

EXPERIENCE DATA BASES AND CASE STUDY ANALYSES

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and
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1. Introduction

The working group involved in discussing and analyzing "Experience Data Bases and Case Study Analyses" consisted of sixteen people with a wide range of experience. The working group included representatives of oil companies, engineering companies, consulting companies, and the Minerals Management Service. A list of the members of Working Group 1 is included at the end of this report.

The scope of the working group was defined as reviewing the potential use and usability of existing offshore reliability and accident databases, establishing requirements and needs for future databases and determining ways in which greater industry participation and acceptance can be accomplished.

Three theme papers were presented by the co-chairmen during the working session. Mr. Visser presented a paper entitled "Offshore Accidents - Lessons To Be Learned". This paper reviewed major accidents that have had a major influence on improving the reliability of offshore operations. Mr. Gjerstad presented theme papers entitled "Brief Review of the Oreda Project" and "Data Collection on Hydrocarbon Leaks and Ignitions - The E&P Forum Approach". The first paper discusses the results from the ongoing Oreda reliability data collection project. The second paper discusses the planned approach for a new data collection project by the E&P Forum.

2. State of Practice

The increasing use of probabilistic risk analysis methods to evaluate the reliability of offshore operations has brought with it a demand for reliable information of historical events. As a result there are now a large number of offshore related databases of varying sizes in existence. There are databases run by governments, industry associations, universities, consultants and oil companies. The quality of these databases varies greatly.

There was a discussion what organization, i.e. industry or government might be best qualified to obtain and gather data. A government organization has the regulatory power to ensure that the data collection is complete and from all operators. A further advantage is that the information is public and available to all interested parties. Industry data collection requires cooperation between a number of companies and data will not be available to outsiders. On the other hand the data collection effort can be directed to specific objectives that are only of interest to the participants.

There are basically three types of databases that are of potential use to the offshore oil industry. These are (1) accident or event databases, (2) accident or event frequency databases, and, (3) equipment reliability databases.

2.1 Accident databases

An example of the first type of database is the offshore events file being maintained by the Minerals Management Service. The database was initiated in 1971 to keep track of blowouts, fires, explosions, oil spills and fatalities in the federal waters of the Gulf of Mexico. At the present time it contains more than 4700 events which go back to 1965. This data comes from a population of some 3700 platforms. Prior to 1971 only major blowouts and fires were entered. In 1971 the regulations were revised requiring all operators to report all fires, explosions, oil spills greater than one barrel, and fatalities to the Minerals Management Service. The data is currently located in the GYPSY database program. This is a non-standard program and precludes the data from being readily accessible. The data is at present being converted into the dBase IV format, which will greatly improve accessibility and use by industry. Currently the system is not being used much outside the Minerals Management Service. It was reported that the Minerals Management Service has only five to ten inquiries per year for data.

The Minerals Management Service offshore events file is not currently tied in to the population data and frequency data are, therefore, not readily available.

Another example of this type of database is the worldwide accident database compiled by the Institute Francais du Petrole. There are also a number of specialized accident databases being maintained by individual oil companies, insurance companies, etc. Examples are mobile drilling unit failures, offshore worker fatalities, etc.

2.2 Accident frequency databases

There are a number of accident databases that are tied in to the population data. One example is the Worldwide Offshore Accident Database (WOAD) database being maintained by Veritec, a subsidiary of Det Norske Veritas. Data has been collected since 1970. Access to this database is expensive and annual membership fees are in the order of \$5,000 per year. Veritec does publish a statistical summary report every other year which is available at a lesser cost.

2.3 Reliability databases

An example of an offshore equipment reliability database is the Offshore Reliability Data (OREDA) database program.

The program was launched in 1983 after a pilot project. As an illustration of the difficulty of getting one of these programs organized is the fact that it took five years of crusading to get Phase 1 of Oreda in operation with eight companies. There are now nine or ten oil companies sponsoring a Phase 3 data collection effort in this program. The Phase 1 data results were published in a handbook which is now available for free. Data from Phases 2 and 3 are not available to non-participants because it is in computer format and only available

to the participants. Two U.S. companies, i.e. Phillips and Exxon, have recently joined OREDA. This is a shift from the early eighties when there were only European participants.

The E&P Forum has recently initiated a program to gather hydrocarbon release data. This program, which started this year, has two objectives. One is to develop data collection guidelines for hydrocarbon leak and emission events. The second objective is to set up an initial database of release data.

The data collection guidelines will be available to anyone who wants them. The initial database of release information will also be available (not necessarily for free but at a reasonable price) because it is in the interest of the E&P forum to make the collection effort itself as broad as possible.

The Minerals Management Service has been collecting since 1988 a database on structural platform inspections. In that year reporting of the structural condition of offshore platforms became mandatory. With some 3700 platforms in the Gulf of Mexico and a requirement that each platform be inspected at least once every five years, this will in a few years become an extremely valuable database. This database will be particularly important for determining deterioration trends as offshore platforms become older and require increased maintenance and/or repair.

3. Problem Areas

3.1 Misuse of information

Misuse of the information from a database is one of the concerns in the use of databases in the offshore oil industry. The data may be misinterpreted by a regulatory agency. For instance, a statistical review of failure rates of fixed and flexible risers may lead to the conclusion that flexible risers are more hazardous. Based on this data a regulatory agency might wish to ban the use of flexible risers. If databases are used for such a purpose they are indeed being misused. The database in this example should be used to determine what causes the flexible riser failures and to make improvements rather than banning them from use.

The same concern has been raised with databases that use manufacturers' names. One could perceive from such a database that one manufacturer has an advantage over another one. That concern turned out to be overstated. The OREDA database in its Phase 1 program used only generic names without mentioning the manufacturer names. This was changed in the later phases where manufacturers names are now included. This really benefits the industry. How else is the manufacturer going to get information so that the product can be improved?

These are, however, traditional concerns and come up each time a new database is being proposed.

3.2 Confidentiality

Joint industry programs restrict access to the data to only those companies that participate in the program. For instance, the current OREDA information is not available to outsiders and this limits the usefulness of applying the data that has been generated. The reason is, of course, that otherwise it will be impossible to get a joint industry program started.

3.3 Taxonomy

The various databases currently in existence use a great variety of methods for data collection. It would have been beneficial if a standard methodology had been adopted for the data collection.

In this connection it was mentioned that there is an European organization, EuReData (European Reliability Database Association), which has been in existence for eighteen years and has an offshore subcommittee. The association has developed a taxonomy, i.e. an equipment inventory system, for its user members.

3.4 Legal Problems

Legal concerns include the misuse of data in, for instance, liability court cases involving negligence. This is not much of a concern in Europe but it is a potential problem in the United States and may keep companies from participating in a database program. Since there were no attorneys in the work group it was decided that, if the industry really wants to do something jointly, that these concerns can be overcome. It was mentioned that the airline industry has been quite successful in establishing and maintaining equipment failure databases without apparent legal difficulties.

4. Research Needs

4.1 Case Analyses

There is still a need to convince people in the industry that it is important to collect information for databases. It was felt, therefore, that it would be worthwhile to collect a series of case analyses that demonstrate the usefulness of having databases available.

These case analyses should include not only quantitative analysis of risk to people on a platform but also analyses that are used to determine an optimum solution for a particular production operation approach. There are examples available where an operator was able to demonstrate through a risk analysis that a better and cheaper solution was superior to one that followed the exact regulatory requirement.

4.2 Minerals Management Service Events File

The Minerals Management Service events file is not currently tied in to the population data. Population data, however, has been collected in other available databases of the Minerals Management Service. The working group felt that it

would be extremely worthwhile to incorporate the population data into the events file. If this is done there would be an excellent and very extensive database available for U.S. offshore operations.

4.3 Offshore Database Directory

There are many offshore databases already available that are not widely known. The working group believes that it would be very useful to compile a listing of databases that already exist in a single report. Such a directory should include the ownership, characteristics, cost and actual or potential application of the databases.

4.4 E&P Forum Data Calibration

When data from the E&P forum database becomes available later this year it would be very worthwhile to calibrate and check this data against the data available from the Minerals Management Service events file.

4.5 Expand OREDA membership

The OREDA database provides equipment reliability data. Although originally set up by North Sea operators, two U.S. companies have recently joined. The OREDA group is quite anxious to cooperate with the U.S. offshore industry and/or expand its membership to have more U.S. participation and make the database more widely accessible and complete. One possibility might be a U.S. chapter of OREDA rather than having a separate activity.

4.6 Organizational and Human Factors Failures Database

The need for databases addressing the origin of accidents due to organizational and human factors was mentioned. Although there are some databases that devote themselves almost exclusively to human factors, such as the Norwegian Petroleum Directorate's databases on drilling injuries, there is a problem segregating the human and/or organization element from the other causes in databases. It may be possible to do so from the OREDA equipment reliability databases either in its current form or in an expanded format.

4.7 Perform Technical Audits

Outside technical audits of offshore platform facilities may be one method of improving offshore reliability.

For instance, one of the recommendations made by the technical advisors to the Ocean Ranger Royal Commission was that mobile rigs entering Canada should be required to submit to a technical audit. Much like financial system audits, the technical auditor should report not to the field management, or the project team, but to the highest level in the owner's organization.

The audit work should concentrate not so much on nitty-gritty detail and nominal compliance with regulations and standards, but with fundamental platform safety and life safety, reviewing systems, training, etc. with a view to reporting on the problems that everyone else has missed. This is one of the few methods of

detecting potential "human error" problems.

4.8 Data Collection Conference

Thought should be given to organizing a database data collection conference or workshop. At such a conference standards for data collection could be established.

5. Implementation and Application

An illustration of how databases can be implemented and applied in an offshore production organization is presented in the following recent exercise by a company operating in the North Sea.

The company used available database data to prepare a number of comparative, quantitative risk assessments of planned activities on platforms in the North Sea in the United Kingdom sector. Examples of these assessments include:

1. Determination of potential fatal accident frequency rates for personnel in the platform safe haven with and without a compression module installed next to the safe haven.
2. Determination of potential fatal accident frequencies for personnel in the platform safe haven and for divers with and without subsea emergency shutdown valves in the platform pipeline and subsea flowline.
3. Determination of potential fatal accident frequencies for personnel in the platform safe haven with two firewater pumps and with three firewater pumps.

The types of data used and sources consulted included:

1. Leak frequency data. Sources of the data were:
 - (1) "Update on Loss of Containment," report prepared for the United Kingdom Department of Energy.
 - (2) Equipment reliability data pertaining to leak frequencies on (1) flanges, (2) piping, (3) vessels and, (4) rotating equipment seals.
2. Safety equipment reliability data for emergency shutdown valves, gas detectors, fire pumps, shutdown systems, etc. Sources consulted included: (1) OREDA data handbook; (2) CCPS (Center for Chemical Process Safety) data handbook; and (3) U.S. nuclear power industry and military equipment reliability data banks.

Specifically, the data was used to define frequencies of scenarios that could cause safe haven fatalities. This was accomplished by constructing fault trees to define the combinations of various release events and safety system failures required to generate the scenarios.

WORKING GROUP #1

EXPERIENCE DATA BASES AND CASE STUDY ANALYSES

LIST OF PARTICIPANTS

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REPORT OF WORKING GROUP #2

RISK MANAGEMENT PRACTICES

J. E. Vinnem

1. Introduction

A Workshop similar to the present one was sponsored by MMS in 1984, with a similar theme, organization and participation. However, the viewpoints had changed considerably. In 1984 the experience in the use of risk management and risk assessment was limited to Norway. In other countries there was significant opposition to similar practices at that time. However, in 1991 a much broader consensus on this subject had developed across the continents.

Some of the main emphasis in 1991 was therefore devoted to defining what was a practical and cost effective use of these techniques, rather than debating whether they should be used at all.

This report describes the background to the use of risk management techniques and summarizes the discussions and conclusions reached during the working-group sessions.

The objective of the working group sessions was to provide an overview of the state of practice and of the problem areas, and to explore and discuss research needs and opportunities for implementation and applications.

The participants in the working group consisted of representatives from European and U.S. government bodies, oil companies, engineering, consulting and manufacturing firms, and classification societies.

The following countries were represented in the Working Group:

- U.S.: 12 participants
- U.K.: 3 participants
- Norway: 1 participant

The parent organizations were:

- Government bodies: 5 participants
- Classification societies: 2 participants
- Oil companies: 7 participants
- Engineering companies: 1 participant
- Safety equipment manufacturing: 1 participant

Working group activities were organized by Dr. John M. Campbell of John M. Campbell Company, U.S.A., and Dr. Jan Erik Vinnem of SikteC A/S, Norway. Dr. Vinnem was responsible for the presentation of the theme paper and with the preparation of the present report, which incorporates the material presented in the theme paper.

The table below presents an overview of the time table followed in the discussions of the working group.

Item	Title	Day	Time
1.	Introduction, Theme Paper	Wednesday March 20	3:15-5:15
2.	State of Practice	Thursday March 21	9:00-10:30
3.	Experience, achievements	Thursday March 21	10:30-12:00
4.	Problem areas	Thursday March 21	12:00-12:45 14:00-15:00
5.	Research needs	Thursday March 21	15:00-16:00
6.	Opportunities for implementation and application	Thursday March 21	16:00-16:45
7.	Conclusions, recommendations	Thursday March 21	16:45-17:00

2. State of Practice

2.1 Norway

Systematic risk and environment management philosophies have been developed by industries with significant hazard potential and environment protection needs for some decades. The development started with industries such as commercial aircraft, aerospace, chemical and petrochemical, nuclear, as well as offshore oil and gas industries.

The main principle of risk and environment management is to plan, coordinate and document all actions which are carried out in order to implement a predefined and desired safety and environment protection level¹.

Another illustration of the nature of safety management is to describe safety and environmental protection management as a process, which typically may be illustrated by an ordinary control loop, as shown in Figure 2.1 (from Ref. 1). The following are the main principles in the diagram:

- Element 1: Safety and environmental goals and acceptance criteria should be formulated and decided upon.
- Element 2: Activities should be defined and planned to meet given goals and requirements.
- Element 3: Work tasks should be performed in accordance with the plans, with approved working methods and recommended means as well as tools.
- Element 4: Work tasks should be followed up through suitable analyses and audits, and necessary corrective actions should be carried out when deviations from goals, requirements or plans are identified.

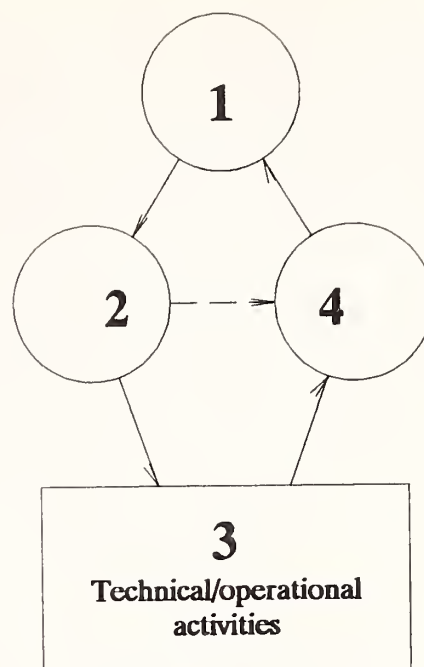


Figure 2.1 Safety control loop illustrating the process involved in safety management

Norway was the first country to adopt an approach based on risk and environment management principles in the regulation of the offshore oil and gas (upstream) industry. This occurred around 1980-81, and the Norwegian Petroleum Directorate is the governmental body that initiated this process. The United Kingdom had previously adopted basically the same approach for the control of the downstream oil and gas industries, as well as the chemical industry, the main regulatory body being the U.K. Health and Safety Executive.

Later, a number of other industries in various countries have been (or are in the process of being) subjected to the same control, including the offshore (upstream) oil and gas production facilities in the U.K.

Environment protection management has not received the same systematic treatment, except in later years. This area is given an equal consideration in report.

2.1.1 Implementation in Norway

The implementation of regulatory control in Norway has changed since the first exploration and production activities began in the late 1960s and early 1970s. The implementation described herein is limited to risk and environment management principles.

2.1.1.1 General Policies

Overall risk studies are used for assessment of overall policies. To a large extent they have been motivated by the occurrence of accidents, the most significant of which being a series of fatal helicopter accidents (1973-1978), a blowout from a production platform (1977) with some 20,000 tons of oil spilled in the North Sea, and the capsizing of the semi-submersible hotel platform 'Alexander L. Kielland' in 1980.

The objectives of these studies have been:

- to gain in-depth insight into hazard mechanisms, especially for novel concepts and systems
- to decide on focus and priorities for general policy aspects

General policy making may apply to areas such as:

- R&D for safety improvement
- training needs
- new regulations
- audits and reviews

2.1.1.2 Overall Functional Structure

Figure 2.2 presents a structure for breakdown of essential elements within risk and environment management. The main levels are:

- Goals for the safety and environment work
- Acceptance criteria
- Specifications

The implication of the structure is that goals for safety (and environment) establish the basis for definition of more detailed requirements.

Acceptance criteria are developed from goals. Technical and operational specifications are developed from acceptance criteria.



Figure 2.2 Safety structure relating to breakdown of goals and criteria

2.1.1.3 Management Process

Management of risk and environmental protection is often described as a process. Such a management process shall tie in with all operations, design work,

subcontractors and suppliers, and shall fulfil the following functions:

- ensure that possible hazards are identified at the earliest possible instance
- analyze hazards to determine what shall be the Design Accidental Events and associated loads
- communicate results of risk assessments to designers, operational personnel, managers and all personnel affected by those risk elements
- use results from risk assessments to plan and implement emergency plans, and provide necessary equipment and external backup assistance
- implement operational experience and accident, incident, near miss and failure data in a planned effort to improve safety and learn from past experience

2.1.1.4 Control of Operations

Unlike the United Kingdom, Norway has not adopted for regulatory purposes the principle of **third party (independent) control** by certifying authorities (or classification societies). The certifying authority operates on behalf of the appropriate government authorities, which in this manner take an active role in the control of safety in operations and systems.

The principle used in Norway for the management of safety, environmental and regulatory bodies is somewhat different, and – it may be argued – clearer. It consists of using internal control within the operator's organization.

Internal control is defined (see § 2 of Internal Control Regulations) as:

"All systematic actions which the Licensee shall initiate to ensure that the activity is planned, organized, executed and maintained according to requirements stipulated in or in accordance with acts or regulations."

Internal control means that the operator always has the responsibility for the operations and the safety and environment protection during those operations.

2.1.1.5 Technical and Operational Requirements

The Norwegian regulations have traditionally been rather extensive, with many technical details prescribed by authorities. However, since the introduction of the internal control principle there has been a constant trend towards less detailed regulations.

The functional requirements shall further be coupled with extensive use of risk assessments, to define acceptable hazard control in relation to specific installations, systems and operations.

2.1.1.6 Safety Goals and Acceptance Criteria

Formerly, the Norwegian Petroleum Directorate issued acceptance criteria for the design of new production installations². The most recent developments in regulation require operators to set their own long term safety goals, from which the acceptance criteria shall be developed for new installations and the operation of existing platforms.

Identification of Design Accidental Events (DAE) shall be the primary objective for risk assessments during planning and design. The same shall apply to risk assessments relating to modifications and extensions. In the operation phases the primary goal for risk assessments shall be the identification of the most critical risk elements that may be candidates for further risk reduction.

All elements of risk shall as far as possible be subjected to risk reduction efforts, either in the form of elimination of the hazard, or in the form of risk level reduction, by consequence reduction, frequency reduction, or both.

After all possible risk reduction measures have been adopted, estimates are made of Residual Accidental Events, that is, of accidental events that violate the acceptance criteria. These frequencies are then compared with the cut-off limit, which is 10^{-4} /year per safety function and for each hazard type. The safety functions are the following:

- Escapeways
- Shelter Area ("Safe Haven")
- Main Support Structure
- Control Functions

It should further be noted that an additional criterion has been added recently, stating that Design Accidental Events shall not cause substantial environmental pollution.

The overriding goal for all safety work is, at a minimum, to meet all official requirements in applicable rules and regulations. This is the tie between use of risk assessments and internal control. Use of risk assessments is hereby an element of a total internal control system.

The overriding official requirement is that the safety level shall be fully satisfactory with respect to personnel, environment and economic assets. This is defined by NPD³ as entailing:

- avoidance of accidents
- minimization of risk at all times
- continuous reduction of risk level by use of technological means and operational experience

Typical examples of safety goals may be the following:

- relating to serious accidents: there shall be a negligibly low probability of Residual Accidental Events over the field lifetime, for all installations involved in the production from the field.
- the probability of serious accidents in the form of Design Accidental Events shall also be low over the field lifetime, for all field installations.
- personnel outside the immediate vicinity of such an accident shall not be at risk, even if emergency evacuation is necessary. This will impose special requirements for the emergency preparedness systems.

In this context oil pollution from accidental releases can be considered. Norwegian authorities will not accept that accidental release of oil may give rise to impact on environmental resources such as fish, seabirds, sea mammals, recreation, aquaculture, and so forth. Thus they require an emergency preparedness from the offshore operators to tackle small and large accidental oil spills.

2.1.2 Concept Safety Evaluation

The Concept Safety Evaluation (CSE) was formally required as of September 1, 1981 for production installations on the Norwegian Continental Shelf. The CSE has been one of the main 'building blocks' for the use of risk assessments as a risk management tool in offshore operations.

The principles for CSE need to be described in order to appreciate the acceptance criteria, in a quantitative as well as a qualitative sense. A brief description follows below:

- (1) The concept is analyzed in order to identify possible accident scenarios, taking into account:
 - possible initiating events
 - possible failures of safety systems
 - environmental conditions

From this analysis, a number of possible accidental events are defined.

- (2) Based on evaluation of consequences, the Design Accidental Events (DAE) shall be derived from amongst the possible accidental events. This derivation shall be based on evaluation of quantified accidental effects.
- (3) For the DAE the installation concept shall be compared with qualitative acceptance criteria in order to verify that the installation concept has an acceptable safety level.
- (4) According to the revised Guidelines, each of the RAEs will be evaluated carefully to determine if risk reducing measures can be implemented. Such risk reduction may be either reduction of accidental effects or frequency of occurrence, or a combination of the two. In the first case the

accidental event may be transformed into a Design Accidental Event, if impairment of the safety functions can be avoided. In the case of frequency reduction, the event will still be a RAE, but a less critical event.

- (5) Maximum allowable frequency for RAEs is 10^{-4} /year per accident type and per safety function. This is, according to the revised text, the last step to be taken.

The primary acceptance criterion for personnel safety states that in a design accident situation the consequences shall be limited to personnel in the immediate vicinity of the accident.

This general criterion has also been spelled out into three requirements concerned with the main safety functions:

- (a) At least one escapeway from central positions which may be subjected to an accident shall normally be intact for at least one hour during a DAE.
- (b) Shelter areas shall be intact during a calculated accidental event until safe evacuation is possible.
- (c) Depending on the installation type, function and location, when exposed to the Design Accidental Event, the main vessel structure must maintain its load carrying capacity for a specified time.

2.1.3 Terminology

The terminology used in connection with these studies is based on that developed by the Norwegian Petroleum Directorate in their Guidelines for Concept Safety Evaluation⁵. The terms listed below shall have the following meaning:

Accidental Event is an unwanted incident or condition which may cause one or more accidental effects.

Accidental Effect is the result of an accidental event, expressed in terms of heat flux, impact force or energy, acceleration, and so forth, which is the basis for the safety evaluation.

Impairment means that the actual function or object studied is **unusable for its purpose** (e.g. escapeways filled with heavy smoke).

Shelter Area is an area on or outside it (adjacent platform or bridge) where the crew will remain safe for a specific period of time in an emergency situation.

Design Accidental Event (DAE) is an event that the platform should be designed to sustain.

Residual Accidental Event (RAE) is an event that the platform is not assumed capable of sustaining.

Vulnerability is used as a measure for the extent to which an object is

susceptible to impairment by relevant external loads.

Acceptance criteria are functional requirements which are concerned with the platform's resistance against accidental effects, aimed at definition of the authority's view on acceptable safety level.

Safety Goals. Concrete targets against which the operations of installations at the field are measured with respect to safety. These targets shall contribute to avoidance of accidents or resistance against accidental consequences.

Acceptance criteria. Distinctive, normative formulations against which the results of a risk assessment may be compared. The criteria shall in a short term perspective express the implementation of the safety goals.

Personnel Safety. Safety for all personnel involved in the operation of a field.

Environment Safety. Safety relating to protection of the environment from accidental spills which may cause damage.

Material Damage Safety. Safety of the installation, its structure and equipment relating to accidental consequences in terms of production delay and reconstruction of equipment and structures.

Escape. Actions by personnel on board surface installations (as well as those by divers) taken to avoid the area of accident origin and accident consequences to reach an area where they may remain in shelter.

Evacuation. Abandonment of the platform from sheltered areas by the dedicated evacuation means. Emergency evacuation is normally the main consideration, as precautionary evacuation is less demanding on the evacuation resources.

2.1.4 Other Risk and Reliability Studies

Risk and reliability studies (other than the CSE) shall be used actively to develop specific specifications, design loads, design scenarios, and explore residual risk, to be compared with acceptance criteria. This is the breakdown in practice of safety goals and acceptance criteria into specifications.

The use of risk and reliability studies shall replace the detailed technical specifications formerly stipulated by authorities, and shall secure a more flexible and cost effective achievement of an acceptable safety standard.

One of the means to implement specific safety and reliability requirements is by means of Design Accidental Loads, associated with Design Accidental Events. These conditions specify which accidental conditions shall form the design basis for different components and structures. This may for instance apply to the extent of fire loads from pool fires, impact loads from falling objects or ship collisions.

2.1.5 New Regulations

The use of Probabilistic Risk Assessments (PRAs) in the offshore oil and gas

industry is likely to be rapidly expanding over the next few years. This technique has been successfully applied in the Norwegian sector of the North Sea for a decade. The expansion of this application is imminent; for instance new British regulations are being developed as a result of the Piper Alpha accident.

Other countries are also seen to be more interested in PRAs than was the case some time ago, for instance the United States and countries in South-East Asia.

Such a development will mean that the tools will need a wider application and recognition. Philosophies, techniques and data need to be consistent and well developed. This will require development of models, data bases and practical tools, in order to fulfill the operator's needs to establish viable techniques, acceptable to management, government authorities, and the public. The scope of such studies will cover personnel, environmental, and material damage safety.

The results should be communicated to designers, operational personnel, managers and all personnel affected by those risk elements. The results of risk assessments shall be used to plan and implement emergency plans, provide necessary equipment, and provide external backup assistance. Operational experience and accident, incident, near miss and failure data should be implemented in a planned effort to improve safety and learn from past experience.

Similarly, the requirements in the United Kingdom are expected to be roughly the same as in Norway. The emphasis will be placed on active use of risk assessment in the design process and in the operations phase. Further, risk to the environment is a focal point, in addition to economical risk aspects. Economical aspects of risk as well as environmental spill risk are likely to be the most important in the United States.

The trend that these new regulations are expected to bring about (according to Ref. 3) can be characterized by the following:

- The scope of such assessments will be increased considerably, from the present limitation to development of new producing installations. Requirements to carry out these studies are in the future expected to apply to all offshore activities, from the exploration activities, through production platform design and installation, and during the production phase, until it ends in platform removal.
- Offshore operating companies will be expected to develop their own set of safety goals and acceptance criteria. These would be replacing the widely known, single value criterion 10^{-4} per year, which is not expected to play the same key role as it has so far. This apparently recognizes that a single valued criterion cannot cover all foreseeable situations.
- There is in parallel with the development of risk assessment regulations also an internal process to simplify the technical regulations considerably, and to remove as many of the specific detailed requirements as possible. This implies that distinct technical requirements which have been very detailed and voluminous up until now shall be replaced by more functional and shorter technical regulations.

This implies in practice that a requirement for a lifeboat seat capacity of 200% of the number of beds on the platform will be replaced by a functional requirement to provide such a capacity as may be required to secure safe evacuation in all Design Accidental Events.

The government authority requirements are expected to focus primarily on safety of personnel, whereas safety against environmental spill and safety protection of the investment will be given less consideration.

The new regulation specifies the following risk reducing measures for each DAE:

- a) personnel outside immediate vicinity are not injured
- b) evacuation in a safe and organized manner
- c) personnel can remain safely until safe evacuation is expected
- d) control rooms/other areas of importance remain operative until safe evacuation is expected
- e) external assistance received/carried out effectively
- f) environmental damage is avoided

The following were the DAE requirements in the 1981 Guidelines:

- personnel outside immediate vicinity not injured
- safe evacuation shall be possible
- remain safely in shelter area
- control room in safe area
- external assistance after four hours
- integrity of support structure

The practice inherent in the new regulations is nothing more than what companies like Conoco Norway Inc., Norsk Hydro, Saga Petroleum, Shell and Statoil have been doing for the last few years on the Norwegian Continental Shelf.

2.1.6 Design Tools

A brief example may illustrate the use of Risk Assessments in the design process. The following is a presentation of the basis for selection of ESD versus PSD valves, based on fire risk assessment.

2.1.6.1 Fire Integrity

All fire partitions (either as physical partition or as distance) between two separate fire areas will have to be designed to maintain their integrity under the design fire loads for the areas.

2.1.6.2 Assessment of Design Fire Load

A fire load assessment for a closed module will have to reflect limitations to

oxygen supply due to capacities and characteristics of a mechanical ventilation system. On the other hand a potential initiating explosion may open up module walls and give additional air supply.

In the case of significant explosion overpressure additional air supply may also be created for semi-enclosed modules. This will also have to be taken into consideration. Explosions may also lead to secondary ruptures of other process systems, and the combined effect of leaks from different systems may then have to be accounted for.

The detailed premises and assumptions which should be used for liquid as well as gas fires are outlined below. These apply to the contents of pressure vessels and associated piping.

2.1.6.3 Liquid Fire

The design fire loads in a case of a pool fire should be assessed based upon the following premises:

- The maximum contents of hydrocarbon which can exist within a process section
- The cross sectional area of the leak should be a high value implying that the leaking rate of the hydrocarbon is high. This means that the duration of the pool fire will be significantly longer than the duration of the leak.
- A realistic assessment should be performed of the area on to which the leak is spilt. This implies that the position of possible leaks will have to be assessed in relation to obstructions such as drip pans. The capacity of drip pans as well as the location will have to be considered. Possible grated floors will also be taken into account.
- The regression rate (rate of combustion expressed as height of liquid film burning per time and area unit) will have to be realistically assessed according to the relevant type of hydrocarbon liquid.
- The duration should be assessed without consideration of drain systems.
- Possible ventilation shut-down in the case of fire detection should be considered for closed modules.

2.1.6.4 Gas Fire

The design accidental loads for gas fires should be assessed based on the following premises:

- The amount of gas leaking will take the volume between isolating valves into account.
- The duration of gas jet fire is strongly dependent on the mass flux, which

again is determined by the cross sectional area of the leak. A large hole implies a high mass flux and a short duration. The design case should be a relatively small cross sectional area which gives the significant duration. The realistic leak area must be related to the dimensions used in the area.

- The calculation of volumes will have to consider the time required to activate pressure relief systems according to available systems and relevant procedures.
- A fire jet may expose equipment in any direction and all systems within a fire area must be considered as potentially exposed.

2.1.6.5 Fire Areas

A fire area is often enclosed by passive fire partitions in order to limit the systems that may be exposed to fire loads. The design fire loads will be the basis for establishing the capacity required for the fire partitions.

A fire area may also be segregated by distance alone, without any fire partitions. This implies that the distance must allow the design fire to burn without exposing the surroundings to excessive fire loads.

2.1.6.6 Availability Requirements

The availability requirements in this section apply to the need to isolate process sections in the event of a fire, in order to limit the fire loads. The considerations discussed here apply to the isolation function, and not the process control systems.

Availability of the isolation function implies in the present context that the following requirements must be satisfied:

- The valve must close on demand as intended without failure
- The valve must initially be tight in both directions, and must continue to isolate completely, even if a high pressure gradient across the valve exists.

The selection of PSD or ESD valves is dependent on these two factors, in order to prevent fire escalation. High reliability of the isolating function may be achieved by:

- a PSD valve, if process shutdown is initiated as part of the process safety function, and the activation system has a high reliability
- an ESD valve, if the valve or its activation appliances may be subjected to the same fire as the valve shall isolate against

This evaluation assumes that an ESD valve has a higher level of protection against leaks through the valve, in the case of a fire load impinging on the valve or its controls.

2.1.7 Areas of Special Concern

2.1.7.1 Burning Blowouts

Burning blowouts are often seen to be the main cause of impairment of the platform and of fatalities in the case of large platforms. Only limited improvement has taken place over the last years with respect to the frequency of occurrence of blowouts.

2.1.7.2 Gas Riser Leaks

The gas riser leak with possible escalating fires and explosions has been considered with great attention since the Piper Alpha accident. The scenario can indeed be a devastating escalation of an accident into something similar as a blowout. However, with the use of subsea barriers, risk reduction is suddenly possible. A number of platforms have had subsea barrier valves installed during the last few years. Application of such barriers calls for detailed studies of possible merits and optimization of the installation.

2.1.7.3 Collision by Merchant Vessels

A possible major collision by a passing merchant vessel is among the main hazards in the North Sea, where no traffic lanes are defined to keep the traffic well clear of the platforms.

2.1.7.4 Escape and Evacuation

Escapeways may often need special protection to allow access to shelter areas or evacuation means in case of severe fire and explosion.

Evacuation by conventional davit launched lifeboats has often been proven difficult due to complicated launching procedure especially in bad weather conditions. The so-called free fall lifeboat concept has gained much credibility in the North Sea, as it is independent of weather conditions as far as the probability of successful launching is concerned.

2.1.7.5 Novel Production Systems

Novel production systems are particularly difficult to assess owing to the limited experience with their operation and the lack of pertinent quantitative as well as qualitative data.

2.1.8 Assessment of Old Installations

Following the Piper Alpha accident all operating companies on the Norwegian Continental Shelf have been required to update their safety studies of installations performed in the past, and safety studies have been required for installations for which such studies had not been performed. The objective of the studies are aimed at assessing the risk of occurrence of accidents of the Piper Alpha type. Risk reducing measures have to be applied if this risk is shown to be significant. This has required a great deal of attention to the oldest platforms on the Norwegian Continental Shelf.

2.2 United Kingdom

The following is a brief summary of the Cullen recommendations with respect to safety management:

The 'Safety Case' requirement is a major change in U.K. offshore risk management philosophy. Although many aspects will differ from those in the current Norwegian regulatory regime, the new U.K. and Norwegian regulatory systems will be much more alike in the future.

The main feature of this requirement is that the approval of safety is based on dedicated assessment of the specific conditions on each installation. This is in sharp contrast to a philosophy where the approval is entirely based on whether the installation and its equipment meet standards defined in regulations, guidelines and common practice.

Further, the safety requirements will be functional, rather than consisting of specifications of detailed technical solutions.

The Safety Case should be made for all installations, both on existing and future platforms. The Safety Case should further be updated regularly. The objective of the proposed Safety Case is to demonstrate that safety protection objectives have been satisfied, including:

- (i) that the entire safety management system of the company is adequate to ensure that the design and the operation of the installation and its equipment are safe
- (ii) that the potential major hazards of the installation and the risks to personnel have been identified as a means to identify the appropriate risk control measures which need to be provided
- (iii) that, in a major emergency, adequate provisions are made for:
 - Temporary Safe Refuge (TSR) for personnel on the installation
 - Safe and full evacuation, escape and rescue

It is recommended that the safety objectives are specified in the Safety Management System (SMS). Further, the SMS should include a quantified risk assessment, a fire risk analysis and an evacuation, escape and rescue analysis.

Further, regular audits are recommended, to be performed internally by the operator in accordance with the SMS, and by the regulatory body.

2.3 United States

Risk assessment and risk management techniques are just beginning to be used within the U.S. offshore industry. One of the main applications of such techniques in the recent past was the MCAPS project (Methodology for Comparison of Alternate Platform Systems), which in a full scope reliability analysis framework assessed possible methods for lifecycle cost analysis. These methods

considered economical risk, availability of production, personnel risk, and environmental spill risk. In particular, the project looked into the comparison of platform concepts and systems given prevailing uncertainties.

The extension of the U.S. offshore industry into deeper waters has been one of the main driving forces behind the use of risk assessment techniques. Many of the U.S. oil companies had gained experience in the use of such techniques from the European offshore industry.

3. Experience and Achievements

Experience in using Risk Management principles are illustrated by discussing the risk management process adopted in a recent development project on the Norwegian Continental Shelf.

3.1 Case Study

The use of formal risk assessments as a tool for evaluation and optimization of safety protection in the North Sea is illustrated by means of a case study, based on risk assessments performed by SikteC for Statoil in connection with the development of the Veslefrikk project. This project started in early 1986 and has resulted in a novel production concept. On account of the novelty of the design concept the project has been studied carefully, formal risk assessments being used with respect to safety for personnel and for the installation itself.

The paper will draw upon the results and conclusions of the studies to make observations for general use. The way these studies have been utilized by the engineering contractors is also reviewed. The studies of the Veslefrikk installations have been carried out as quantitative risk assessments, and the applicability of such studies for offshore platforms is discussed. Conclusions from the risk management process are discussed in a general context. Possibilities for continuation of the risk management process into the operational phase are also outlined.

3.1.1 Introduction

Legislation in Norway has required quantitative risk assessments since 1981 as part of the risk control process of offshore operations. Many safety professionals feel that considerable improvements have been made in the last ten years.

The use of safety evaluations in the Norwegian offshore industry was typically based on the use of Probabilistic Risk Assessments for the nuclear industry⁴. Some companies had explored the possibility of using this approach on offshore platforms in the late 1970's. A significant step forward was taken by the Safety Offshore research program, initiated by the government and jointly sponsored by the offshore industry in response to the Norwegian Shelf Ekkofisk Bravo blowout during a well workover in 1977.

Recent offshore accidents in the North Sea have focused attention on the potential for fire and explosions. Design of fire control systems on offshore

platform has traditionally been based on regulations, standards as well as good engineering practice. Considerable conservatism is often built into this approach, and large protective systems are often seen, with significant cost impact. Tools for optimization of the design have been lacking until recently, and are not used to any significant extent. Use of probabilistic risk assessment methodology has recently been extended to consider optimization of safety design. The Veslefrikk development includes several examples where such optimization took place.

3.1.2 Description of the Veslefrikk Field

The Veslefrikk field is located in the Norwegian sector of the North Sea in the Northern region. The water depth is 175 meters. The field produces oil and gas at an approximate flowrate of 10,000 l.0 m³ per day. The Veslefrikk installations consist of:

- a Wellhead and Drilling platform, supported by a steel jacket structure (deck size 30 by 40 meters)
- a pre-installed template at the seabed, allowing production wells to be pre-drilled before installation of the jacket
- a semi-submersible platform (third generation) converted from drilling mode to production, utilities, drilling support and accommodation (deck size 80 by 80 meters)
- a telescopic aluminium bridge for connecting the platforms at an operational distance of 38 meters
- flexible hoses for production flow, export of crude oil and gas, and all connections required for supporting of the drilling and production systems

3.1.3 Safety Features

The Veslefrikk platforms have many unique safety features, some of which contribute considerably to making the two platforms a safe installation. The main safety features can be summarized as:

- The bridge connection as a way to escape from an accident over to the next platform
- Structural safety of a third generation semi-submersible platform
- Evacuation philosophy based on use of the bridge as the primary means, prior to deployment of conventional lifeboats
- Optimized combination of active and passive fire protection
- Use of a single line, high integrity diverter for handling of possible shallow gas blowouts
- The Veslefrikk field has a limited blowout flowrate potential, owing to

limited reservoir pressure, which decreases as the field is produced.

3.1.4 Safety Evaluations During Engineering and Fabrication

3.1.4.1 Overview

A typical schedule of risk assessment studies during engineering and fabrication phases may look as follows:

Concept selection:

- Comparative safety evaluation of alternate concepts is often the first step, intended to provide insight for selection of the optimum concept.
- First coarse Concept Safety Evaluations (CSE).

Engineering:

- Several more refined stages of Concept Safety Evaluations (CSE). The hazards covered in these studies are blowouts, riser/pipeline failures, process system leaks, collisions, and structural and marine related failures, as shown in Figure 2.3.
- Limited design accidental load studies, reliability/availability studies of safety system design, and so forth, to clarify detailed solutions, and evaluate whether premises from earlier studies have been implemented in practice.
- Emergency Evacuation studies to assess the expected success rate of the evacuation system and procedures, in order to optimize the emergency evacuation system.
- Collision risk studies to determine what (if any) risk reduction measures may be required, in order to control this aspect of risk.
- Total Risk Analysis (TRA) at completion of engineering design work, to document the fatality risk level, and provide basis for specification of requirements to operational procedures.

Fabrication:

- Updated studies concerned with design changes that are performed during fabrication and construction
- Updated studies concerned with revisions made to procedures for operation or emergency preparedness.

3.1.4.2 Risk Quantification

Figure 2.3 presents a typical risk level graph for a fixed offshore production platform. The frequencies shown in the figure are for Residual Accidental Events, which, according to Guidelines by the Norwegian Petroleum Directorate⁵, are acc-

identical events of such severity that at least one safety function is impaired, the safety functions being:

- Escapeways
- Shelter Area
- Support Structure

The contributions to the risk level in Figure 2.3 are structured according to NPD Safety Evaluation Guidelines⁵, where the major subdivision is in two categories associated with fire and explosion and the second category associated with structural impact.

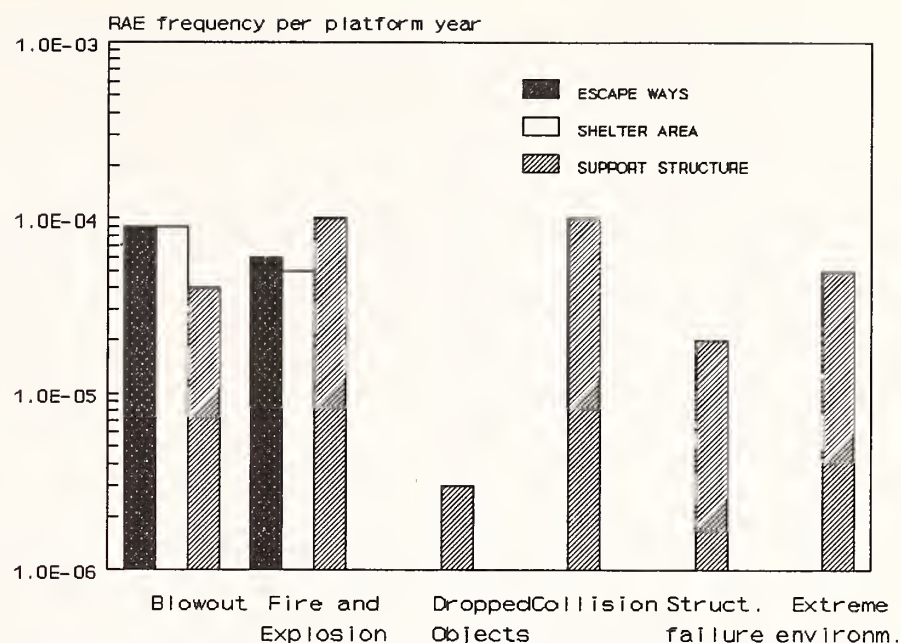


Figure 2.3 RAE Frequencies for Fixed Production Platform.

The blowout category is often seen to be the highest contribution to platform risk. Fires and explosions in process areas and/or collision against platform will often belong to the second highest category. Evaluation of accidental consequences following a hydrocarbon leak in the processing areas is therefore important. This is often performed by means of an event tree analysis which takes safety systems and protective measures into account.

The terminal events from an event tree following a hydrocarbon leak can be collected in three different groups, one of which is the unignited events, while the two others are ignited events with short or extended duration. Short duration implies that the ESD system works, while extended duration occurs when the ESD system or valves, or the shut-off valves, malfunction, so that a larger volume may leak.

A fatality risk picture is presented in Figure 2.4.

Figure 2.5 presents a typical event tree for a hydrocarbon leak.

3.1.4.3 Selection of Design Accidental Events

Accidental Events may be classified into three categories:

- Events that normal safety systems can control (these belong to the group of Design Accidental Events)

- Events which will form the design basis for safety systems, in order to control the frequency of residual risk (events which belong initially to the group of Residual Accidental Events, but which are transferred to the group of Design Accidental Events)

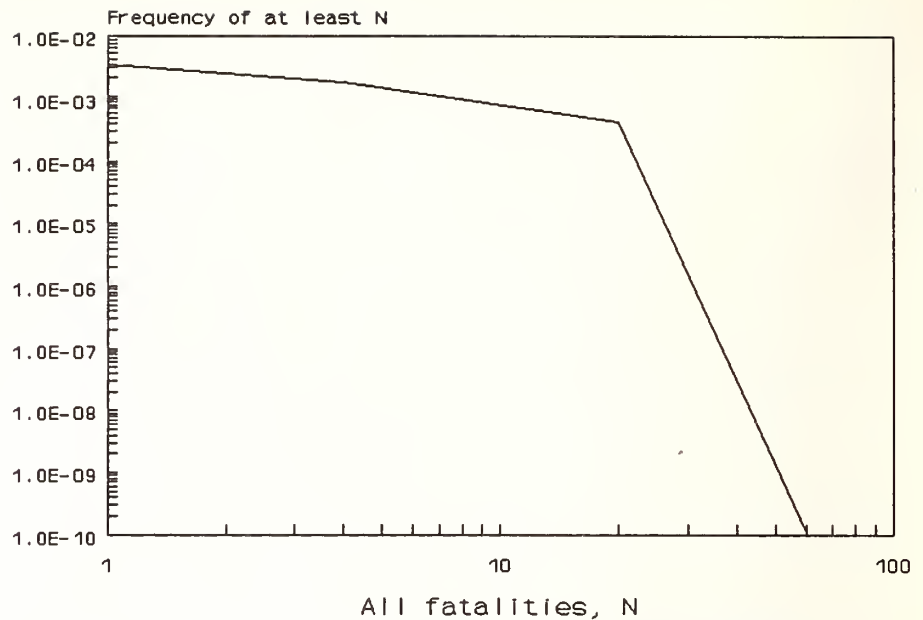


Figure 2.4 Cumulative Fatality Risk Distribution

- Events which initially belong to the group of Residual Accidental Events, on account of the severe accidental consequences. However, if the frequency of occurrence is sufficiently low, these events will not increase the residual risk level dramatically, and they may not need to be transferred to the group of Design Accidental Events

The accidental events on a platform can therefore be considered with respect to frequency, in order to define the design fires. All events which, when summed together, have a frequency below 10^{-4} per year may be disregarded. Typically, small/moderate ignited gas leaks (up to 5 kg/sec of leak rate) have frequencies higher than 10^{-4} per year. More extensive leaks (above 5 kg/sec) have been found to have such low probability that they could be disregarded.

For the sake of conservatism large liquid leaks are selected as design fire conditions for all liquid leaks, even though in some cases they could have been disregarded on the basis of frequency.

Typical design accidental loads are radiation levels (e.g., 50 kW/m²) for equipment and structures, with a given fire duration.

3.1.5 Safety Evaluations During Field Operations

Safety evaluations during platform operation consists of the following activities:

- Updating of safety evaluations to keep up with the modifications which are implemented
- Separate safety studies of significant modifications which are carried out

EVENT TREE:
NIST, TEST, TEST, TEST, OIL LEAK
SURF

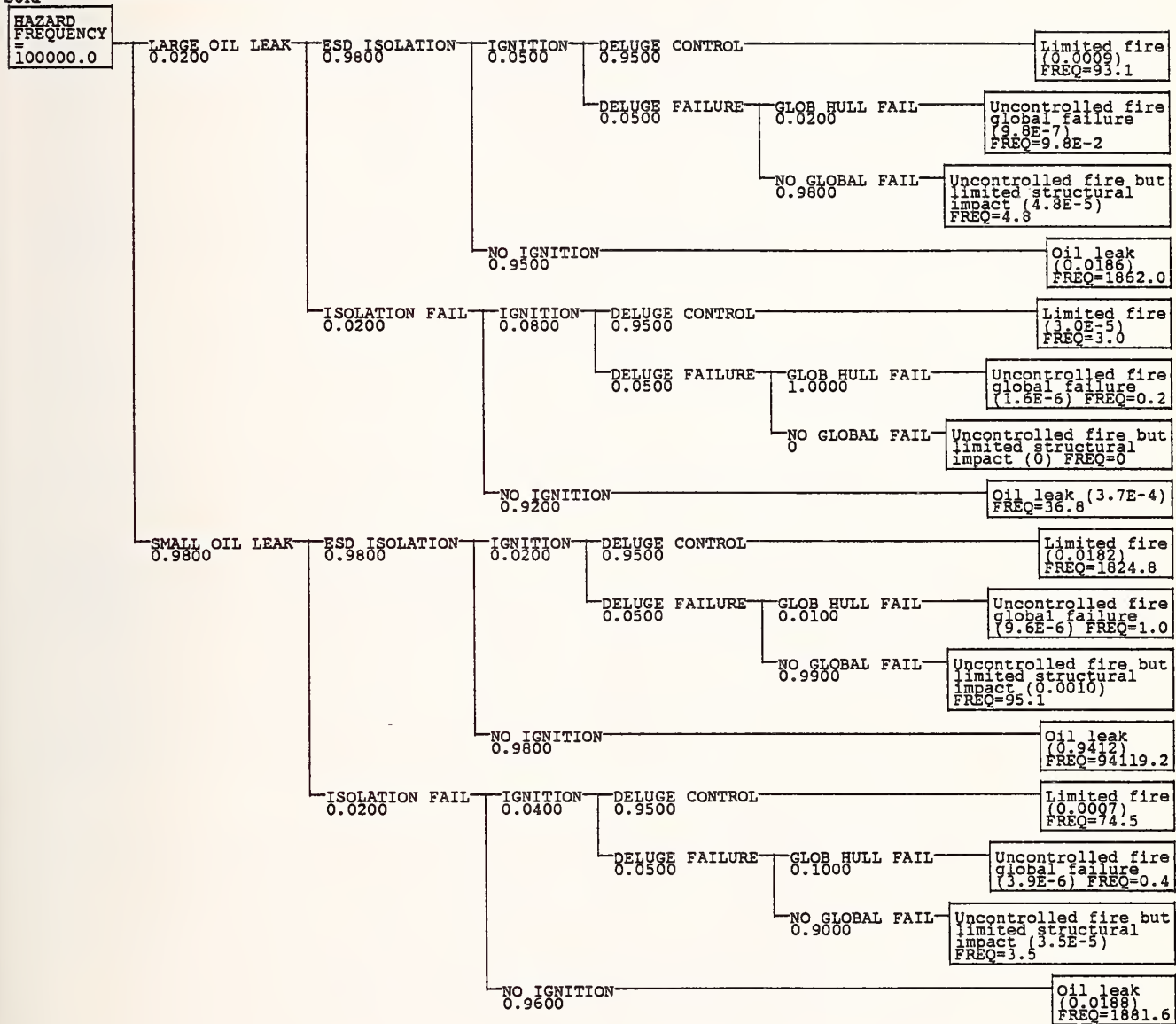


Fig. 2.5 Sample Event Tree for Hydrocarbon Leak

- Safety evaluations of significant changes to operational premises that are implemented

A systematic approach to follow up on analytical premises and operational assumptions is sometimes implemented. This may be carried out in a database format, which may allow searching and retrieval of information.

Another approach that may be implemented in the future is the utilization of expert systems, where platform operation and risk modelling are integrated, to obtain advice on how to operate the platform most efficiently and safely.

3.1.6 Use of Quantitative Risk Assessments

The use of quantitative risk assessment studies was often viewed rather critically at the beginning of the 1980's, when this was a new exercise. Some of the main aspects that were viewed as negative at the time were:

- lack of frequency data, based on relevant operational experience
- lack of risk assessment expertise combined with technical/operational expertise
- studies which produced absolute risk estimates that were useless for practical design purposes

While some of these points may have been difficult to solve satisfactorily in the first few years in the late 1970's and early 1980's, today more practitioners believe that the safety evaluations are useful in the search for optimum safety on offshore platforms. Justifications for this belief lie in:

- The use of quantitative risk estimates primarily in a relative sense
- The interest in extracting from the studies design accidental premises and loads
- The development of Design loads based on consequence analyses, related to dimensions and durations of fire, impact loads in collisions, and so forth
- The emphasis placed on technical details and design-related aspects in reliability and risk studies, in contrast to the overall coarse (more or less generic) studies being conducted in earlier years
- The possibility to follow up on premises and assumptions from an operational and procedural point of view
- The finding that the main benefits of the studies is the risk analysis process, rather than the analytical results
- The fact that the experience data base has improved significantly over the years.

3.1.7 Overview Safety Studies

A number of studies and assessments were performed during the Veslefrikk development project. These included such aspects as:

- Vulnerability of the bridge connection
- Vulnerability of the catenary flexible hoses
- Structural safety of a floating platform
- Evacuation philosophy using a conventional lifeboat concept
- Collision hazard between a floating and a fixed structure
- Use of active and passive fire protection
- Use of a single line, high integrity diverter
- Use of subsea barriers on pipelines

The reason why such studies have been carried out is twofold:

- Being novel, the design concept was studied in depth to make sure that no hazards were overlooked or forgotten
- Risk assessment studies were used repeatedly to optimize the safety protective design.

3.1.8 Results and Conclusions

- The safety level assessed for Veslefrikk is better than for most other recent, comparable installations in the North Sea
- The field development concept has been proven to be cost effective, and to entail a favorably low risk level
- More specifically, the blowout risk is low compared with that shown for other similar developments, mainly owing to the extent of predrilling. Also other risk factors, such as fire and explosion due to riser leaks and leaks from process equipment, are low owing to good ventilation and the possibility to separate functions on two structures
- The use of flexible hoses between the fixed and floating platform for transfer of gas and oil does not increase risk, given the possibilities for isolation, and the consequent limited amounts of hydrocarbon in case of a leak from one of these lines
- The main features with respect to safety are the bridge connection between the platforms, the modern semi-submersible platform with many special safety features, the separation of areas, and the existence of an open process area which prevents escalation of accidental effects
- The use a bridge connection as the primary evacuation means for personnel makes up for the use of conventionally launched, covered lifeboats

- Safety studies have contributed to an optimization of the safety protection, in the sense that detailed studies of accidental scenarios has shown that the protection could be simplified, without reducing the protective characteristics
- A specific accidental load study was used to justify the proposition that functional properties for a separating deck were satisfied given the actual loads, even though detailed specifications could not be adhered to
- Comparison of two alternative active fire protection solutions was performed in order to assist in the optimization with respect to safety and installation cost.

3.1.9 General Observations

The following general observations may be made in relation to the safety evaluations carried out for the Veslefrikk platforms:

- Use of quantitative risk assessment models from the first stage of the development has provided the possibility to respond in a precise manner to queries that have been made concerning protection aspects for the Veslefrikk A and B platforms
- The quantitative process has offered the opportunity to make decisions regarding safety that have led to an improved safety level
- Consideration of design details in the risk assessments has turned these studies into useful tools for the engineering team throughout the course of platform development
- A unified risk model used from the earliest concept definition stage and carried through into the operations phase has provided a useful tool for a continued risk administration process and an efficient utilization of resources.

3.2 Evaluation of the Usefulness of Probabilistic Risk Assessments

3.2.1 Benefits Due to Application of Risk Assessments

Those benefits are:

- Qualitatively, the operator gains insight into: risk mechanisms, how hazards are created and can be prevented, possibilities available for mitigating accident effects, risk aspects of overdesign and underdesign
- Quantitatively, an appreciation of the dominant contributors to risk, and of the optimum level of protection against unsafe events

3.2.2. Facilities for Which Risk Assessments Should be Used

Risk assessments should be used for the following types of facilities:

- All facilities involving investments on the order of at least a quarter to half a billion dollars (over the field lifetime), even if traditional development technology is utilized
- Facilities with significant novel design, construction, installation or operation aspects
- Deep water facilities
- Installations designed by using principles and approaches that deviate significantly from recognized international or domestic standards.

The risk assessment methodology should not be used for facilities involving application of 'off-the-shelf' technology and limited investment.

3.2.3 Time and Manpower Requirements

The North Sea experience in applying risk assessments is that these studies may be conducted in parallel with planning, design, construction, fabrication and operations with no significant, if any, effect on overall time schedules.

Typically, these studies are conducted in stages, with a duration of up to 2-4 months (down to 1 month) per study per stage.

The total manpower requirements are to a large extent a function of the order of magnitude of investment. Typically, for a field development schedule, 0.2 to 0.5 percent of the total field development cost (drilling costs excluded) have been estimated to be resources used on MCAPS methodology and related studies. This figure also includes the internal resources needed to monitor an outside contractor.

For a one billion dollar investment, a complete, detailed risk assessment study installation would typically require a budget of the order of one staff-year, extended over a two to four months period.

3.2.4 Potential Cost/Benefit Ratio

It is argued that the Cost/Benefit ratio often is less than 1 over 10.

Risk assessment studies used in a 'non-prescriptive' environment (i.e. where there are no minimum standards that have to be satisfied irrespective of risk level) have often been viewed as reducing overall development costs. An example is the finding that a certain deluge system can be removed without significant effect on the overall risk level for equipment and personnel.

3.2.5 Availability for Use

The risk assessment methodology has been used extensively in the Norwegian offshore industry for more than 10 years, and in the entire North Sea for the last two to three years. It appears to be a relatively consistent view taken by most operators that the methodology yields clear benefits.

It can be argued that the new Risk Analysis Regulations enforced by the Norwegian Petroleum Directorate (NPD) from February 1, 1991 represent a follow-up by the part of NPD on what the dominant operators have been doing voluntarily for several years. The regulations will make adherence to appropriate risk analysis practices uniform among operators.

Thus, at least operators in the North Sea (that is, most of the major international operators) should view the methodology as being now available for use.

This does not mean that no problems exist. Indeed many difficulties exist. An effective and defensible use requires that all involved be well aware of weaknesses and problems. However, the techniques are available for use to an extent that the benefits very often exceed the costs by far.

3.2.6 Reliability and Defensibility of Results

The reliability and defensibility of the results depend upon the way in which analysis techniques are used. In the United States the techniques have been used primarily in the nuclear industry and in environmental protection for verification purposes. In this context the main concern was the uncertainty in an absolute sense.

In the North Sea, however, the primary use of the risk assessment methodology has been as a design tool, where relative uncertainties are of interest. Such use is much less controversial.

For the latter type of use the reliability and defensibility of results depend on:

- the models that are used for probability estimation and consequence assessment
- the data that are fed into the models
- the competence (know-how) of the analysts with respect to risk modelling, offshore design practices and offshore operational practices.

For the relative, comparative use of reliability estimates it is argued that the models and data are largely sufficient for yielding reliable and defensible results capable of supporting clear conclusions.

Some forms of use require interpretation in an absolute sense. This is when significant uncertainties arise and can be a matter of serious concern.

The know-how aspect is perhaps the most difficult to deal with satisfactorily in practice. Both the resources being planned and budgeted for the analysis and the qualifications and capabilities of the personnel must be adequate.

4. Problem Areas

4.1 Technological Barriers

Lack of data for novel systems is one of the main obstacles for efficient use of risk management techniques. This may be compensated for to some extent by:

- Comparison with similar concepts and systems
- Theoretical studies on component level

By comparison with similar concepts and systems it is possible in some cases to achieve assessments of risk levels to within an order of magnitude; closer assessments may be difficult to achieve.

Another action which will gradually improve the situation is development of improved models for physical development of accidental scenarios.

It remains true that risk estimates are characterized by uncertainties, particularly for novel systems. This applies especially to estimates used in the absolute sense, which should be considered as order-of-magnitude values.

4.2 Institutional and Cultural Barriers

Risk assessments are not used in Norway to subject the operator to pressures on the part of the authorities to achieve additional safety improvements. This is probably the main reason why risk management techniques have been rather successful in practical use over a decade in Norway. The following statements can be made concerning on the use of risk assessments in Norway:

- They are not used for verification of safety levels
- They are used primarily as a design tool

It appears sometimes that the oil and gas industry in other countries may fear that the risk assessments' role is to 'prove' an acceptably low risk level, and that such a fear prevents the industry from using these techniques. Such a role would be similar to the role played by risk assessments in other industries, such as the nuclear industry, where it is surrounded by a great deal of controversy.

Based on the Norwegian experience, it appears that it is essential that risk assessment be considered also in other countries as a design tool. Further, the legal framework should in our opinion be such that risk assessments are not used as evidence against the industry if accidents occur.

It will be important for the successful utilization of risk management techniques, that the difference between the process of risk assessment and the results is appreciated. The process of risk analysis provides an overview of the risk picture, identifies the most important elements of risk, and provides suggestions for risk reduction. The insight created by this process are in themselves valuable as a basis for improvement of the overall risk level. Risk assessments indicate which are the most important elements of risk and allow a presentation of the total risk.

It will be important to realize that the quantitative results of a risk assessment should be considered as notional probabilities and not as statistical estimates in an actuarial sense.

It is further important to realize what the actual purpose of the quantitative risk models is. The purpose of developing a quantitative model is to provide an estimate on probabilities of future occurrences. There will always be considerable uncertainties associated with these estimates. Only the order of magnitude of the risk estimates should therefore be taken into consideration.

Finally, it is important to realize that 'exact' physical modeling is not required in the risk assessment process in order to obtain defensible results. 'Exact' physical modeling of particular phenomena will often be so laborious that the costs associated with it and with the assessment of risk would be unjustified. Therefore one has to use more approximate physical models which have uncertainties in line with the overall uncertainties involved in the assessment.

5. Research Needs

5.1 Risk and Acceptance Criteria

In the new Norwegian legislation the task of defining acceptance criteria for risk has been left to the individual operating companies. This has led to some coordinated efforts in the industry to arrive at acceptance criteria that are reasonably uniform among the individual companies.

The working group agreed that such an approach could be successful in Norway, where acceptance criteria had been prescribed by the authorities for nearly a decade. However, in countries where this has not been the case, such an approach might be less desirable. It was noted in particular that the Canadian approach is based on the definition of acceptance criteria by the authorities.

5.1.1 Cost/Risk/Benefit Studies

The use of Probabilistic Risk Assessment (PRA) for the purpose of Cost/Risk/Benefit Assessments (CRBA) is a valuable application of the PRA methodology. The PRA approach is used mainly in a relative sense, which is useful for CRBA's. The CRBA approach is illustrated by the following case relating to isolation valves on subsea gas pipelines.

A cut-off valve is placed on the pipeline at a distance L from the platform. It is intended to reduce the duration of the flow, if a serious leak (or rupture) occurs near the platform or on the riser. The duration of a possible fire should thus be significantly reduced. The size of a possible gas cloud will be reduced also. However, even with the valve being installed, that cloud may be sufficiently large that an extensive gas cloud explosion could occur.

The benefit due to the presence of such a valve is therefore reduced accident costs, should a rupture or leak of the riser or pipeline occur near the platform. This benefit has both an economical aspect, as well as an aspect related to reduced personnel risk.

If a leak occurs, the accident may develop in several ways. As a simple illustration one may regard the accidental consequence, C. C is to be understood as a vector, which has to be assessed through an event tree analysis.

The average benefit may, as a simplification, be regarded to be constant in the operational period, and may further be regarded to include accident and operational costs. Operational and maintenance costs must be calculated as part of other annual cost factors.

The simplification of fixed costs is only made for illustrative purposes. The benefit is in fact always a time dependent function, due to its dependability on production delay, and hence, loss (delay) of income.

For the assessment of net annual benefits, we must take into consideration that running and maintenance costs are deterministic (though the amount may be variable), while reduction in accident and repair costs are probabilistic elements that reflect the probability of occurrence of a leakage.

The evaluation of economical risk in association with personnel risk may be carried out in the following way:

1. An extra safety investment is calculated using the CBRA approach, and the Net Present Value (NPV) is assessed.
2. The safety investment is favourable if the NPV value for the safety investment is positive.
3. The personnel risk effects are included in the evaluation only if the Net Present Value is negative.
4. The investment in safety measures is related to the personnel risk by assessing the NPV value per statistical life saved over the applicable period.

The Cost/Risk/Benefit approach has been used for the Norwegian Continental shelf in tasks such as the following:

- Selection of emergency isolation valves
- Selection of extra well blowout protection valves
- Selection of active and passive fire protection measures

5.1.2 Software Tools

Software tools are important for rationalizing the effort needed to conduct risk assessments. Software tools also allow the studies to be repetitive and provide more precise documentation. Numerous software products are available for limited analytical tasks such as Fault Tree Analysis, Data Analysis, Failure Mode and Effect Analysis, and so forth. For offshore risk analysis purposes no integrated packages for total risk assessment are available. Some packages are available for onshore risk analysis, and there is at present one major development project in progress for offshore risk assessment software.

However, on the management side, few software packages are currently available.

5.2 Integration into Design

The intention is to use the risk assessment methodology in an optimization of the safe design and operation of platforms. This implies development of tools that may assist the industry in automated design of intrinsically safe platforms, with optimum safety built in, based on use of risk analysis. Tools in this category will have to rely heavily on expert system technology.

The following may be stated concerning the use of risk assessments in the design process:

- The risk assessment process should be closely integrated with the design process. A unified model for risk assessment should be used throughout the process, allowing a quick response to any queries from the engineering team.
- The quantitative studies should provide a basis for optimization of the safety level. Design details should be studied in the risk assessments, providing a basis for choosing the best solutions with regard to safety.
- The risk estimates should be used primarily in a relative, rather than an absolute, sense. This reduces the uncertainties in the results and the sensitivity of the conclusions to unavoidable uncertainties in the assumptions being used.
- The focus in the studies should be on the design implications of the risk assessment results rather than on the results themselves. The premises for the studies may be utilized to obtain design accidental loads.
- The focus should be on the evaluation of design details rather than on assessment of the overall risk level of the platform. Overall studies are primarily relevant in relation to the Norwegian Petroleum Directorate criteria while detailed studies are more useful as design tools.
- A realization that the risk assessment process itself has the highest value; the analytical results are usually of minor importance.
- Risk assessments can be used without creating significant controversies.

The experience with this approach is positive, and it is apparent that it has contributed to improving the risk level of the platforms. There is also an aspect of satisfaction for the consultants performing the safety studies, because this process gives an opportunity to influence the design process.

5.2.1 Life Cycle Cost Optimization

Optimization of life cycle costs (including risk costs) will be performed as an overall economic analysis. The following data should be used as input, in addition to the data obtained from event trees:

- Duration for each production period
- Production volumes for each period
- Unit price oil/gas
- Cost and price escalation factors
- Interest rate
- Unavailability of well systems, process systems, export facilities
- Average period of deferment for production delay for each phase
- Average operating and capital costs for each period

5.3 Integration into Operational Planning

Use of risk assessment and risk management techniques may also provide essential input to operational planning. In particular, analytical premises and assumptions may be used as input to the planning of manual operations, maintenance, inspection and intervention. For example, assumptions regarding reliability of safety systems may imply maintenance requirements and inspection and test intervals, in addition to equipment standards.

Premises and assumptions may similarly provide input to preparation of operational manuals as well as procedures and manuals for maintenance and inspection. The objective is that these premises define acceptable standards of work and give warning on possible unwanted consequences or outcomes of the operations.

Design accidental loads can also be used to review the need for modifications and their possible merits with respect to protection against accidental scenarios and loads.

5.4 Physical Modeling

Considerable effort has been spent lately and is still being spent on modeling of fire and explosion scenarios as well as on structural responses and loading. The knowledge and modeling of these phenomena are therefore gradually being improved. However, the models are often related to rather idealized conditions and are not capable of considering the complex conditions on an offshore installation.

In particular, the behaviour and responses of systems and elements under various kinds of accidental loading are difficult to model. Failure mechanisms of novel systems, for instance flexible pipelines, also require additional effort.

5.5 Statistical Data

Reliability data for production and process equipment have been collected over the years, especially in the North Sea. The OREDA project provides a computerized database for participants.

Accident data bases exist from several sources including Minerals Management

Service (Events Data File), WOAD (Veritec, Norway) and others.

For the reliability of safety systems much less data is available. Also, data on leaks, ignition of gas and oil as well as data to describe consequences, are presently lacking to a considerable extent.

6. Opportunities for Implementation and Application

A strong case has been made for risk analysis to be considered as a design tool, rather than a tool for verification of a safe design. Risk analysis viewed as a design tool does not give rise to controversies over numbers such as have occurred in other industries. In fact, although fear of endless controversies was a major concern in Norway when risk assessment was introduced in the early 1980s, it subsided within the first few years. Today, the approach is considered effective and successful by most companies concerned.

The important role of the risk assessment as a design tool is that it allows comparative risk assessment, not absolute statements. A case was made for the design tool risk assessment to be quantitative. Quantification may often be limited to consequence calculation when the study's aim is to find, for example, what fire load to design the pipe support for, or what impact a Tension Leg Platform must be able to sustain. However, in some instances quantification will also have to comprise probability assessment, and in such cases much skill and wisdom are required. The point was made that probabilities should be regarded as notional, in contrast to actuarial probabilities. This consideration goes together with the use of probabilities in a relative sense: a probability of 10^{-5} has no meaning other than that the hazard of concern is much less significant than hazards with probabilities of 10^{-4} or 10^{-3} .

In summary there are many opportunities for application of risk management techniques in the future in the entire offshore industry. In Europe many of the largest platforms of the first generation have to be upgraded in order to meet the safety challenges of the future. Marginal field development with novel production concepts is also being contemplated. These tasks call for extensive use of risk management and risk assessment techniques.

In U.S. as well as in Canadian offshore areas developments are taken into deeper waters. Both economical and personnel safety considerations are expected to increase the need for risk assessment studies.

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WORKING GROUP #2

RISK MANAGEMENT PRACTICES

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REPORT OF WORKING GROUP #3

STRUCTURES: RISK AND RELIABILITY ISSUES

C. Allin Cornell
and
Gordon Edwards

1. Introduction

Both the application and the research in structural reliability assessment are evolving rapidly. Even at the time of the 1984 workshop, probabilistic methods had been in use for two decades to define design loads, and the offshore industry was well on its way to developing a probability-based design code following principles that had been established in the building industry for a decade. Both these applications had the luxury that they did not require explicit probabilistic analysis by the user and that they could be calibrated to existing practice. Therefore the structural community, while long committed to a probabilistic basis for design, does not have a broad experience base with Quantitative Safety Analysis as currently practiced, for example, on the active mechanical topsides systems.

To improve this situation, the insights and advice of our closest predecessors (Working Group II of the 1984 Workshop) have generally been followed. As they suggested, isolated applications, demonstrations, and research have all increased in volume, have in some cases coalesced into larger, coordinated activities (e.g., various Joint Industry Projects), and have provided a basis for the evolution of specifications (e.g., the API-LRFD, the CSA offshore code, the current European considerations of adopting a modification of the API-LRFD, the recent revision to the NPD criteria). While the serious concerns of that 1984 Working Group bear careful re-reading (e.g., organizational and communication problems, risk analysis as a "sterile acceptance hurdle"), we believe the current atmosphere is generally a significantly more positive one.

In particular, the use of probabilistic analysis is now more readily accepted as the only reasonable way to deal with certain problems, and it is beginning to influence not only how research and development are done in other related areas, but which problems are studied. Examples of subjects that must be explicitly probabilistic in their treatment in research and application include environmental descriptions, irregular seas and resultant response, fatigue, inspection updating and planning, and so forth. Examples of research and development that it might be argued are responding to the probabilistic developments in structural design and reassessment include increased interest in collapse analysis of jackets, definition of joint environmental loading criteria, and linear and nonlinear (random) vibrations analysis.

2. Scope

Because of the potentially excessively broad scope of our working group, effective use of time required that our first step be making a focused definition

of the scope. This process was in itself one of the most interesting and most highly charged portions of the group's sessions. The co-chairmen had initially proposed a focus on two reliability dominated subjects: structural systems analysis and joint environmental loading characterization. Other lists were also offered. The observation was made and widely supported that both reliability assessment and safety advances are driven by varying mixes of "technological push" and "industrial pull". Although not unanimous, the consensus was to develop our operating focus by identifying those topics thought (at the outset) to have the greatest opportunity for near-term implementation by dint of their having both pull and push, i.e., because they were both perceived as needed by industry and within the realm of current technology (or its close reach).

Though an interactive process, four topics fell out:

1. Reassessment of Steel Jackets
2. Optimization of Inspection, Maintenance and Repair
3. Risk Management of Novel/High Consequence Systems
4. Design: Reliability-Based Design, Design Norms, and Life-Cycle Design Optimization

For those less familiar with structural engineering, these headings can be briefly described as, respectively: (1) the evaluation for continued use of existing steel jacket structures; the causes for reassessment may be advanced age, life extension and/or revised use beyond the original design basis, identified damage, or revised perception of environment conditions; (2) the development of cost-effective plans for future inspection and repair taking advantage of updating based on past inspections; (3) design of unusual platforms when information is limited due to lack of prior industry experience or when the impact of system failure is significantly higher than in normal practice; and (4) the utilization of risk and reliability analysis in routine design through improved design norms, such as the LRFD proposals now under consideration by the industry, or improved definition of oceanographic input parameters.

Although designed to provide a focus, the four subject areas were understood to be broad enough to require discussion of many other topics that were identified as important for the group's consideration. Several that were consistently mentioned included: low capacity margin systems (e.g., jackups and tripods can be defined as "novel" structures because, although common, they are believed to have lower reserve strength ratios than conventional four and eight leg jackets), TLPs, design for robustness to damage, comparative versus absolute probabilities, target probabilities, treatment of uncertainty in probabilities, cyclic loading effects, etc. It was decided, too, that for efficiency we should not spend time on debate of the details of basic physical modelling issues, except as they have a first-order impact on one of the reliability assessment topics.

3. State of Practice

The working group considered next the state of practice of risk assessment in the four focus topics.

3.1 Reassessment of steel jackets

Although not all companies consider it routine practice, the state of the art in practice is the use of a deterministic, static push-over analysis to establish an ultimate system capacity (establishing a RSR or reserve strength ratio defined as the ultimate capacity divided by the original design capacity, both measured in terms of base shear, for example). Probability enters, at most, by calculating the probability that a wave occurs large enough to exceed this ultimate capacity. Major reservations remain in this structural assessment (see below in the Problem Areas section).

Structural reliability analysis capabilities exist to go further. These are system reliability analysis methods that have been developed significantly since the 1984 workshop, where they were a topic singled out among development needs. Investigations in both the U.S. and Europe have led to illustrative analyses on full-scale structures and to software that has found its way into practice. With few exceptions, the effort has been reliability under extreme loads; several have concluded that the benefits of such multi-failure path, probabilistic systems analyses are marginal (vis-a-vis a simple, single mean-centered deterministic ultimate capacity analysis coupled to a probabilistic long-term wave environment assessment). In contrast, major benefits appear likely for the fatigue/systems problem. Although less well-studied, several published procedures are in the literature and more work is underway.

Other questions associated with this reassessment topic are common to all topics, e.g., treatment of uncertainty in small probabilities, "acceptable" failure probabilities, handling of modelling uncertainties, etc. These problem areas will be discussed below.

We might summarize the state of practice discussions on jacket reassessment by saying that first generation structural-mechanical and structural reliability tools are available, but there is not broad consensus as to how to use the results in decision making.

3.2 Optimal inspection, maintenance, and repair

Discussion of the state of practice here centered on relatively new member-level, reliability-based inspection planning. The procedures are accepted by at least some certification institutions, are practiced routinely by some contractors, and are cited for having justified 50% reductions in certain North Sea inspection costs. Although member-oriented, recent advances have coupled these analyses with multiple deterministic push-over studies designed to identify the more critical members for inspection focus. Although this process reflects system-wide effects, it is not the true system-reliability-based inspection optimization method that one can visualize being within reach of relatively near-term reliability analysis research developments.

Most group members considered this problem a subset of the topic of reassessment of existing jackets; they believe that in new designs, inspection should not be the "first line of defense" for fatigue reliability. Rather long design fatigue lives coupled with design for system robustness (given a local failure) constitute the more efficient and safe design philosophy.

3.3 Risk management of novel and/or high consequence systems

The state of practice in this topic is mixed. It was widely agreed that reliability analyses should be a major industry tool for unusual systems, new environments, and uncommonly high failure consequence situations. And the group cited many interesting examples of applications in practice. These included several TLP applications (e.g., risers, set-down effects on tendon reliability, and tether failures impacting risers), deck height decisions, caisson-structure design, etc. In some cases the studies involved comparisons among alternate concepts; often the results were "benchmarked" to parallel studies on conventional jacket structures where the preponderance of our experience resides.

Novelty implies less experience that in turn implies less information, whether derived by analysis or observation. Particularly when comparing novel versus conventional concepts, one should consider the effect of this "Type II" (epistemic) uncertainty in the analysis. Commonly included in, for example, nuclear power plant risk assessments, it has only recently begun to make its appearance in offshore analyses.

The general industry acceptability and likelihood of doing such analyses seem both to have improved over 1984, but apparently in a non-uniform way. Still, however, the expertise resides only in certain operators and contractors, the level of encouragement and/or receptivity of regulators varies geographically, and there exists a lack of standardized guidelines for decision making. These conditions (and other problem areas discussed below) continue to limit the application of reliability analyses even in this area where its utility is so apparent to all informed parties.

3.4 Design: reliability-based design, design norms, and life-cycle optimization

In this area there has been marked progress since 1984. Reliability-based design norms (with deterministic formats such as LRFD) are now the standard for code development. In the offshore industry this use of reliability is currently being engaged to re-write codes of practice for conventional jackets in many parts of the world. Further, a parallel development is underway for TLP design. In most cases, calibration to successful past practice has been used as the basis for setting the (often implicit) annual failure probability. The introduction and use of such probability-based norms has encouraged the development of improvements, for example, in the code treatment of joint environmental loadings. A major exception is foundation design where several obstacles to reliability-based code development remain.

A next step might be direct reliability design, i.e., where explicit reliability calculations are made and compared with required reliability targets. Building design developments in Europe are moving in this direction. The computational capabilities exist; standard distribution assumptions are to be made available as default values; widespread familiarity with reliability is missing, however, together with critical joint environmental data in many locations. Education is in place in some universities, but this capability will be slow to develop without a major industry "pull".

The application of the ultimate, full-life-cycle, cost-risk-benefit optimized design process is not on the horizon. Most attendees agreed that the basic tools are available and that the framework is in view. (Joint Industry Projects such as the MCAPS project have addressed the problem.) Again the area needs a major industry pull, which in turn requires that proponents demonstrate and communicate both to engineering colleagues and to management that there are substantive benefits to be gained. These might be improved flexibility of future platform use, limiting of "downside" risks (e.g., by improved robustness to damage), designing out recurrent costs (e.g., by eliminating fatigue inspections), etc.

4. Problem Areas

Review of the state of the art of reliability approaches in the four high leverage areas led the working group to identify a number of broad problems and issues requiring resolution to allow significant further progress in these areas.

In developing this information, it was fully realized that while some problems would demand significant further research for their resolution, others are more linked to industry consensus building, development of common views and agreed "paradigms" for performing analyses. Furthermore, in certain cases, emerging legislative frameworks and the differences between these in various countries are likely to have a strong impact on the direction and pace of technology development.

Due to the strong links among the above issues, it is not felt meaningful at this stage to separate the problems into the different classes. They are recorded here in narrative form in the sense and context in which they were expressed by the working group members.

4.1 Reassessment of steel jackets

Current approaches for evaluating RSR ratios of jackets under wave loading rely on a static pushover model of failure. This is unlikely to be fully realistic in most cases and leads to a (currently) difficult decision in assessing the percentage of identified reserve strength which can be utilized in a reassessment/re-qualification exercise.

A major issue here was recognized to be the possibility of high strain/low cycle "shakedown" or strength reduction in a jacket due to the passage of a sequence of near extreme wave loading events -- either in the same storm or different storms. The problem is both a structural one (i.e., does the structure degrade under such events?) and an oceanographic/wave loading one (i.e., can and do such events take place -- and if so with what probability?) Initial indications to both the above questions are "yes", although work is required to further evaluate these issues. Additionally, inertia effects and "near failure dynamics" are recognized as of importance in assessing the realism of static RSR analyses.

Similar questions about static pushover analyses arise in the re-qualification of structures under earthquake loading -- with additional uncertainties in the area of load distribution (i.e., are inertia loads likely to follow the same pattern as in pushover analyses?). Also, what is the "definition" of ultimate

capacity under earthquakes?

In the situation of re-qualification of damaged structures, group members felt there to be insufficient information to fully characterize the remaining strength of damaged members. This was felt particularly difficult to assess in a risk/reliability mode due to the increased variance (uncertainty) which may be introduced — partly associated with material property changes due to the damage event (e.g., embrittlement). However, it was fully realized that advanced analysis approaches (e.g., non-linear finite element) are becoming widely available to assist here on a case-by-case basis — certainly in a deterministic mode.

Another issue over which the group felt uncertain is the probability of failure which can be accepted over the remaining life of a structure — given, for instance, that the structure has operated for 20 years and another 5 years duty is required. Current views in other public safety areas indicate the same annual probability of failure should be accepted as in the structures' history — providing consequences of failure are similar in the future period of duty. In other words, the future period of operation is irrelevant.

Finally, it was generally recognized in the offshore environment that a proper characterization of the loading and loading uncertainties for the remaining period of duty is critical for rational decision making in a re-qualification exercise. This should not necessarily reflect simply the design assumptions but should include all latest information, e.g., new hindcast wave data methods for accounting for joint probability, latest wave kinematics and fluid loading models. In other words the engineers' best knowledge and information at the time of reassessment is required.

4.2 Optimal inspection, maintenance and repair

To some extent this is part of the above issue — a reassessment exercise should also include, where appropriate, a re-statement of future inspection strategies and frequencies to help assure the required reliability.

In addition to this, however, group members recognize the wider dimension of utilizing probabilistic tools at the design stage to define optimal lifetime inspection plans.

Firstly, it was recognized widely that a key issue in any risk/reliability approach to the problem is characterizing the probability of detection of defects — given a particular inspection device/operator combination. A further issue is the probability of sizing defects correctly — where this is important in reassessment. Broadly, this issue requires more data — in the operating conditions and environment(s) of relevance — a major challenge!

In relation to the important probabilistic methods and tools for inspection planning recently developed in Norway, it was felt that various assumptions are present (e.g., initial flaw sizes for fatigue cracking) that may or may not be relevant in a given situation. Further, the methods seem to require considerable analysis to provide input data, for instance, one or more structure-wide fatigue analysis. Clearly, also, a consequence analysis of a member's importance in the

total system should form part of the decision making process and group members were not fully informed as to the degree to which this issue is included in the various current approaches for assessing component target reliability levels. Fuller awareness of all aspects of these recent tools is required to identify the problems more clearly and work required to develop fully integrated methodologies.

Finally, the group recognized that inspection planning for many structures is not driven only by the likelihood of fatigue cracking. Routine inspections for marine growth fouling, dropped-object damage and other potential scenarios, e.g., foundation mudslides are variously contemplated. Integration of these issues into any optimal inspection strategy was recognized as a difficult issue.

4.3 Risk management of novel and/or high consequence systems

It was generally recognized that for new types of structural systems (bearing little similarity to existing experiences) it is of great importance to develop appropriate physical understanding of their behavior -- either via advanced engineering analysis approaches or appropriate experiments/tests. In many cases, this level of engineering insight is not yet available and tends to limit the application/development of probabilistic risk approaches.

Nevertheless, some degree of modelling uncertainty will always be present and must be formally included in a probabilistic reliability analysis. If the models available for novel/high consequence systems are less complete than for more conventional types, then there will be greater "uncertainty" in the end answer. This must be properly displayed in the total probability of failure forming the final answer and to some extent quantifies the "price of novelty". The main problem in this area is that the mechanisms for doing these uncertainty analyses are not widely agreed upon, and current approaches (e.g., via empirical bias/knockdown factors or subjective probabilities) are heavily laced with expert judgment.

Furthermore, the level of thinking on "target reliability levels" for structures is not yet advanced enough to cater for the "composite" type of probability discussed above while, at the same time, responding to socio-political perceptions of acceptable safety levels -- which are generally based on relative frequency measures of probability.

Further problem areas related to reliability of novel/high consequence structures concern the difficulties of applying standard design codes which are backed up with experience on conventional types. In an unusual structure, robustness under the loss of one or more members may be much lower (especially if it is of the slimline/low cost type) and post-failure system ductility may not be present. Therefore, the "simple" safety factors present in conventional codes may be insufficient to obtain the required high level of reliability.

In situations such as that above, a conventional "engineering" design approach is to check for extreme loadings much larger than the conventional "100 year" value. This presents problems, however, in deciding on the return frequency to select (e.g., 1,000 year or 10,000 year). Also, one must decide on the precise definition of what should be regarded as a novel structure (i.e., one falling

outside current codes).

Broadly, the whole approach to designing for and assuring reliability levels in novel/high consequence structures is a very immature area. A great need exists for developing approaches which can be transferred unambiguously to potential end users (either by special calculation procedures or design code recipes) and for coming to a common understanding of which questions to ask for this type of system.

4.4 Design: reliability-based design, design norms and life-cycle optimization

Current reliability-based (split-factor) design codes are most widely developed for fixed jacket platform (e.g., API RP2A LRFD). In the further development of such codes, a strong need exists however to standardize on the calculation approaches (paradigms) existing in different countries. Examples quoted by group members included the way tubular joints are handled and the various probabilities calculation methods (e.g., FORM and SORM) utilized.

Factors affecting "portability" of such codes to other areas include the lack of explicit system effects and the fact that the main existing version (API LRFD) has been calibrated to Gulf of Mexico data. Re-calibration of such a code to, e.g., the North Sea or the Mediterranean, would require considerable work and/or extra data for these areas. Also, another available code (the Canadian one) has had no structures designed under it yet.

Additionally, there seems to be little information on split factors for use with foundations under varying soil conditions. This is an area where major attention is needed together with the development of appropriate models and data.

In terms of reliability-based codes for other structural types (e.g., Jackups, TLPs) these are beginning to emerge (e.g., API RP2T for TLPs) but are hardly useable yet due to lack of calibration. The whole issue of calibration of new split factor codes in the absence of relevant historical data is therefore of major concern if progress of this technology is required. Generating the right funding levels to do this is also a major hurdle, with a small effort on jackup split factor design (as a follow-up to a larger Joint Industry Project in the UK) being a recent example of the limited exposure the topic is receiving. Overall, final versions of such codes for structures other than jackets are likely to include higher uncertainties and therefore put greater demands on obtaining agreed methods for analyzing such uncertainties.

As a special topic, the issue of ice forces in the Arctic was considered by the group in terms of developing design norms and/or probability-based design codes. It was realized that these forces by their very nature are uncertain and demand probabilistic treatment (similar to waves) but developing models and the required data for probabilistic treatment represents a formidable task.

In terms of design norms and special problems, the general issue of selecting the correct air gap for various structural types was seen to be amenable to probabilistic treatment. It was realized, however, that once the deck is inundated with water, a radical change in the physical loading mechanism takes place which must be very carefully handled in a probabilistic analysis.

Alternatively, the objective of design must be to avoid deck inundation with a specified (high) probability.

Finally, the topic of life-cycle design optimization was seen to be a very challenging goal demanding a great deal of (normally unavailable) information -- for example on service life/topside loads -- to perform rigorously in the early stages. However, practical steps forward to develop specific probabilistic methods, e.g., to limit the downside risk if extended use/duty were required later, were seen in general to be more feasible objectives. This is strongly linked also with one of the other high leverage areas considered by the group, i.e., optimal lifetime inspection and repair planning.

5. Research Needs

Following discussion of overall problem areas, as outlined above, specific attention was given to those items requiring research and development effort to help in their resolution, and to the definitions of the R & D required.

Firstly, a number of R & D items largely common to the four areas were identified. These are listed first. Secondly, specific items related to the individual areas emerged and are listed under separate headings.

Overall, the group considered R & D having a "first order" impact on the ability to assess system risk/reliability should be given high priority -- together with those items brought into focus by the wish/need to undertake such analysis. Thus, for example, some key physical modelling and analysis are included -- but "refinements" to existing principles are not.

5.1 Common R & D items

- Establishing agreed methods for performing system reliability analysis of complex or novel structural systems types, including foundations.
- Acceptable methods of describing/analyzing the joint occurrence of environmental variables and load in a probabilistic domain to form input to system risk/reliability analysis. This effort should include the uncertainties induced by limited data.
- Development of agreed procedures for catering for model uncertainty in system reliability analysis together with the fundamental analysis/experimental data, etc., which underpins the characteristics of model uncertainty.
- Development of general philosophies for setting performance goals and acceptance criteria to be utilized with risk/reliability analysis.
- Development of suitable methods for transferring reliability analysis methods to end users -- and agreed "paradigms" for performing analyses.

5.2 Jacket reassessment/re-qualification

- Establishment of agreed performance goals or acceptability criteria when reassessing jackets from a risk/reliability viewpoint (e.g., reserve strength ratios, robustness, consequences, ductility).
- Techniques for realistically assessing material parameter characteristics in an existing jacket (e.g., toughness, yield) for probabilistic analysis.
- Assessment and probabilistic modelling of damaged member strength and properties.
- Modelling of the potential occurrence of several, sequential near failure loads (in the same storm or subsequent storms) and the resultant high stress/low cycle degradation of the jacket.
- Assessment of inertia and near failure dynamics effects and adjustments to static RSR values required.
- Evaluation of repair techniques and their probabilistic properties for reliability analysis and decision making.
- Agreed approaches for analysis and definition of ultimate capacity of structures under earthquake loading.
- Efficient and reliable methods for performing static pushover RSR analysis including importance of multiple failure modes.
- Collating and summarizing relevant platform databases for use in the public domain, e.g., damage occurrences, typical as-built defects and inspection results.
- Establishing and calibrating models to account for wave-in-deck loads.
- Realistic characterization of environmental loading uncertainties -- due both to natural variability and uncertainties due to imperfect models -- during the remaining life of a structure.

5.3 Optimal inspection, maintenance and repair

- Research to quantify the probability of detection and sizing of defects correctly for various operator/tool combinations (i.e., both human error and inspection tool reliability are of importance)
- Development of system-level probabilistic inspection planning tools which link component reliability with the importance/criticality of the component in the overall system, as part of a system reliability analysis.
- Generation and probabilistic descriptions of appropriate crack

propagation data for modelling fatigue of complex components, e.g., multiplanar/overlapping joints.

- Agreed methods and data for accounting for fabrication defects and internal cracks (e.g., in cast/stiffened joints).
- General approaches and philosophies for foundation condition assessment and inspection.
- Linking of probabilistic inspection planning tools with jacket reassessment approaches.

5.4 Risk management of novel and/or high consequence systems

- Research to study and establish relevant failure modes.
- Probabilistic system reliability tools to investigate the sensitivity of overall reliability to modes which are overlooked.
- Reliability assessment of human error effects during design and influence of accidental load effects.
- Incorporating uncertainties in analytical tools/models in system reliability analyses.
- Establishing target risk levels for high consequence structures and procedures for assessing them, taking into account modelling uncertainties and damage tolerance measures.
- Assessment of installation risk.
- Establishing a rationale for deciding on the environmental design criteria for checking the structure (e.g., 100 year, 1000 year or 10,000 year) and use of conventional design codes/factors.
- Use of measured data during operations to update/tune reliability/risk models.
- Proper modelling of combinations of load effects.

5.5 Design

- Reflection of Type II (modelling) uncertainties in probability-based design codes.
- Development of a reliability-based design code format for compliant/dynamic platforms
- Combination of environmental events for design of compliant/dynamic platforms.
- Consequence and system redundancy/robustness factors in probability-

based design codes.

- Split-factor code design approaches for foundation systems and for seismic loadings.
- Probabilistic modelling of ice forces for reliability-based Arctic design.
- Probabilistic design approaches to limit "downside risk" in the event of later operational decisions to extend platform duty/use.
- Development of commonly agreed procedures/paradigms for developing probability-based design codes.

6. Opportunities for Implementation

By their original selection, the four topic areas selected above are both opportunities and needs for near-term implementation. More pointedly, the working group concluded that the first-generation reliability tools and relevant physical/ probabilistic models exist — or are relatively high on the development curve — to conduct risk assessments of (1) jackets under reassessments, (2) novel or high consequence systems, and (3) direct reliability-based design. In fact, the industry has some experience in all these topics; impediments to broader use include lack of firm guidance in use of risk analysis results, narrow dissemination of expertise and tools, and in some cases, management/regulator resistance.

Optimized inspection is in use at the member level (with limited member importance considerations), and apparently the techniques will be extended to full system level in the near future. The direct benefits have already been demonstrated at the member level.

In all cases, the implementation will be accelerated with the reduction of the impediments mentioned above and with further research, development, and "institutionalization" (in the form of broadly agreed procedures) of analyses of systems effects, joint environmental phenomena, Type II uncertainty in loads and behavior, and reliability performance goals.

WORKING GROUP #3

STRUCTURES: RISK AND RELIABILITY ISSUES

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REPORT OF WORKING GROUP #4

PRODUCTION FACILITIES

J. Frank Davis
and
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1. Introduction

This paper presents the conclusions of the Working Group on Production Facilities at the International Workshop on Reliability of Offshore Operations, March 1991. The paper reflects the general consensus of the Working Group, and does not necessarily reflect the opinions of all the Group members. The paper is structured after the nine theme questions established by the two co-chairmen (J. Frank Davis and Magne Torhaug) for the workshop:

- a. Do we need to adopt more formal risk assessment technologies?
- b. Do we need to prepare a safety case similar to that proposed for the U.K. offshore activities?
- c. What techniques should be used to identify hazards?
- d. What tools are suited and necessary for consequence analyses?
- e. Should frequencies be calculated?
- f. What risk assessment criteria should be used?
- g. Should regulations, including risk acceptance criteria, be prescriptive or performance (objective) oriented?
- h. What additional resources are needed to enhance process safety of offshore production facilities?
- i. How should mitigating measures be implemented?

The Working Group did not get adequate time to discuss question i), and this is therefore not covered in the following.

The Working Group had the benefit of prepared presentations from

- Roy McKay of Arco, who presented Arco practice for installations in the Gulf of Mexico and the U.K.,
- Jim Galloway of Exxon Production Research Company, who presented

Exxon practice for platforms in Australia,

- Harvey Schultz of Mobil, who presented Mobil practice for installations offshore Nigeria,
- Ken Arnold of Paragon Engineering, who presented points of view as seen from a small Gulf of Mexico operator,
- James Breaux of Shell Oil, who presented the Shell Oil practice for Gulf of Mexico installations,
- Magne Torhaug of Det norske Veritas, who presented a Working Group theme paper as an introduction to the workshop.

It is noted that the focus of this paper is on risk analysis. This is in accordance with the defined purpose of the workshop. The title reference to reliability analysis could therefore be misleading.

In the following, each theme question will be discussed. Many of the theme questions are complex, and could alone be subjects for entire workshops. The purpose of the workshop, as well as the paper can not be in depth discussion of each topic, but rather to generate overview and a basis for further work in various forums/organizations.

2. Do We Need To Adopt More Formal Risk Assessment Technologies for Offshore Production Facilities Design and Operation?

Is there "hard" data to support an affirmative answer to this question?

Risk assessments are widely applied today in the offshore industries of Denmark, Norway and the U.K. In Canada, there will also be formal risk assessments of all offshore production facilities. Basis for this development has been regulations by national authorities. There are requirements for Quantified Risk Assessments (QRA) in all four countries.

From the Working Group discussion, it is evident that several oil companies are now applying risk analyses of various forms in many of their operations around the world, also where this is not required by authorities.

Thus, it was concluded that both authorities and oil companies must have found the application of formal risk assessments useful.

The Working Group also concluded:

- The extent of the risk assessment and the methods used should be tailored to the facility and the situation in question. Simplified assessments are adequate in cases where great detail and/or accuracy is not needed. It was also pointed out that the practice of risk analyses of offshore installations had been established in areas where the platforms are on average much larger and more complex than in the Gulf of Mexico and many

other parts of the world. The term "risk assessment" is here used in a wide meaning of the word, and it may mean both a full quantitative risk analysis as well as a qualitative assessment.

- The risk assessments may in some cases be qualitative and still provide adequate information.
 - There may be no needs for risk assessments for some facilities, typically
 - facilities which are sufficiently similar so that industry developed generic risk assessments are adequate.
 - small and simple platforms.
 - The risk assessments should consider the entire field, not only the facilities of the platforms.
3. Do We Need a Safety Case Similar to that Used by the Downstream Refineries and Plants in Europe and Proposed by Lord Cullen for the British Offshore Industry?

The Safety Case, as proposed for U.K. offshore industry by Lord Cullen, combines the Safety Management System with "technical risk control." In short, the Safety Case demonstrates that:

- The Safety Management System (SMS) of the company and the installation(s) in question are adequate for design and operation.
- The potential major hazards have been identified and appropriate controls provided.
- There are adequate provisions in cases of major emergencies for:
 - Temporary safe refuge,
 - Safe and full evacuation, escape and rescue.

The Safety Case is updated regularly (every 3 - 5 years).

Thus, the Safety Case is a document showing the adequacy of the Safety Management System (SMS) and the technical measures to control risks.

Risk assessments will not be useful unless the results are implemented. This is not restricted to implementing the design recommendations of the risk assessment. In addition, it is desirable to follow up assumptions made in the risk assessment, to reassess the risk if operating conditions and/or design are altered, and to follow up that actual performance of the facility is at least as good as assumed in the risk assessment.

The SMS is obviously a part of a company's QA system. In many companies and

countries, the SMS should therefore comply with given standards (e.g. for the EEC, ISO Standard 9000) and be subjected to regular audits. An additional safety case documentation may therefore be unnecessary in some cases.

The compliance of a SMS system with modern QA standards may also affect the answers to some of the other Theme Questions. Can such compliance be achieved without

- Objective oriented risk criteria? (How do we otherwise specify risk/safety to be achieved?)
- Systematic use of risk assessment? (How do we otherwise measure compliance with the criteria?)
- Systematic experience retention, e.g. on failures and accidents?
- Systematic updating of the risk assessment?

The Working Group concluded:

- There are needs for Safety Management Systems.
 - API RP 750 provides adequate recommendations for such management systems.
 - Preparation of a safety case exactly as proposed by in the Cullen Report is not deemed generally necessary.
4. **What Techniques Should be Used to Identify Hazards in Offshore Production Facilities?**

Hazard identification is the first step of the risk assessment work process. Oversights in this step will lead to omissions of hazards. This step is therefore the most important part of the risk assessment.

No technique for hazard identification can substitute experience in risk assessment, other safety work, and design and operation of the type of facility considered. This indicates that the hazard identification will have to be conducted jointly by several people representing diverse experience, e.g., design, operations, maintenance, etc.

Another important aspect of hazard identification (which is unrelated to the technique) is proper definitions and subdivisions of the facilities and activities being studied. No hazard should be omitted because a part of a system was not considered, and no hazard should be counted twice.

Typical techniques for hazard identification are:

- HAZOP's (the most commonly used technique).
- Use of checklists.

- Failure mode and effects analysis.
- Search for possible unwanted energy releases.

None of these techniques guarantee identification of all relevant hazards.

The guide word-based techniques (HAZOP and use of checklists) have the advantage that it is easier to bring designers, operations and other non-risk analysts into the hazard identification. The disadvantage with these techniques is that they are developed/fitted to specific types of facilities. Radically new applications may require development of additional/new guide words. If this is not realized, omissions may occur.

The Working Group concluded that it would be possible to develop special checklists for hazard identification for most offshore production facilities. This is due to the similarities (or at least a limited range of variations) found with most offshore facilities. This checklist could be supplemented with other techniques as needed.

5. What Tools Are Best Suited to Perform Consequence Analyses?

The consequence analyses may be subdivided into four groups:

- a. The development of accident scenarios, e.g. by event trees or cause-consequence diagrams. These techniques are fairly simple, well-defined and seem to be adequate for typical analyses of offshore facilities.
- b. Calculation of the physical effects of accidents. A large number of techniques and a wide range of technical expertise is required to cover all aspects of a complete set of platform (or even a topside) consequence analyses.
- c. Reliability/availability analyses of devices and systems. There are a few well-defined techniques including: Direct failure statistics for some equipment, fault tree analysis, or reliability block diagrams.
- d. Analysis of variance. Due to the large number of variables involved and due to the complicated dependencies in the various parts of a full consequence analysis model, such calculations are complicated.

As is seen, these types of analyses include a wide variety of expertise. Many structural analyses require finite element capabilities, which are also used for accurate assessments of gas spreading inside rooms. It is therefore doubtful that the risk analyst alone should decide on what tools/techniques are to be used. What could be discussed, however, are:

- The use of standardized values for parameters included in the various analyses.
- What factors should be included in the various types of calculations?

The Working Group commented that there are many inadequate modeling tools in use. In particular this pertains to software. The Group especially discussed gas dispersion tools. There are needs for some sort of qualification system for the tools which are distributed commercially to assist users in their selection when new tools are purchased.

The Working Group concluded that a common data base for reliability assessments would be beneficial. The data base should cover selected equipment which is common for most platforms and which is vital for safety. Also, there are needs for better data on the reliability of human interventions and reactions in accidental or other critical situations.

The question of variance was not discussed in detail.

6. Should Frequencies of Incidents be Part of a Risk Assessment or a Safety Case?

There is hardly any risk assessment without some form of assessments of accident frequencies. Such assessments are made, e.g. to exclude from further evaluation hazards due to low risks. These assessments may or may not be explicit, i.e. certain accidents have such a low probability that their exclusion can be considered trivial, e.g. meteorite hits.

Accident frequency adds one important dimension to the risk picture. Decisions without this dimension will, in many cases, be very difficult, e.g. the possible maximum consequences of a process area release and fire may be similar for two platform concepts, but the probability of the maximum consequences may be different.

Still, there are problems connected to expression of frequencies or probabilities; the concept of an annual frequency of 10^{-4} , or once every 10,000 years, tends to confuse. How can one trust such an estimate when the total number of platform years in the world is less than 10,000? The answer is of course that this frequency is for a combination of several events, each event with a frequency based on observations from actual operations. There is, however, a threshold frequency level below which one should consider that it is impossible to maintain a complete overview of all possible accidents.

The Working Group concluded that the extent to which a risk analysis needs be quantitative will depend on the purpose of the analysis. If the risks connected to the various decision alternatives can be adequately described without assessing accident probabilities in detail, the analysis need not be quantified further. The Working Group was not necessarily in full agreement on what this means in practice, i.e. the interpretation of what constitutes adequately described risks may vary.

7. What Types of Risk Acceptance Criteria Should be Used?

It is assumed that risk assessment is used as a tool to provide information to decision makers about the risk associated with different decision alternatives,

or one particular design/set of activities. What should be their criteria for acceptance? Some observations should be repeated at this stage:

- Society has no consistent view of what risk levels are acceptable. The risk levels tolerated in society (for risk to life) vary over wide ranges - factors of 10,000 can be observed. Perceived risk is often determined more by public (and political) reactions to risk than real risk.
- The maximum risk levels tolerated for voluntary risks are generally much higher than for non-voluntary risks.

Still, there are limits as to what a company (and society) can spend on safety. Therefore there are needs for risk acceptance criteria to provide the basis for a rational distribution of resources for reduction of risk. There are major decisions in, e.g. all field development projects, with significant impacts on risk. In these decisions, there is, explicitly or implicitly, always a decision to tolerate a certain risk level. To which extent shall there be specific criteria for the decision maker?

There are examples of risk acceptance criteria defined by authorities. In the offshore industry, the Norwegian Petroleum Directorate (NPD) until 1990 used to specify maximum allowable probability for failure of defined platform safety functions. The functions were:

- Integrity of the main support structure of the platform
- Integrity of escape routes at the platform (at least one from each area)
- Integrity of the shelter area (i.e. the area where crew will shelter before evacuation)

The integrity should be maintained for periods adequate to undertake safe escape and evacuation of the platform. The maximum probability for failure of any safety function within the given time period should be less than 10^{-4} per year for any type of accident (nine types of accidents were specified). NPD does not specify the maximum allowable risk, but requires the operator to provide such a specification.

The Cullen Report specifies similar requirements, and specifies that "the acceptance standards for risk and endurance time should be set before submission of the Safety Case". As far as we have been informed, the U.K. authorities will themselves specify these acceptance standards.

The Canadian regulations are similar to the new Norwegian ones, i.e. the operator is required to specify his acceptance criteria.

There are examples of more demanding risk acceptance criteria in certain parts of California, where frequency-consequence diagrams are used.

Examples show that the formulation of risk acceptance criteria can pose problems. The criteria should be:

- Realistic, i.e. achievable, in reality this means reflecting the currently achieved risk levels,
- Challenging, i.e. secure improvements when needed,
- It is also desirable that the criteria secure optimal utilization of all kinds of technologies and measures.

The Working Group concluded that acceptance criteria should preferably be qualitative. However, in cases where Quantified Risk analyses had to be used, the criteria should be in the form of maximum allowable probability for loss of specified safety functions.

8. Should Regulations, including Risk Acceptance Criteria, be Prescriptive or Performance Oriented?

One of the recommendations in the Cullen Report is that "The principal regulations in regard to offshore safety should take the form of requiring that stated objectives are to be met (referred to as "goal-setting regulations") rather than prescribing that detailed measures are to be taken" (Ref. 1, pp. 390 and 391).

Prescriptive regulations are today the most common. Some advantages and disadvantages are:

Advantages of prescriptive regulations:

- High degree of predictability as to what will be accepted.
- Technically easy to verify.
- Easy to understand for technically qualified personnel.
- Mostly in accordance with current practice.
- Securing a fixed basis for what is considered the principles of safe design and operation based on years of experience.

The disadvantages are:

- Normally voluminous.
- Handling of new technology is difficult.
- May be reactive in development, i.e. some changes are based on experienced accidents.
- Requires much manpower for verification and updating.

It should be noted that no offshore regulations are based solely on performance oriented regulations. Considering the volume of regulations and recommendations as well as the practice, they are all basically prescriptive, some with performance oriented regulations in addition.

An important principle included in, e.g. the rules of Det norske Veritas Classification, is the "equivalent safety principle". This opens for deviation from the prescriptive rules if it can be proven that the result provides the same level of safety, e.g., by a risk analysis.

The Working Group concluded:

- Prescriptive regulations are desirable for simple platforms in well known environments such as the Gulf of Mexico where a lot of previous history is reflected in the regulations.
- Performance oriented regulations may be desirable in situations or areas where the situation is more complex, e.g. with larger, more integrated platforms and more extreme environmental conditions.
- The "Equivalent Safety Principle" should always be included.

9. What Additional Resources are Desirable to Enhance the Process Safety of Offshore Production Facilities? Which Organization(s) Should Take the Lead in Providing the Resources?

The Working Group concluded on the following list of needs for offshore production facilities:

1. The industry should cooperate to develop:

- a) Risk Management and Design Guidelines pertaining to
 - Hazard identification,
 - Fire water and deluge systems,
 - Gas detection, fire detection,
 - Riser locations,
 - Layouts.
- b) Failure Rate Data Bases(s) on
 - Offshore production equipment, about 25 different types of equipment,
 - Human "errors".
- c) Structural Design Guidelines for accidental loading from fire or

explosion.

- d) Exchange of accident and incident data for production facilities.
 - e) Better quality databases covering a broader range of accident severity.
2. Industry and agencies should cooperate to develop and/or accept physical effects models and corresponding parameters for use in accident consequence assessments.

10. Conclusions

The Working Group concluded that the reliability of offshore production facilities may be enhanced by use of more formal risk assessment technologies. However, preparation of a safety case as proposed by Lord Cullen for use in the U.K. offshore was not deemed necessary nor justified for facilities that are installed in the open atmosphere, such as is typical for the Gulf of Mexico or other semi-tropical or tropical regions. The likelihood of damaging overpressures increases as the number of enclosed modules increases. Confinement within modules, density of obstacles and potential sources of release such as process equipment, ventilation conditions and ability to vent explosions are all factors that influence the need for formal risk assessment. In general, the benefits of risk assessments increase as the mechanical complexity of the facilities increases. The fluids handled by offshore production facilities (except for hydrogen sulfide) are not a major factor in applying formal risk assessment since crude oil and natural gas are considerably less hazardous than the fluids handled by downstream processing facilities such as refineries or chemical plants.

11. References

1. Lord Cullen (1990). The Public Inquiry into the Piper Alpha Disaster Department of Energy United Kingdom.

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PRODUCTION FACILITIES
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REPORT OF WORKING GROUP #5
PIPELINES AND SUBSEA SYSTEMS

John E. Strutt
and
P. St. Jasper Price

1. **Introduction**

This report summarizes discussions and conclusions of the Working Group on the reliability of subsea systems and submarine pipelines. The membership of the Working Group is attached. Discussion papers were prepared and distributed by the co-chairmen. These outlined the state of the practice, problem areas, data acquisition and research needs and opportunities for implementation from their respective perspectives. The scope of the discussion papers chosen by the co-chairmen responded to conclusions and initiatives recommended in the reports from the 1984 International Workshop on "Application of Risk Analysis to Offshore Oil and Gas Operations" held at the National Bureau of Standards.

2. **Scope**

The objectives set for Working Group #5 were to discuss the current practice, progress, and future directions in the fields of risk management and safety/reliability analysis of offshore oil and gas pipelines and subsea systems. The focus of the Working Group initially defined by the co-chairmen was:

- a. To discuss the current state of practice of risk and reliability analysis and assess whether the technology was at a sufficient level for the subsea industry to use it in assessments of subsea systems and pipelines.
- b. To address the question posed at the 1984 workshop on whether a code(s) of practice should be developed to support the application of these techniques in the subsea industry.
- c. To discuss research and short term actions needed to effectively implement the technology.

The initial position defined by the co-chairmen was focused primarily on the techniques for the assessment of reliability and availability of subsea systems; and on the potential needs, benefits, practicality and effectiveness of a comprehensive code of practice for planning, design, construction, operations and maintenance, monitoring and control, inspection and rehabilitation of pipelines, appurtenances and subsea systems. Diving and inspection equipment, and intervention systems required to maintain and repair subsea systems and pipelines were not included in the discussions. At an early stage of discussions within the Working Group it became evident that operations would also need to be considered and the scope was accordingly increased.

Differing practices are currently relied on to assess risks and to assess the reliability of subsea systems and submarine pipelines respectively. Hence the two areas were discussed separately in the workshop. Although there was insufficient time to cover both pipeline reliability analysis and subsea system risk analysis in the same level of detail the discussions were reasonably conclusive.

3. State of Practice

There appear to be several approaches to assess risks and reliabilities of subsea systems and submarine pipelines. For pipelines, first order component limit states methodology is often used for structural design purposes, and consistent higher order evaluation of system structural strength condition may be generally more relevant for inspection and integrity (risk) assessment of operating systems. On the other hand, a component based systems reliability/availability approach seems to be generally favored for subsea systems.

The co-chairmen reviewed the range of reliability and hazard assessment methods with potential example applications to subsea systems and to pipelines detailed in the appended discussion papers, and solicited discussion from the working group.

3.1 Subsea Systems

3.1.1 Techniques Discussed

A wide range of Risk/Reliability analysis techniques can potentially be used for the assessment of subsea systems. Several methods were discussed by the work group as follows:

(i) Failure mode and hazard identification techniques including:

- Check lists
- Failure Modes and Effects Criticality Analysis (FMECA)
- Hazard and Operability Studies (HAZOPs)

(ii) System evaluation methods including:

- Fault trees
- Event trees
- Network analysis
- Parts counts/parts stress method
- Availability modeling
- Dropped object risk assessments

3.1.2 Techniques Currently in Use

The most common techniques in use for the assessment of subsea systems are failure modes and effects analysis backed up in some instances by fault tree analysis or event tree analysis for reliability assessment.

Availability analysis is widely used for the assessment of a subsea system and for investigation of field scenarios. Computer packages such as MIRIAM and MAROS are in common use for modeling production availability.

Although reliability and availability studies are common practice, hazard analysis techniques appear not to be in widespread use for subsea systems and subsea pipelines at this time (apparently some limited hazard analysis work has been carried out by operators in Norway and the U.K.). With the introduction of new safety legislation in the U.K. the use of these techniques is likely to increase.

3.2 Pipelines

3.2.1 Techniques Discussed

The discussions for submarine pipelines were initially focused on the application of various levels of structural reliability analysis method to submarine pipeline design (a priori target safety/reliability planning); and on consistent assessment of current integrity and safety of existing systems from surveillance of actual environmental and operational loadings; and from pipe strength and integrity assessment from corrosion, defect and structural deformation and stress/strain inspection data. The discussion papers were intended to respond to the following questions posed at the 1984 Workshop:

"The primary concern of the standard-making bodies is the safety and integrity of the offshore installations and the protection of human life and the environment. If more sophisticated approaches to risk analysis can enhance the chances of achieving these goals, they should be included as part of the general formulation of the standards, codes, and practices.....An initiative to include more sophisticated or structured risk analysis in industry standards or to address them through government regulations should be evaluated against such criteria as: is it needed, is it beneficial, is it accomplishable, is it cost-effective?"

The purpose of the discussions included testing whether the answer to these questions should be positive, and whether to push reliability in a structured code formulation further toward reality.

3.2.2 Techniques Currently in Use

The participants felt that at the present time reliability design and evaluation of pipelines was not common in U.S. practice. Industry generally relied on the ANSI/ASME pipeline design standards to provide a safe and reliable pipeline. They felt that a quantitative value for pipeline reliability was not often required and any doubts about the condition of a pipeline were handled by internal and external inspection. Questions on how to specify and assess data from inspection

equipment were not resolved.

4. Problem Areas and Future Directions

4.1 Subsea Systems Hardware

Two principal items: namely, data deficiencies and modeling deficiencies stimulated dialogue. The discussion on data deficiencies covered data collection studies and reliability prediction studies. The discussions on modeling deficiencies were not fruitful owing to insufficient time.

4.1.1 Reliability Data Collection

The discussion centered on the need for a data base to support reliability and availability studies. The principal need identified was for definitive failure rate data for subsea components. The discussions did not define the level of detail that would be required for the component reliability data. The group did not perceive a need for component reliability dependency information, i.e., failure causes, partly because it does not appear to be useful in current practices and was considered to be difficult to obtain. Reliability data gathering was considered to be a primary area for concentrated effort.

4.1.2 Reliability Prediction Studies

Techniques for reliability prediction used by current practices at a systems level were considered in general to be adequate to meet most industry requirements. It was considered not possible to predict the reliability of a specific component in a particular application from fundamental principles with any degree of certainty, and development of techniques for the prediction of reliability at the component level was felt to be impracticable and largely unnecessary in the context of operators needs and current practices. However, it was felt that methods of relating specific component reliability to design, QA, or manufacturing practice for novel "on-off" systems would be of use to manufacturers of components and for reliability specifications. Such techniques, if developed, could also be useful to operators in special component selection studies in which reliability comparisons of particular component types supplied by different manufacturers are required.

4.2 Pipelines

Although the existing standards have served industry well, it was felt by some that they were falling behind oil industry practices and are deficient in a number of areas:

- a. They do not explicitly deal with all potential structural and strength failure modes that a pipeline might suffer. Particular examples discussed included assessment of pipeline integrity and pressure containment of corroded and otherwise damaged systems; and assessment of upheaval buckling risks in the North Sea and Arctic.
- b. They rely on subjective stress safety indices and do not explicitly deal

with quantification of component or system reliability (i.e. real safety with consideration of damage/failure consequences) of a pipeline section or pipeline system.

- c. There is no guidance for inspection data accuracy and how inspection data should be effectively used in risk/reliability assessments for maintenance and rehabilitation decisions to upgrade specific reliability levels. (It was emphasized that assumed validity of standard design stress indices from current standards for risk/reliability assessments of existing operating systems is not generally valid for real safety analysis and could potentially lead to unnecessarily costly maintenance or derating requirements of aged, corroded and otherwise damaged systems, on the one hand; and sometimes unconservative design requirements on the other hand.)

The reasons for these deficiencies may be that techniques for the quantification of reliability and risks of existing pipelines are not well established or widely used for submarine pipelines, or for less sensitive on-land pipelines. In availability studies of subsea systems it is quite common to assume that the pipeline reliability is so high relative to the components of the subsea system that the pipeline system can be excluded from the analysis. Whether this is a reasonable assumption was not resolved.

Failure statistics on reportable incidents for on-land lines are collected to help identify the types of inspection and maintenance measures needed to reduce the failure risks and upgrade existing pipelines. The statistics seem to support the need for a more structured and rational approach both for economic and for real safety reasons. Rationalization of pipeline integrity is an issue that should be studied for all systems, whether on-land, marine or in frontier areas. Discussions in this section focused primarily on whether the industry was ready at this time to make the transition to a reliability based design code for pipelines. The group had insufficient time to resolve this issue but in the co-chairmen's view, the techniques are available and further work is appropriate to demonstrate the need for, and the approaches, the effectiveness and the usefulness of the techniques.

There was general interest in use of rational risk and reliability assessment methods for existing pipelines; and there was some support for a future code of practice to standardize and guide the industry, with the pragmatic constraint of gradual transition and development.

4.3 Subsea Operations

Operating practices and procedures related to subsea systems and pipelines were discussed briefly. In particular the need for and benefits of dropped objects risk assessments was discussed. Well established procedures are emerging for assessing the risk of dropped objects but there appears to be a difference in perceived need comparing the Gulf of Mexico and North Sea experience. A dropped objects risk assessment is more often required in the North Sea sector because of the rougher seas and the consequent difficulties of transferring and handling objects.

It appears that the main thrust for the development of a code of practice for

dropped objects risk assessment is coming from companies operating in the North Sea sector. There was a feeling that more research might be needed for developing more realistic models for trajectories and velocities of objects.

4.4 Hazard Assessment

There is a growing demand for hazard assessments to be carried out on offshore installations. The importance of this was recognized by the Workshop participants and as a result the Workshop objectives were modified to include this as an agenda item for discussion. In particular the workshop discussed whether the techniques are sufficiently advanced for industry to use them now for offshore system assessments.

HAZOP (hazard and operability studies) and HAZAN (hazard analysis) techniques were discussed in the context of a complete development systems which included subsea system, pipelines and topside facilities. There is a genuine need for these techniques not only because they could lead to cost effective designs and rational decisions for design routing, and layout of equipment and pipelines, but also because it will be mandatory soon in the U.K. sector and may well become mandatory in the Gulf of Mexico and elsewhere.

It was felt that the techniques of hazard analysis were well established in the offshore industry and in general the techniques were applicable to subsea systems and pipelines. Documented guidance such as a code of practice on the use of these techniques was seen as an important step in establishing the more widespread use of the techniques and in standardizing the approaches in the subsea industry.

5. Concluding Remarks - Opportunities for Implementation and Application

The North Sea and other European areas have experienced numerous subsea development and maintenance activities and the same trend is expected in the Gulf of Mexico. Subsea technology including maintenance and rehabilitation for consequence control and prolonged useful life is improving at a time when there are increasing requirements for safe, reliable and pollution free operations. The main points of particular interest to the workshop participants seemed to be:

- a. Reliability, availability and hazard assessment tools are vitally important for effective subsea technology implementation and application. This importance is emphasized by the need to improve the rationality of safety and integrity specifications and regulations; and the capabilities of these tools for consistent and rational balancing of tradeoffs for safety and cost effectiveness and extreme hazard or event probabilities.
- b. Tools needed to carry out reliability, availability and hazard analyses exist but there are no standards, guidelines or recommended practices to ensure a uniform consistency in their application to subsea operations.
- c. There was some support for the eventual development of a comprehensive reliability based code of practice for planning, design, construction, operations and maintenance, monitoring and control, inspection and integrity assessment and rehabilitation of submarine pipelines, appurtenances and

subsea systems but it was felt that in practice this objective could not be developed in the short term. It would be more appropriate to phase in such a code of practice gradually as experience is gained in the need, benefits, utilization and effectiveness of reliability methods; and an effective data base is developed.

- d. There was agreement on the need for a recommended practice including techniques for the application of qualitative and quantitative risk and reliability analysis to subsea systems and pipelines.
- e. The initial scope of a recommended practice identified for the short term included recommended practices, reliability and event data requirements, and recommended data sources related to subsea systems for:
 - HAZOPs
 - FMECA
 - Fault Trees
 - Availability Analysis
- f. It was felt that API in cooperation with the Mineral Management Service may be the most appropriate bodies to generate recommended practices and future codes.
- g. Current lack of a generally available reliable data base for subsea operations was considered a major obstacle to the application of quantitative reliability assessment techniques. Some data is available but it is limited in extent, and other data bases are restricted. For example, OREDA III will include some reliability data for subsea systems and EXXON have made some subsea reliability data publicly available.
- h. There was general agreement that subsea reliability data and event data is sparse and it is recommended, as a first priority, to initiate an international joint industry-government program on reliability and event data collection for subsea components, pipelines and systems.

WORKING GROUP #5
PIPELINES AND SUBSEA SYSTEMS
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REPORT OF WORKING GROUP #6

DRILLING OPERATIONS

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1. Introduction

This report summarizes the results of deliberations by the Working Group on Drilling Operations at the International Workshop on Reliability of Offshore Operations, March 1991.

Offshore oil and gas operations began in the shallow waters of the Gulf of Mexico. From this beginning in the 1950's the oil and gas industry has gradually developed the capability to explore in water depths greater than 7,000 ft. Drilling contractors now operate in the harshest environments in the world and in areas containing icebergs or covered by pack ice part of the year. For the many companies involved in these offshore operations, the reliability and safety of the systems used has been and continues to be a major challenge. Specialized groups and procedures have evolved to manage these operations.

Because of their complexity, organizations for offshore oil and gas management have historically been broken into the two main areas of drilling operations and production operations. Oil companies handle these functions at the field level by different sub-organizational groups. This division of responsibility permits more specialization of engineering and operations expertise. This report will consider primarily offshore drilling operations.

Early in the development of the offshore industry, it became apparent that economics greatly favored the use a mobile offshore drilling unit (MODU) that can move easily from one well location to the next. As industry extended the search for oil and gas to greater water depths, drilling contractors developed four distinct types of MODU's. Bottom supported MODU's were developed for exploring the relatively shallow water of the continental shelves. MODU's that can operate while floating were developed to explore the deeper waters of the continental slopes.

The bottom supported MODU's include Submersibles and Jack-ups. Submersibles can operate in water depths less than 100 ft. They are towed to a well location and then ballasted to rest on bottom. Jack-ups are currently the most common type of MODU and are available in a wide variety of sizes and shapes. Jack-ups are towed to a location and then jacked above sea level on long legs. The largest have legs 600 ft in length and are capable of operating in water depths of up to 450 ft. Another limitation besides water depth is the need for calm seas during the jacking process.

For water depths beyond 450 ft, two types of MODU's are available that can drill while floating. The semi-submersible has two hulls with vertical columns

connecting them to the main deck. The hulls are ballasted down to a draft of 60 - 80 ft for drilling operations. The large mass below sea level produces a low motion response to wave forces. The drill ship is a ship-shaped floating drilling vessel that is more easily moved long distances, but has a large motion response to wave forces and cannot operate in rough seas. In water depths less than about 1500 ft, floating drilling vessels are anchored over the well location. For greater water depths, dynamically positioned vessels are available that can be held on location during drilling operations by thrusters.

Figure 1 shows the historical MODU population since 1965 and Table 1 shows the 1990 distribution of MODU's by geographic area and by rig type. The mid 1990 total MODU count was 680. Note that the North Sea and Gulf of Mexico areas account for about half of the total. Note also that the jack-up design accounts for about two-thirds of the total population. MODU reliability is especially important in areas of harsh environment such as the North Sea that can make a safe rig evacuation much more difficult.

"Reliability" can be defined as the probability of a device or system performing its purpose adequately for a given period of time under the operating conditions encountered. For well defined systems, the overall reliability can be calculated from a knowledge of the reliability of each component. The probability of a system failure (catastrophic event) is one minus the system reliability. "Risk" can be defined as the product of the probability of failure and the consequence resulting from the failure. It is most often expressed in terms of lives lost or as a monetary loss. It is also sometimes expressed in terms of barrels of oil spilled into the environment. For well defined systems that lend themselves to classical reliability analysis methods, risks associated with alternative designs can be evaluated. Using an iterative process, the statistical relationship between system cost and reliability can be estimated.

In this report the current practices used to promote a safe and reliable offshore drilling operation are discussed. Problem areas are listed and research needs are recommended. In addition, opportunities for implementation and application of formal reliability analysis methods are presented.

2. State of Practice

Reliability analysis methods are not routinely used in drilling operation. In order to understand their potential application, let us first review the basic concepts used in this type of analysis.

2.1 Classical Reliability Analysis

The essential components of a classical reliability analysis method are shown in Figure 2. The first step in the process is to completely define the system or alternative procedures being evaluated. The second step is to identify all possible hazards and determine their causes and effects. The "hazards" are substances, situations, or events that have the potential to cause harm directly or initiate a sequence of events leading to harm. The "effects" of the hazards are determined by estimating the consequence to people, the environment, and the economic resources of the investors. The "causes" of the hazards are the

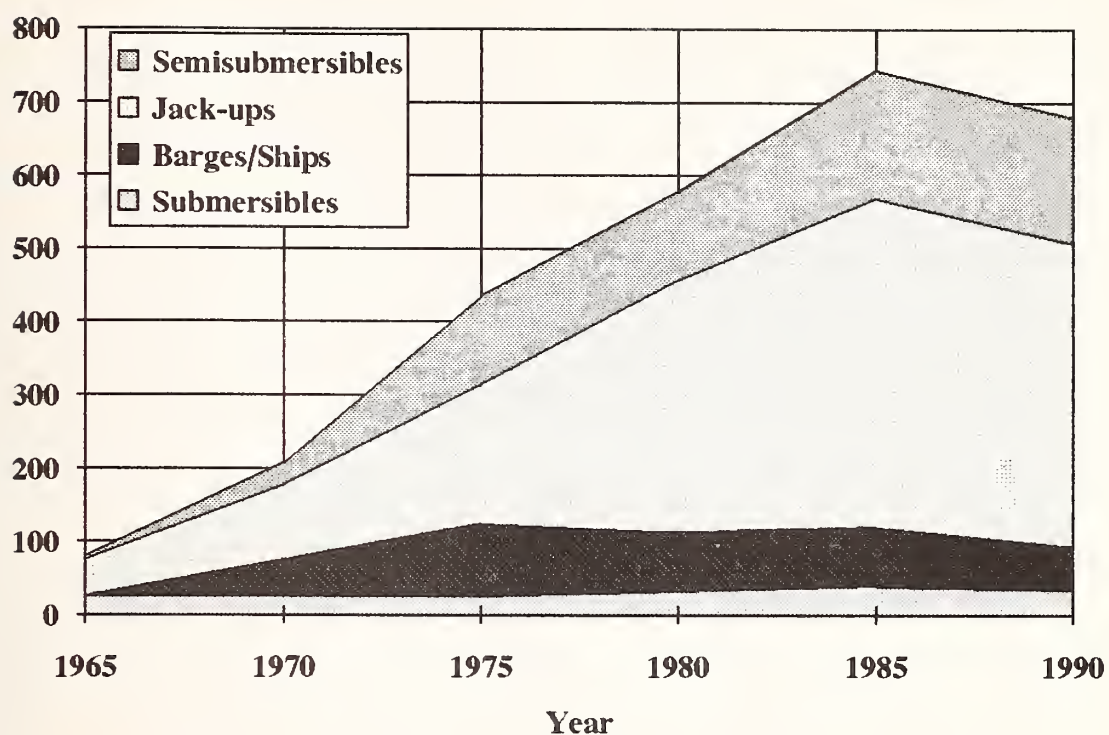


Figure 1 - Population of Mobile Offshore Drilling Units, 1965-90

TYPE	GULF OF MEXICO	NORTH SEA	ASIA	AFRICA	OTHER	TOTAL
Jack-ups	159	49	70	71	66	415
Semisubmersibles	37	60	20	10	44	171
Drillships	3	1	18	-	36	58
Submersibles	15	-	1	2	18	36
TOTAL	214	110	109	83	164	680

Table 1 - International Population of Mobile Offshore Drilling Units, 1990

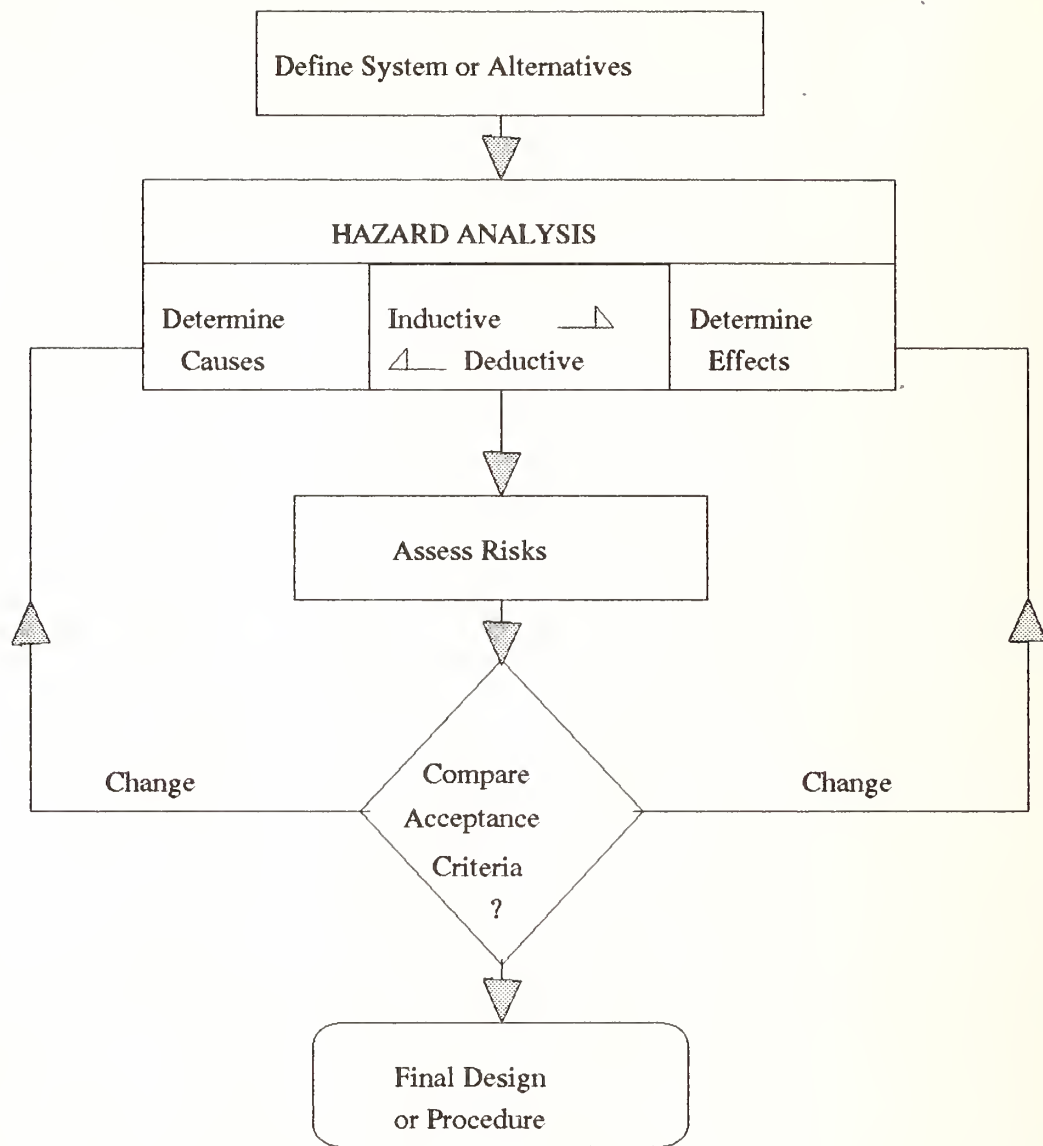


Figure 2 - Reliability Assessment Procedure

combinations of system component failures and/or operator errors leading to the undesired effects. The determination of the causes and effects can be either inductive or deductive. The inductive process starts with an assumed failure, and the possible effects are identified. The deductive process starts with an assumed effect or catastrophic event, and the possible causes are identified. The third step involves assessing the risks from all hazards. This step requires a knowledge of the probability of the various causes identified in the previous step. This information is generally sought by developing a detailed data base identifying the various possible modes of failure of each component and the observed frequency rate of each failure mode. Once the risks are assessed, it can be determined if they are acceptable. If the risks are determined to be too high, changes are made and the analysis is repeated. This is called the "iteration process" and characterizes reliability assessment methodology.

Although all reliability analysis methods are variations of the classical approach outlined in Figure 2, there are many variations that have been developed. The most common variations used for hazard identification include:

1. Preliminary or Gross Hazard Analysis,
2. Hazard and Operability Studies (HAZOP),
3. Failure Mode and Effect Analysis (FMEA), and
4. Concept Safety Evaluation (CSE).

The most common variations used for risk assessment include:

1. Event Trees,
2. Fault Trees,
3. Reliability Diagrams,
4. Markov Diagrams,
5. Monte Carlo Simulation, and
6. Common Cause Analysis.

A detailed description of these reliability analysis methods is beyond the scope of this paper. However, a brief summary description of each technique is given in Appendix A. Often the analysis of a system will involve the use of more than one technique.

In order to understand how reliability analysis methods can be applied to offshore drilling operations, it is important to understand how these operations are managed. The current management system has evolved since the start of offshore drilling in 1955.

2.2 Management of Offshore Drilling Operations

Offshore drilling operations are carried out using a very complex organization of personnel and equipment. Because of the high cost of offshore drilling, many highly specialized service companies have evolved to assist the well operator. The drilling contractor provides the MODU and its crew. The operator also contracts for secondary services such as cementing, drilling fluids, well logging, helicopters, and supply-boats. This functional sub-division of equipment, engineering, and operations personnel into highly specialized units

tends to promote a high level of efficiency and frees the operator to concentrate on the overall coordination of the drilling operations.

Although a large amount of planning takes place prior to initiating a new drilling program, the overall process always involves many poorly defined geologic variables and requires frequent decisions to be made while the work is in progress. The on-site operator's representative is a key person in this process. However, he is supported by many specialists and managers in his company and in the service companies assisting with the work.

The main elements of the approach used to manage offshore drilling operations are illustrated in Figure 3. Company policies play a central role in defining equipment standards and operating procedures. The policies are defined in various Procedures Guides, Safety Manuals, and Drilling Operations Manuals. These documents are based on the collective experiences of the operations personnel, engineers, and managers of the company. The process used to maintain these documents is somewhat similar to the iterative process shown in Figure 2, except that it is based on actual experience and carried out by large organizations over a long period of time. Upper management often sets goals and targets for reducing the frequency of accidents. They also offer incentive programs to help promote safety awareness among field personnel.

Company policy is based on input from many sources. When an offshore drilling operation moves into a different operating environment or involves the use of unproved technology, central research and development groups and technical support groups will undertake a very detailed system design and analysis. Technical support from many service companies is commonly part of this effort. Reliability analysis methods are most often used at this phase of the operation. In more mature operating environments, prior experience provides valuable input. Collective experiences from many sources are pooled in joint industry groups such as the American Petroleum Institute (API), the International Association of Drilling Contractors (IADC), and the Offshore Operators' Committee (OOC). API sets standards for various types of drilling equipment and publishes recommended practices. Classification societies have also been developed to provide standards for the construction and maintenance of the vessels. The first rules for MODU's were published in 1968 by the American Bureau of Shipping (ABS). Government regulations also provide minimum standards to insure acceptable policy is followed throughout the industry.

The greatest problem faced in controlling risk is not the development of safe procedures, but the consistent implementation of these procedures. Considerable effort must be continuously directed towards personnel training to insure all field personnel are kept abreast of the appropriate policy for their job functions. This is accomplished through training seminars, safety meetings, and on-the-job training. These activities also stimulate discussion among employees about hazard recognition and occasionally provide feedback to engineering and management concerning new problems or a need for procedural changes. Detailed emergency procedures are developed for every foreseeable situation that might arise while implementing the well plan. Examples include well control procedures, diverter procedures, emergency evacuation plans, and special procedures for simultaneous drilling and production operations. Drills are conducted on a regular basis to insure that rig personnel have learned and remember the critical

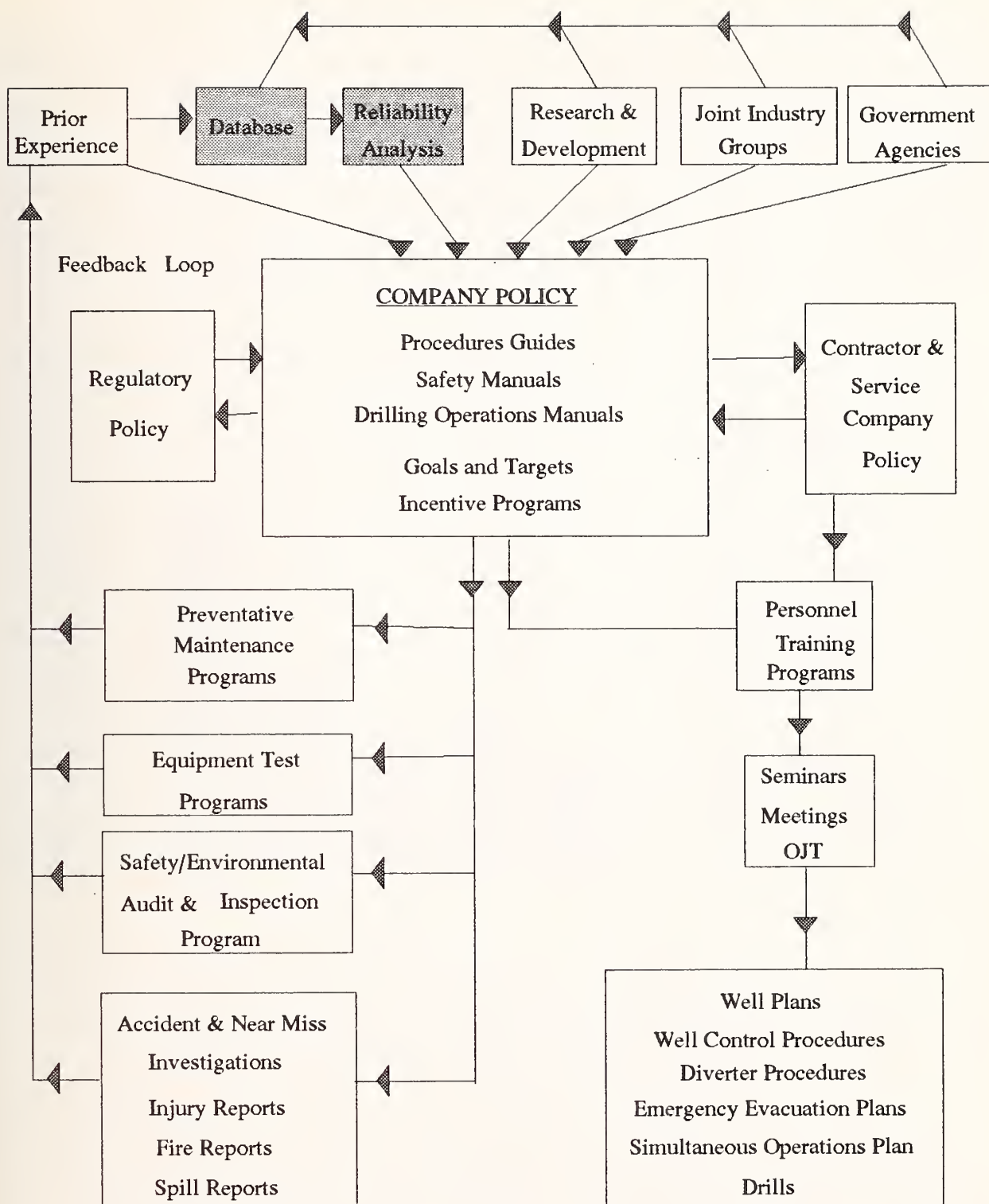


Figure 3 - Management of Risk in Offshore Drilling Operations

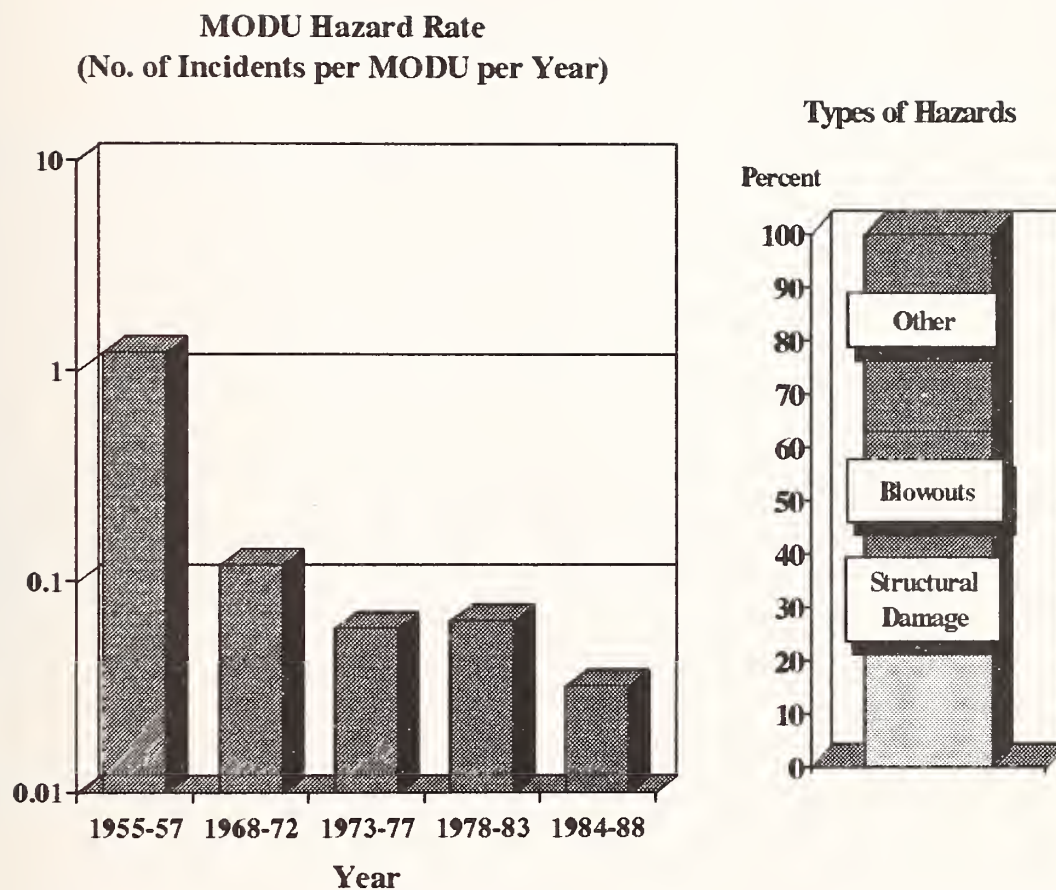
safety procedures.

Company policy of drilling contractors provides for comprehensive preventative maintenance (PM) programs on rig equipment. Large rig contractors maintain a data base of MODU equipment components and their failure rates to assist in scheduling preventative maintenance. Regular schedules for testing of safety system components are also followed. In many areas, government regulations specify a minimum test frequency for well control equipment. Records from the PM and Test programs can provide valuable input to the database needed for reliability studies of critical well systems. Overall rig reliability is high with most contractors reporting rig shut-downs for equipment repair of 1 to 3 percent of the contract time.

Many companies now have special groups concerned only with safety and environmental protection. These groups often conduct field inspection programs to insure that all systems are up to standards. Comprehensive check lists are followed when a field audit is made by such a group. In many areas, regulatory authorities also conduct periodic inspections. Different government agencies are concerned with different aspects of the operation and each may have their own inspection program. The MODU is inspected periodically for marine safety by its flag state to maintain its registration. International conventions have been developed by the International Maritime Organization to set minimum safety standards for maritime vessels. Two conventions that apply to MODU's are "Safety of Life at Sea" (SOLAS) and the "Load Line Convention." Individual countries may supplement these requirements. Some countries require a certificate issued by one of the Classification Societies before a vessel can operate in their jurisdiction. Inspection results can also provide input to the managers deciding company policy.

When problems occur, the companies involved conduct a study of the causes to determine if any changes could be made to prevent similar occurrences in the future. Accident Reports, Near Miss Reports, Injury Reports, Spill Reports, and Fire Reports are all common report types used to communicate problems throughout the company's organization. In most countries, a Regulatory Notification Program must also be followed. Serious accidents are also investigated by government regulatory agencies.

The importance of past experience in the current management approach is illustrated in Figure 4, which shows the MODU hazard rate history. The "hazard rate" is based on the frequency of accidents that were severe enough to cause the rig to have to be repaired before it could resume operations. Note that the hazard rate has decreased dramatically from 1.2 incidents per MODU per year just after offshore drilling began (1955-57) to 0.03 incidents per MODU per year during the 1984-88 period. While the most dramatic improvements were made during the first decade of activity, improvements have continued to the current time. Proponents of formal risk management methods argue that early use of these methods could have improved this learning curve. Figure 4 also shows that structural failures and blowouts were the hazards accounting for most of the accidents.



*Figure 4 - Historical Hazard Rate for Mobile Offshore Drilling Units, 1955-88
(Incidents Requiring MODU to be taken out of Service)*

2.3 Primary Hazards

The greatest hazards affecting offshore drilling operations that were identified in this study included:

1. damage to structures (weather, collisions, etc.)
2. blowouts
 - a. deep, high pressure hydrocarbons
 - b. shallow gas
3. personal injury (rig floor accidents), and
4. spills

2.3.1 Damage to Structures and Blowouts

Listed in Table 2 are the 10 worst accidents (most lives lost) suffered by the offshore oil and gas industry. Note that eight of these occurred on MODU's, although the Alexander Kielland was being used as a personnel accommodation unit (Hotel). Five of the MODU's listed were either on standby due to severe weather or under tow at the time of the accident. Only two were engaged in exploratory drilling activities at the time of the accident and they involved loss of well control (blowouts). The C. P. Baker, which was the only case listed in U.S. waters, was a shallow gas blowout. In the Gulf of Mexico, about one well in 900 experiences a shallow gas flow.

The blowout hazard rate for MODU's is shown in Figure 5 for several time periods. The blowout hazard rate decreased dramatically from about 0.15 blowouts per MODU per year during 1955-57 to about 0.006 blowouts per MODU per year during 1984-88. The slight reversal in the downward trend during 1978-83 occurred in a period of high oil prices, rapidly increasing activity and shortages of experienced manpower.

2.3.2 Personal Injury

The reported rate of personal injury for offshore drilling operations is shown in Figure 6. The rate reported in 1989 was 2.44 accidents per 200,000 hr in U. S. Waters and 0.87 accidents per 200,000 hr outside of U. S. Waters. For a 2000-hr work-year, these rates correspond to a personal injury risk of about 0.01-0.02 injuries per worker per year. It was not determined if reporting practices were consistent throughout the world. Personnel accident statistics are usually broken down into the following categories:

1. occupation or job description,
2. part of body injured,
3. accident type,
4. equipment being used,
5. operation in progress, and
6. location.

Statistics compiled by IADC show that the most commonly injured worker is the roughneck; the most common injury is to the back; the most common location is the drill floor; and accidents most commonly occur while handling drill pipe or other tubulars while tripping operations are in progress. This justifies continued

DATE	NAME	STRUCTURE TYPE	LOCATION	ACTIVITY	FATALITIES
6/6/88	Piper Alpha	Fixed (Steel)	Scottish North Sea	Production	167
3/27/80	Alexander Kielland	Semisubmersible	Norwegian North Sea	Accommodation	123
3/11/89	Seacrest	Drillship	Thailand	Stand-by (Storm)	91
2/15/82	Ocean Ranger	Semisubmersible	Newfoundland	Stand-by (Storm)	84
10/26/83	Glomar Java Sea	Drillship	China	Stand-by (Storm)	81
11/25/79	Pohai 2	Jack-up	China	Under Tow	72
8/16/84	Enchova PCE-1	Fixed (Steel)	Brazil	Development Drilling	37
6/30/64	C. P. Baker	Drillship	Louisiana	Exploratory Drilling	22
12/30/56	Qatar 1	Jack-up	Qatar	Dry Tow	20
10/2/80	Ron Tappmeyer	Jack-up	Saudi Arabia	Exploratory Drilling	19

Table 2-Ten Worst Accidents during Offshore Oil and Gas Operations, 1955-88.

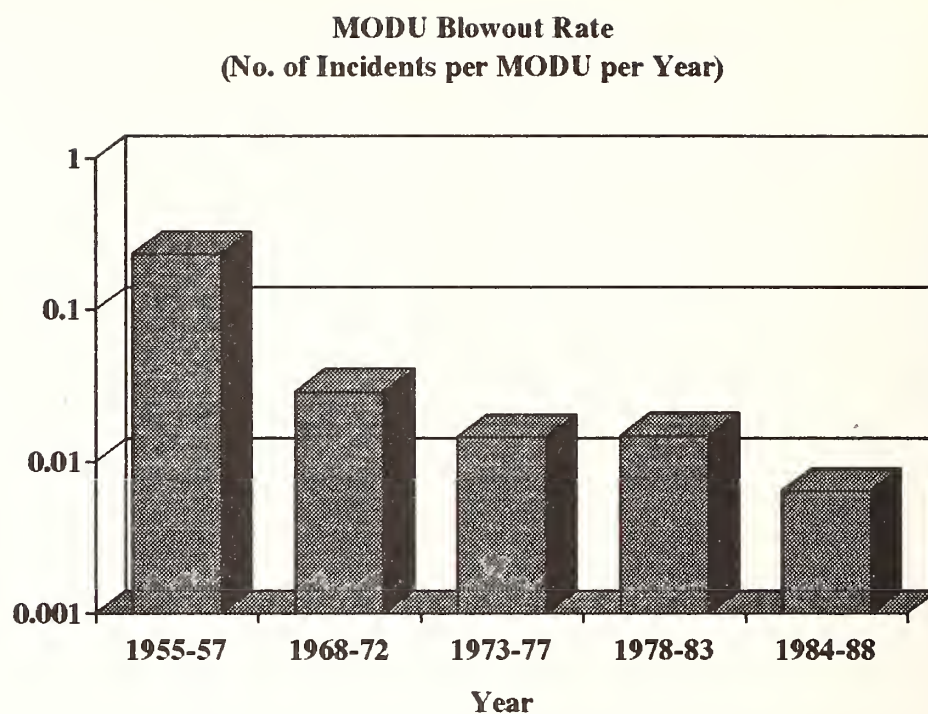


Figure 5 - Historical Blowout Rate for Mobile Offshore Drilling Units, 1955-88

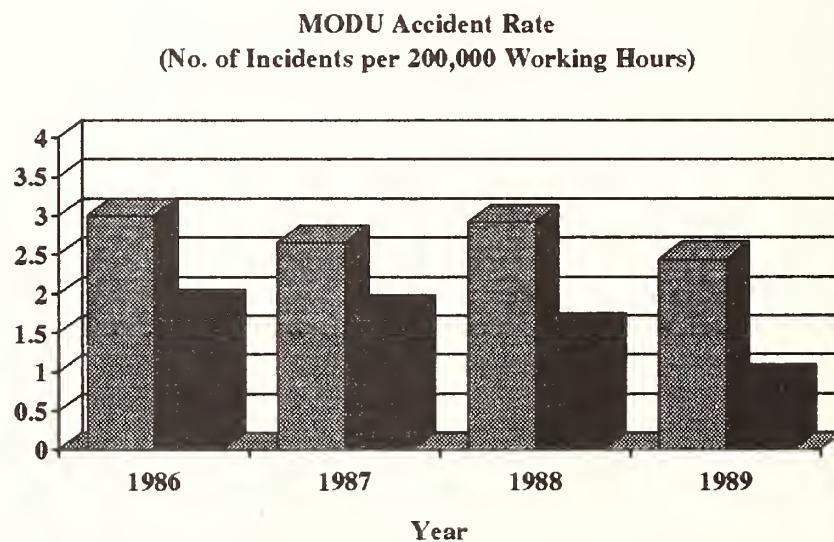


Figure 6 - Personal Injury Rate on Mobile Offshore Drilling Units (IADC Accident Statistics)

emphasis on developing more automated systems for the drill floor.

Table 3 compares the fatal accident rate (FAR) for U.K. offshore drilling operations to other industrial and non-industrial activities. The FAR for offshore drilling in the U.K. is reported to be 20 fatalities per 100 million working hours. Using the IADC database, the FAR for offshore workers worldwide is 21 fatalities per 100 million working hours. For a 2000-hr work-year, this corresponds to a risk of 0.0004 fatalities per worker per year.

2.3.3 Spills

Table 4 shows the top 13 oil spills from offshore drilling operations. All of these spills resulted from blowouts. The total oil spills associated with drilling operations worldwide while drilling 53,000 wells is approximately 6 million barrels. Assuming that one drilling unit can average about 5 wells per year yields an apparent risk of about 600 bbl per year per rig. Over 80 percent of this oil was spilled in two blowouts. One was offshore near Mexico and the other was offshore near Dubai. The apparent probability of a spill of greater than 150,000 bbl is about 0.0001 per well.

2.3.4 Overall Risk

Shown in Figure 7 is a recently published estimate (Bea, 1990) of the overall risks of various system groups as of 1984. Note that MODU's fall near the author's "marginally acceptable" line and covers the ranges of 0.1-1.0 lives per year and 0.1 to 1.0 million dollars per year. The estimated risk for MODU's was below that of merchant shipping but well above that for commercial aviation. This estimate appears to be in approximate (order of magnitude) agreement with an apparent value from recent statistics reported to the Worldwide Offshore Accident Data bank (WOAD). During the 32 month period of 1/1/88 to 8/31/90 there were 115 reported fatalities associated with 33 accidents to MODU's. For an average annual rig count of approximately 700, the apparent annual risk for this period was $115 / [(2.5)(700)]$ or 0.07 fatalities per MODU per year. During this same period, the estimated total monetary loss associated with these 33 accidents was 432 million dollars or 0.25 million dollars per year.

2.4 Current Use of Reliability Analysis

The overall drilling process does not lend itself easily to classical reliability analysis. Use of formal reliability analysis methods are generally limited to critical operations and the design of important sub-systems of the MODU. Often these sub-systems are designed and built by a service company and purchased or leased by the well operator. The operator will take a lead role in designing new systems primarily when they are needed to move into a frontier area requiring the use of unproved technology. Examples of offshore drilling sub-systems and processes that have been studied using reliability analysis procedures include:

1. escape systems,
2. shelter areas,
3. structure response to wind and waves,
4. dynamic positioning and vessel mooring systems,
5. diverter systems

INDUSTRY	FAR
Chemical Industry	3.5
Steel Industry	8
Offshore Drilling	20
Fishing	35
Coal Mining	40
Construction	67

Table 3 - Fatal Accident Rates (FAR) per 100 Million Working Hours for Industrial Activities in Great Britain.

OFFSHORE AREA	REPORTED SPILL (BBLs)	YEAR	OPERATION UNDERWAY
Mexico	3,000,000	1979	Exploratory Drilling
Dubai	2,000,000	1973	Development Drilling
Iran	480,000	1983	Production
Mexico	247,000	1986	Workover
Nigeria	200,000	1980	Development Drilling
Norway	158,000	1977	Workover
Iran	100,000	1980	Development Drilling
California	77,000	1969	Development Drilling
Saudi Arabia	60,000	1980	Exploratory Drilling
Mexico	56,000	1987	Exploratory Drilling
Louisiana	53,000	1970	Unknown
Louisiana	30,000	1970	Production
Trinidad	10,000	1973	Development Drilling

Table 4 - Large Oil Spills resulting from Offshore Oil Well Blowouts

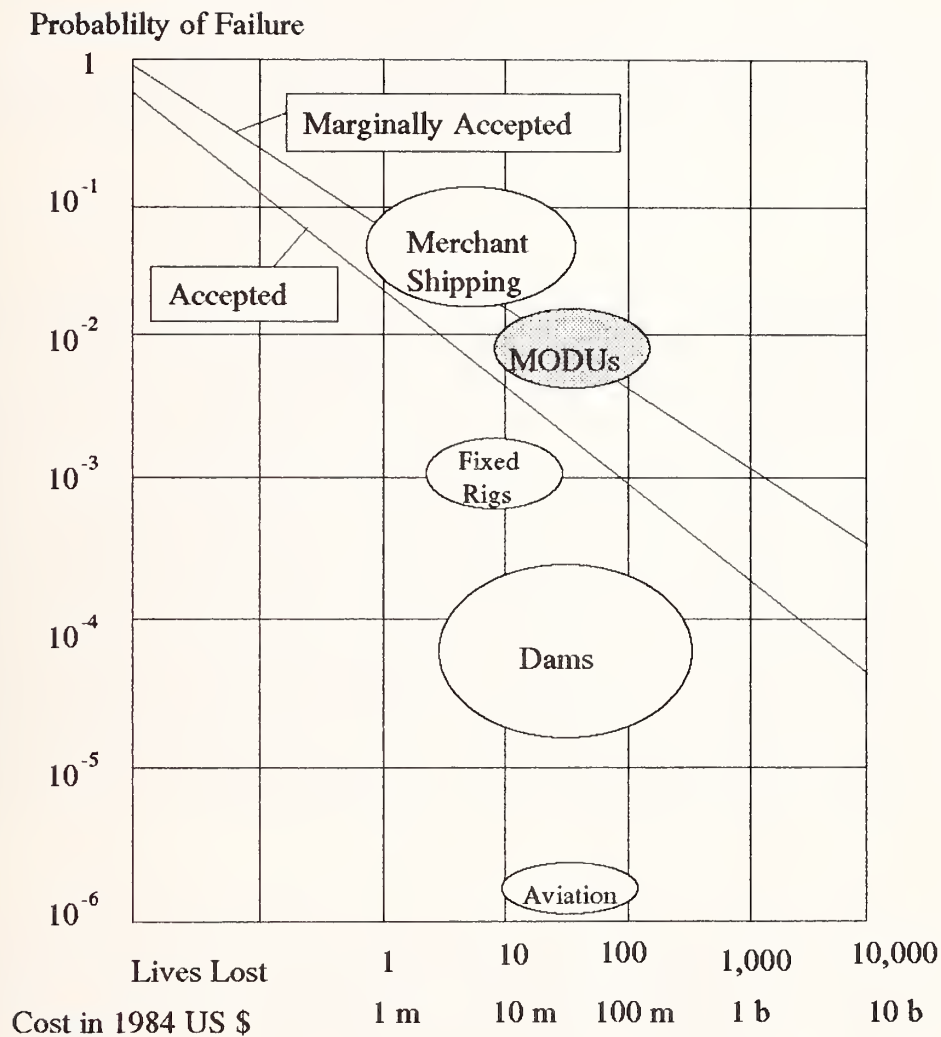


Figure 7 - Historical Relationship of Risks and Consequences for Engineered Structures (After Bea, 1990)

6. blowout preventer control systems,
7. ballast control systems,
8. pressure vessels and piping systems,
9. simultaneous drilling and production operations, and
10. surface well testing on MODU's.

Several of these types of studies have been documented in the literature. (Ritchie and Van Cleave, 1972; Ingram and Dee, 1973; Lewis and Ostebo, 1989; Moss, 1990; Lindemann and Huse, 1991; Oillier, Imrie, and Talbott; and Pietersen and Engelhard, 1991) Most of the published work has been done by consultants specializing in reliability analysis procedures.

3. Problem Areas

Formal reliability analysis methods have been and will continue to be one of the many tools for managing risks in offshore oil and gas operations. However, quantitative reliability analysis methods for offshore drilling operations are hampered by difficulties in obtaining accurate failure mode and failure rate data for the many components in a given system. It is likewise often difficult to obtain an accurate probability distribution for losses resulting from a system failure. Failure rates are often affected by the conditions under which the component was operated and by the PM program followed. The operating environment can vary from well to well and the PM program can vary from company to company. Manufacturers are continually modifying their products in attempts to improve reliability or reduce costs. Failure rates and failure modes are also influenced by human errors in the way the system is operated. The accurate modeling of human error in reliability analysis becomes increasingly difficult as the complexity of the system increases and as the amount of interaction required for system operation increases. All of these factors complicate the development of accurate reliability databases. A quantitative reliability analysis is usually possible only for relatively simple, highly automated sub-systems.

3.1 Human Error

Detailed studies conducted after every major accident invariably determine that errors in judgment were major contributors to the problems that occurred. This justifies continuing and intensifying the large effort being made in the area of personnel training. Regulatory requirements now specify minimum training requirements for most offshore drilling job descriptions. Training certification procedures vary from country to country.

3.2 Multiplicity of Regulatory Agencies

The companies, equipment, and personnel involved in offshore drilling operations are becoming increasingly mobile and international. Certification, training, and other regulatory compliance procedures are becoming difficult to learn and manage due to the growing number of agencies that may have to be dealt with in a short period of time. Some of these agencies have overlapping requirements. Internationally recognized standards and certificates are badly needed.

4. Research Needs

Four general areas were recommended to be given a high priority for additional research. These included:

1. rig automation, especially in the area of pipe handling,
2. escape and evacuation in harsh environments,
3. handling shallow gas flows (including early consideration in facility design),
4. optimum frequency of testing subsea blowout preventer equipment, and
5. safety margins in casing programs.

5. Opportunities for Implementation and Application

Current international trends show an increasing emphasis being placed on reliability analysis methods by regulatory agencies responsible for public safety issues in offshore drilling operations. The consensus of the working group was that a routine use of formal reliability analysis mandated by government regulations will probably be of minimal benefit in improving safety of routine offshore drilling operations in mature operating areas. The most promising opportunities for implementation and application of formal risk analysis continue to be in evaluating new designs and concepts. For example, all of the recommended research and development areas listed above could benefit from the use of reliability analysis methods.

As a result of the Piper Alpha Disaster, the Cullen Report (1990) was recently released. Although Piper Alpha was a production operation, some of the recommendations of this report are pertinent to offshore drilling operations. This report recommends that, " ... no mobile installation should be brought into these waters ... unless a Safety Case in respect of that installation has been submitted to and accepted by the regulatory body." A Safety Case is required to demonstrate that:

1. the safety management system of the company and the installation are adequate to insure that the design and the operation of the installation are safe,
2. that major hazards and risks have been identified and appropriate controls provided,
3. that adequate provision is made for ensuring, in the event of a major emergency, a temporary safe haven and a safe evacuation and rescue.

Safety Case and HAZOP Plans are currently being formulated for several MODU's to meet regulatory requirements. It is recommended that the differences and benefits resulting from this work as compared to existing plans and methodology be carefully studied and the results of this study published.

Many engineers involved in offshore oil and gas operations are not familiar with the various reliability analysis techniques available. Additional training opportunities in this area could make these tools available to a much larger group. The engineers involved routinely in solving the problems of the offshore

drilling industry are in a good position to see areas where these tools can be effectively applied.

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Appendix A

Preliminary or Gross Hazard Analysis - A Preliminary Hazard Analysis is usually the first step in the reliability assessment procedure. Check lists and forms are used to list all of the hazardous materials, situations, events, potential accidents, and potential human errors that can be identified. Previous experiences of similar installations are systematically incorporated into the special forms of check lists used. The last step of the procedure is to define rules, policy, and procedures that will control the hazards identified. A distinction is sometimes made between a Gross Hazard Analysis and a Preliminary

Hazard Analysis based on the arrangement of items on the forms. The preliminary analysis is inductive, starting with the possible causes and leading to the possible losses. The Gross Hazard Analysis is deductive, starting with the possible losses and proceeding to their causes. Safety manuals and MODU inspection checklists are often the product of a hazard analysis.

Hazard and Operability Studies (HAZOP) – Hazard and Operability Studies are used to identify potential types of accidents that can be traced through a series of events. Possible deviations of each physical parameter are considered to determine combinations that are potentially hazardous. Often the HAZOP approach will be undertaken by an independent safety review or audit group that has no involvement in the project development. In other cases, the HAZOP team will include the key personnel from the project group.

Failure Mode and Effect Analysis – The Failure Mode and Effect Analysis (FMEA) procedure can be used to identify how the system under consideration works and fails. A related procedure, called the Failure Mode, Effects, and Criticality Analysis (FMECA), is used to identify the weakest links in the design. These methods are inductive, starting with all of the possible failure modes of each system component and proceeding to the effects or consequences of these failure modes. The final step involves identifying corrective action for control of the hazards identified. These methods can be extremely time consuming and often are not practical for large systems with substantial redundancy. They are more useful for analyzing equipment failures than for situations involving possible human actions, which can be more difficult to forecast.

Concept Safety Evaluation – Concept Safety Evaluations have as their main objective the determination of the accidental loads that the safety functions of the escapeways, shelter areas, and support structure should be able to withstand. The accident loads are called the Design Accidental Events (DAE) and are expressed in terms of heat loads, explosion overpressures, and impact energies. The evaluation thus defines the conditions under which people outside the immediate vicinity of a fire or explosion will be able to reach the shelter area and remain safe while an orderly evacuation is taking place.

Event Trees – Event Trees are used to study identified hazards in more detail. The starting point of an event tree is the initiating event or failure that can be traced through the system. Each operation or system leads to two paths of known probability (success or failure). The failure path of each branch proceeds to the next back-up device, and composite probabilities are calculated. Failure paths are then studied in more detail using a Fault Tree.

Fault Trees – Fault Trees are similar to Event Trees except that they are deductive rather than inductive. Thus, the undesirable event is the starting point of a fault tree. The cause of the event is identified, and this is considered an event for subsequent cause evaluation. When an intermediate event is caused by several simultaneous events, they are linked by an "or" gate symbol. This process is repeated until all of the possible root causes are determined. By using Boolean algebra, it is possible to find all combinations of basic events that will lead to the top event. Single basic events that will lead to the top events are called first order failures. When two basic events are required, they are called second order failures, etc. When failure probability data are

available on each component, composite probabilities can be calculated.

Reliability Diagrams - Reliability Diagrams are used to graphically represent all possible combinations that can cause a given failure mode. Thus, they are somewhat similar to Fault Trees but are usually used in a qualitative manner. Generally each component is considered to have two states (good or failed), and each component is represented graphically as a switch (open for failed). In order to find the combination of events leading to system failure, the diagram is studied to determine the combination of open switches that will result in an open composite circuit. When a combination of open switches that will cause system failure is identified, they are called a "cut-set." When all of the open switches are necessary to cause failure, the cut-set is said to be "minimal." Similarly, a combination of closed switches that will prevent system failure is called a "tie-set," and the minimal number of closed switches to prevent failure is called the "minimal tie-set."

Markov Diagrams - Markov Analysis is a procedure that can be employed when it is necessary to define component failure as a function of time. It allows for change of state of each component with time and requires a knowledge of both failure rate and repair rate. Markov Analysis is extremely complex, practical only on a high speed computer, and, in general, only applied for limited systems with a high maintenance requirement in order to prioritize maintenance work.

Monte Carlo Simulations - The Monte Carlo simulation method is a general technique that can be applied to determine the probability of different modes of failure of a complex system. Frequency diagrams for the various possible states of each component are defined. Also, the range of possible physical values of each parameter in the system (such as pressures, flow rates, etc.) can also be defined in terms of a probability or frequency distribution. The probable state of each component and physical parameter is then simulated through the use of random number generators or tables. By running a large number of simulations on a computer (perhaps as many as 100,000), a sample of possible events is obtained that can be used statistically to determine the composite events that are most likely to occur at their corresponding probability.

Common Cause Analysis - The Common Cause Analysis method is used to correlate events. The probability of a second order failure will be greater if the two basic events required for system failure have a common cause. Also, redundancy systems cannot be depended upon if they have a common failure cause with the primary system. Common mode failures can arise on a redundancy system as a result of either poor design or improper installation. A common cause failure search is very difficult to conduct, generally requiring considerable experience and judgment.

WORKING GROUP #6
DRILLING OPERATIONS

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APPENDIX I

THEME PAPERS

OFFSHORE ACCIDENTS - LESSONS TO BE LEARNED

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ABSTRACT

Major offshore accidents receive a large amount of publicity and are instrumental in enacting new and/or revised industry standards and governmental regulations. The paper discusses major accidents that have occurred during the past two decades and the effect that these accidents have had on improving the reliability of offshore operations. The paper also discusses the importance of analyzing minor accidents that are not in the news through the use of databanks.

1. Introduction

1.1 Scope

This discussion on offshore accidents, and what has been learned from them, relates to operations involving fixed offshore platforms and facilities. Accidents involving mobile offshore drilling units are outside the scope of this paper.

1.2 Background

Until the late 1960's the integrity of the design and operational safety of offshore platforms was largely the responsibility of the owner-operators who used a variety of industry and in-house standards. Industry structural design standards were first introduced following the disastrous 1964 and 1965 Hilda and Betsy hurricanes during which 23 platforms were destroyed. These incidents received little publicity outside the industry because no lives were lost and little pollution occurred.

This was not the case, however, with two high visibility accidents that occurred in 1969 and 1970. The Dos Cuadras platform A blowout offshore California in the Santa Barbara Channel and the Bay Marchand platform B fire in the Gulf of Mexico, focused the attention of the news media, and thus the public, on the real and perceived hazards of offshore production operations.^{1,2}

The offshore industry has not been the same since. These accidents resulted in stricter regulations and a much greater involvement by governmental agencies. The indirect consequences of the Santa Barbara accident on offshore California development are being felt to this date through drilling moratoriums and missed development opportunities.

Accidents in the North Sea, both offshore Norway and the United Kingdom, created a next level of government involvement through requirements for the platform operator to perform detailed platform and risk management safety analyses.

There is thus an ongoing trend by regulatory agencies to require that the design of an offshore platform and facility be based on a reliability analysis. The Norwegian Petroleum Directorate has adopted this methodology in their regulations.³ The Cullen report, adopted in its entirety by the British government, recommends the use of Formal Safety Assessments.⁴ In the United States there is considerable hesitancy to adopt the use of reliability methods because of difficulties encountered by the nuclear power industry when it adopted the reliability analysis concept. It is recognized, however, that the method is useful for specific applications, such as an evaluation or re-evaluation of a platform operation.^{5,6}

2. Accident Databanks

For designers and regulators alike it is, therefore, of importance to know what causes offshore accidents. Determination of the causes of offshore accidents, the probability of occurrence and their potential impact requires an accurate database of offshore accidents covering a number of years.

Offshore accidents have been compiled in databanks by several organizations. The Institute Francais du Petrole database contains a listing of some 850 accidents on fixed platforms and mobile drilling units.^{7,8} The World Offshore Accident Database (WOAD) compiled by Veritec contains some 1800 accident and 4000 incident entries.^{9,10} The Offshore Reliability Data (OREDA) handbook provides statistical information on the failure rate of specific equipment items.¹¹ The Mineral Management Service database contains all reported accidents in the United States federal waters from 1965 to 1986.¹²

None of these databases are complete or even accurate and interpretation of the data requires judicious and knowledgeable analysis. The frequency of accidents may be particularly misleading because during the earlier years of data gathering minor incidents were not reported. The databanks do, however, provide a valuable tool to analyze the frequency and magnitude of potential accidents and determine an acceptable safety level.

3. Offshore Accidents

3.1 Hazards

The principal hazards that may result in a loss of, or damage to, an offshore oil and gas installation are:

- ° Platform collapse due to storms, earthquakes, foundation failure, corrosion or collision,
- ° Blowouts during well drilling or well workovers,
- ° Fires and/or explosions due to process upsets or equipment failure.

3.2 Causes

The causes for all offshore accidents can be grouped into one or more of the following categories:

- Human error,
- Inadequate maintenance,
- Underdesign of platform or facility,
- Simultaneous operations,
- Collision.

Of these, the human error factor is by far the predominant cause of accidents. The WOAD databank reports that some 70 percent of all accidents are caused by human error.¹⁰ Of course, many accidents classified as human error also belong in one of the other categories. A further breakdown of human error into categories such as, inadequate procedure, communication error, violation of procedure, etc., is recommended in the companion paper at this session dealing with data collection methods for hydrocarbon leaks.¹³

3.3 Consequences

The consequences of an offshore accident include:

- Death and/or injury to personnel,
- Loss of, or damage to, platform and facilities,
- Pollution and associated clean-up costs,
- Loss of production income,
- Loss of reserves, the capital assets of the owner-operator.

As noted earlier, these losses may far transcend the direct financial loss from the accident if it results in new, more restrictive, regulations or, worse, in precluding opportunities for further development.

It is estimated, for instance, that as a result of the Cullen report recommendations as many as ten percent of the remaining undeveloped United Kingdom offshore fields may no longer be commercial because of increased development costs.¹⁴

3.4 Risk Management

Corrective and preventive measures to reduce the risk of an accident form the basis of all governmental and industry regulations and standards. These measures include:

- Training and/or qualifying operating and drilling personnel,
- Inspection and maintenance,
- Design requirements and verification,

° Prohibition of certain operations.

Revisions to offshore regulations are to a large extent reactive. In other words, a specific accident, such as the Piper Alpha accident, will focus attention upon a specific hazard and regulations are then promulgated to reduce the possibility of that particular hazard from occurring again.

Because of public involvement in these decisions the actual risk of a particular failure occurring is often ignored.

4. Major Accidents

Major accidents are defined for this discussion as those accidents that had a profound effect on the way we do business. In other words those accidents that resulted in new or revised regulations and/or industry standards.

The six incidents that, in the author's opinion, had the greatest impact are:

1. Platform failures during hurricanes Hilda and Betsy,
2. Dos Cuadras platform A blowout in the Santa Barbara Channel,
3. Bay Marchand platform B fire in the Gulf of Mexico,
4. Ekofisk platform Bravo blowout in the North Sea,
5. Alexander L. Kielland capsizing at the Edda platform in the North Sea,
6. Piper Alpha explosion and fire in the North Sea.

Details of each of these accidents are described in the following. A summary of the accidents is presented in Table 1.

4.1 Platform Structural Failures

During hurricanes Hilda (1964) and Betsy (1965) twenty-three platforms out of a then total population of about 1000 platforms in the Gulf of Mexico either collapsed or were damaged to the point that they were no longer useable.¹⁵ The majority of the failures were attributed to structural underdesign. There were no injuries and no lives were lost. An unknown amount of pollution occurred but this was not of public concern in 1964 and 1965.

The commonly used design criteria at that time was a 25 year storm, equal to the anticipated economic life of the field. As a result of these failures the storm design criteria was replaced with a more conservative 100 year storm. At the same time the offshore industry recognized that a more uniform offshore design guide was required, leading to the formation of the API RP 2A committee and the subsequent issuance in 1969 of the first offshore platform design guideline. Over the years this document has evolved from a rather simple set of guidelines to a detailed design manual covering all aspects of structural design in various locations around the United States. The current issue was published in September 1989. It is 153 pages long. By comparison the first edition in 1969 totaled 15 pages.

The success of this industry effort is illustrated on Figure 1. The annual fail-

ure rate P_f has decreased from an average of 38×10^{-4} during the 1963 to 1968 period to an average of less than 2×10^{-4} during the most recent 1983 to 1988 period.

4.2 Dos Cuadras Platform A Blowout

The now infamous Platform A blowout in federal waters of the Santa Barbara Channel in January 1969 occurred during the drilling of the fifth development well from the platform and was caused by an inadequate conductor and surface casing design. Although the blowout equipment was successful in controlling the blowout, the well subsequently blew out next to the platform through near surface fractures. There were no injuries or fatalities. A portion of the estimated 70,000 barrel oil spill reached the coast and created immense public uproar and media attention.

The accident would not have occurred if conventional casing design and setting depth had been used. Following the incident the Mineral Management Service substantially revised its OCS orders to strengthen the requirements for drilling procedures and include requirements for near surface seismic surveys to assist in the design of casing setting depth.¹⁶ The OCS orders were superseded in 1988 by the currently used general rules and regulations.

4.3 Bay Marchand Platform B

The Bay Marchand Platform B platform (usually referred to as South Timbalier Block 26 in the databanks) was a typical Gulf of Mexico structure with space for 36 wells and located in 55 feet of water. At the time of the accident in December 1970 twenty-two wells had been completed and were producing 17,500 barrels of oil per day. Two drilling rigs were drilling additional development wells. A wireline unit was installed on one well to remove obstructions from the tubing. The safety valve had been removed. During a coffee break of the wireline crew the well started flowing past the incompletely closed master valve and caught on fire.

The heat from the fire damaged other wellheads and ultimately eleven wells were on fire. The platform was totally destroyed and it took 136 days and ten relief wells to kill the fire. Of the 60 men aboard there were four fatalities and 37 injuries. Most of the oil that was spilled burned. None reached the beach.

The cause of the accident was attributed to the fact that several simultaneous operations, i.e. drilling, production and wireline operations, were ongoing without clear responsibility directives. A major contributing cause to the extent of the accident was that most of the subsurface controlled subsurface safety valves (storm chokes) leaked or failed.

As a result of this incident, and others in the same time period, the Mineral Management Service substantially expanded its platform inspection and compliance program.¹⁷ Additionally, much more stringent OCS orders were issued which included restrictions on simultaneous operations. The use of surface controlled subsurface safety valves became mandatory.¹⁸

4.4 Ekofisk Platform Bravo

In April 1977 a blowout occurred on the Bravo platform in the Ekofisk field. The blowout did not result in any loss of life or injuries or fire but did cause a large spill. The blowout occurred during a well workover and was ascribed to human error. A contributing cause to the accident was attributed to simultaneous operations, i.e. concurrent drilling and production operations. The blowout received extensive worldwide press coverage.

Following this accident the Norwegian Petroleum Directorate issued guidelines for simultaneous operations which introduced specific restrictions and required specific approval before such operations could be conducted.

4.5 Alexander L. Kielland Accommodation Platform

In March 1980 the Alexander L. Kielland floating accommodation platform moored adjacent to the Edda platform in the Edda field capsized during a storm resulting in a loss of 123 lives. The accident was subsequently attributed by the inquiry commission to the rupture of a strut. The rupture was initiated by fatigue cracking at an inadequately welded collar.

The Kielland accident initiated substantial revisions of the Norwegian regulations. Considerable emphasis was placed on establishing a unified safety standard for mobile units and fixed platforms and a more coordinated control system based on the principle of internal control.¹⁹

At the same time guidelines for Concept Safety Evaluation (CSE) of the platform design were promulgated by the Norwegian Petroleum Directorate. These guidelines required that the design be evaluated for potential accidents and that impairment frequency be at an acceptable low level.³

4.6 Piper Alpha Disaster

The Piper Alpha accident occurred in July 1988 and resulted in the total destruction of the platform. Of the 226 persons on board the platform 165 lost their lives. Two rescue workers also were killed.

The initiation of the accident was attributed to poor communication between shifts of the platform operators. As a result an inoperative condensate pump, from which the pressure safety valve had been removed, was started up. The escaping gas ignited and started off a chain of explosions which resulted in extensive damage to vital platform systems. This included the platform internal communication system making it impossible to issue an order to evacuate.

Approximately 20 minutes after the first explosion an incoming 18-inch high pressure gas pipeline riser was damaged, probably by falling debris. The escaping gas collected under the platform and resulted in an enormous explosion which destroyed most of the platform.

The Piper Alpha accident received extensive worldwide press attention and initiated a public inquiry conducted by Lord Cullen.⁴ The recommendations from the Cullen report will have a profound effect on offshore operations and

regulatory practices in the United Kingdom North Sea.

The proposed changes will most likely, in time, ripple through the entire offshore industry and result in changes in the way operational safety is regulated on a worldwide basis.

The Cullen report makes 106 recommendations designed to improve offshore safety. The United Kingdom government has adopted these recommendations in their entirety and expects to implement them as soon as possible.

Significant recommendations include:

- o The implementation of a system of Formal Safety Assessments (FSA), similar to that being used offshore Norway. In this system the operator will be required to demonstrate that the Safety Management System (SMS) of the company and the installation are adequate to assure that the design and operation of the platform and its equipment are safe.
- o A requirement for a safe refuge on the platform to provide temporary protection to personnel during an emergency.
- o Process control, i.e. not just monitoring, from a central control room manned around the clock.
- o Better training of personnel in the permit-to-work system.
- o A single regulatory organization for offshore safety.
- o A requirement that emergency shutdown valves be located on platform risers and that these valves be protected in some fashion from damage.

5. Minor Accidents

The databases mentioned earlier provide a rich source of statistical material which can be used to determine the causes and sources of offshore platform accidents.

An analysis, for instance, of the fires and explosion category reveals that an inordinate number of accidents are caused during welding activities. With this knowledge measures can be taken by the regulators and/or industry to enforce safety regulations and/or prohibit certain activities.

6. Lessons Learned

What have we learned from these major accidents?

6.1 Structural Platform Failures

Platform collapse due to environmental conditions no longer appears to be a problem. As shown on Figure 1 the current average annual probability of a

structural failure is less than 2×10^{-4} and appears acceptable. That is not to say that this rate may not again increase in the future as platforms get older. The average age of platforms in the Gulf of Mexico is 15 years and twenty percent of the platforms are 25 years or older.²⁰

Most platforms are designed for a 25 year life because that is usually the estimate of the economic life of the underlying oil reserves. In practice the economic life is usually much longer because of conservatism in estimating reserves and/or the discovery of additional reserves. Unless the older platforms are upgraded and/or properly maintained the structural failure rate may increase. In fact, the structural failures identified in Figure 1 for the most recent five year period were two older structures that had not been maintained properly. Regulations, as well as industry standards, are addressing this potential problem by mandating periodic underwater inspections.

6.2 Explosions and Fires

Explosions and fires are the principal hazard to offshore facilities. Over the period from 1956 through 1986 a total of 779 incidents involving an explosion and/or fire occurred on platforms in federal waters around the United States.¹² Based on the accumulated platform years this relates to an average annual probability, P_f , of an explosion or fire happening on a platform of about 1.5 percent. These incidents resulted in the loss of three platforms. The annual probability of experiencing an explosion or fire is shown on Figure 2.

There is no clear evidence on this chart of any improvement from earlier years. This is probably because until the early 1970's minor accidents were not reported. Even so, when investigating the last decade, there is no apparent improvement despite regulatory and industry efforts to improve safety and personnel training.

It is quite possible that one of the reasons for the lack of improvement is the fact that production facilities are getting older. As mentioned above, some twenty percent of the platforms in the Gulf of Mexico are 25 years or older. It is reasonable to expect that most of the facilities are of the same vintage and over the years have suffered from wear and tear. In some cases the equipment and the safety systems are obsolete.²⁰

Figure 3 displays the worldwide accident rate of platform explosions. This chart shows a rate that is an order of magnitude lower than the United States experience shown on Figure 2¹⁰. This seems puzzling until it is realized that Figure 2 includes all fires and explosions and Figure 3 includes only those incidents classified as serious accidents.

It points out the necessity of careful analysis of the data between databanks to be certain that one is comparing apples and apples and not apples and oranges.

From Figure 3 it is clear that there has been a significant improvement in the rate of serious accidents, which are defined as damage to one or more modules and/or damage exceeding \$2 million.

6.3 Blowouts

There has been a significant improvement in the blowout accident rate from fixed offshore platforms on a worldwide basis¹⁰. Total platform losses due to a blowout have decreased from an average annual rate of 3×10^{-4} during the 1970 to 1979 period to a rate of 0.2×10^{-4} during the 1980 to 1989 period.

The chart in Figure 3 shows the annual frequency of blowouts causing serious damage, i.e. damage to modules and/or costing more than \$ 2 million. The most recent rates show substantial improvement over the 1979 to 1983 period.

This improvement is attributed to stricter regulations and to training requirements for all drilling personnel.

The improvement in platform drilling accidents is not matched, however, by mobile drilling units where the accident rate over the same period has hardly changed. There is no good explanation for this difference.

7. Summary

Major offshore accidents receive a large amount of publicity and are instrumental in enacting new and/or revised industry standards and governmental regulations. The paper discusses major accidents that have occurred during the past two decades and the effect that these accidents have had on improving the reliability of offshore operations. The paper also discusses the importance of analyzing minor accidents that are not in the news through the use of databanks.

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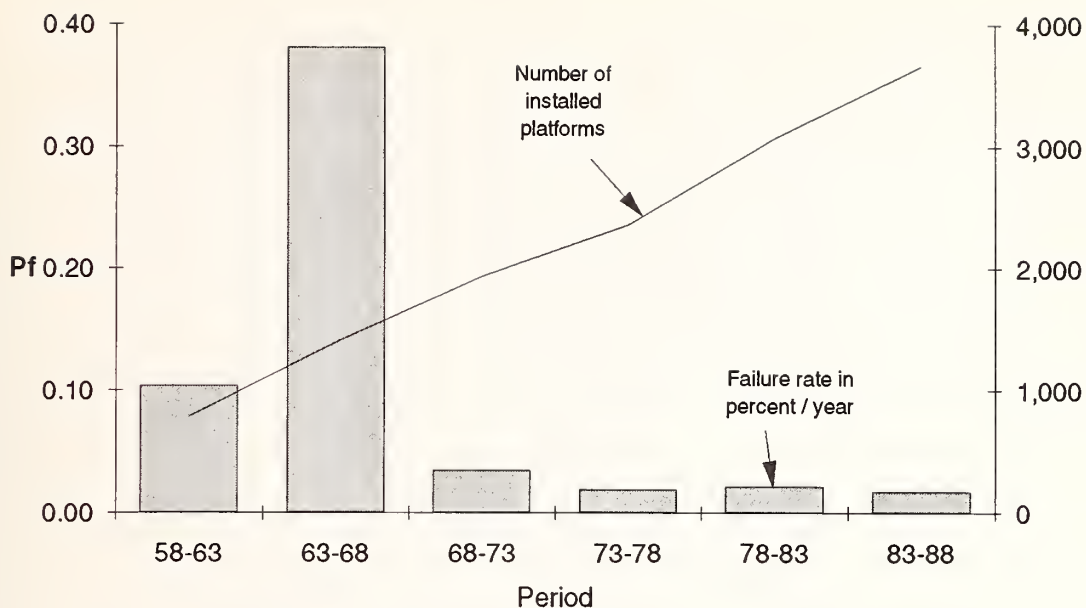


Figure 1. Average annual failure rate of offshore platforms in United States federal waters from environmental hazards.

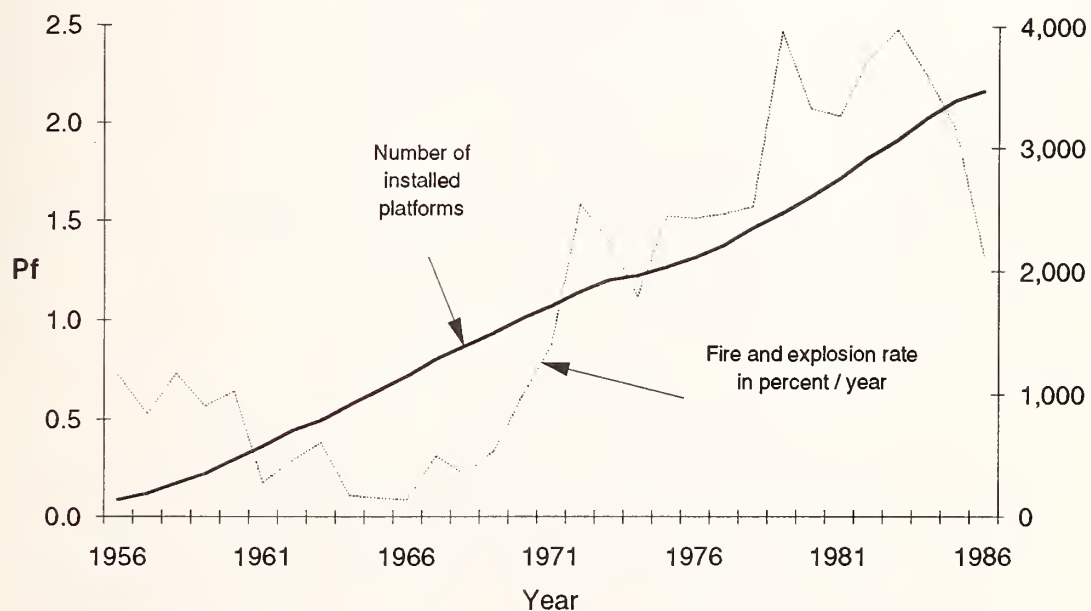


Figure 2. Average annual fire and/or explosion incident rate on offshore platforms in United States federal waters.

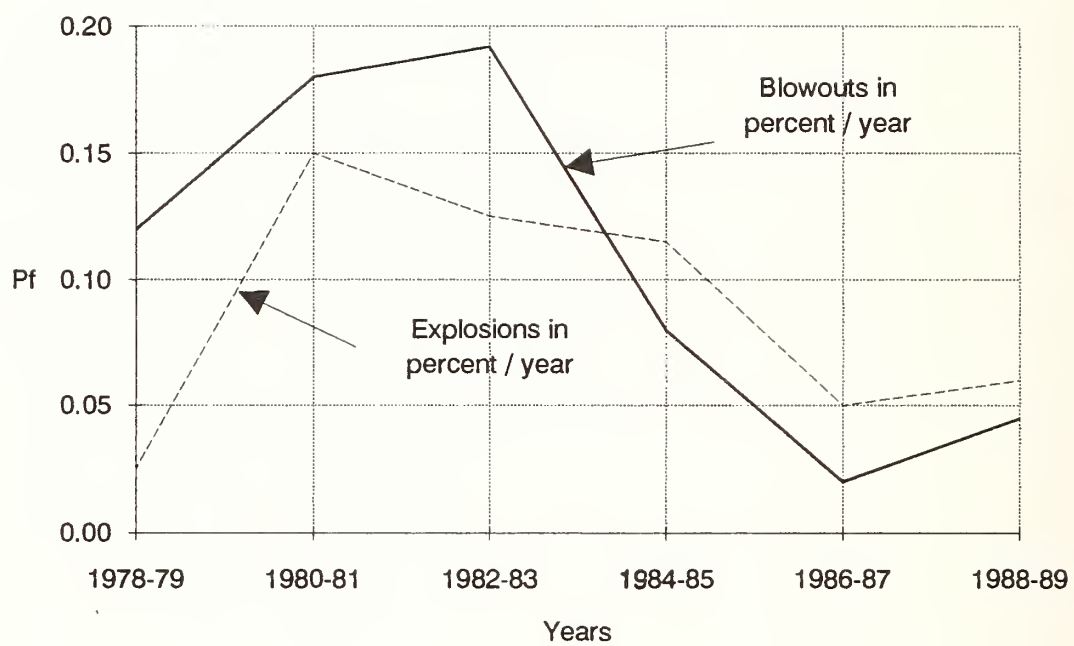


Figure 3. Worldwide average rate of platform blowouts and explosions causing severe damage.

(After Bekkevold)

Table 1. Offshore platform accidents that have had major impacts.

Name / Location	Date	Activity	Cause	Consequence	Impacts
Several platforms Gulf of Mexico	1964, 1965	Shut-in, hurricane warning	Structurally underdesigned	Platform structural collapse	API RP 2A standards Verification program
Dos Cuadros platform A Santa Barbara Channel	1969	Drilling develop- ment wells	Inadequate casing design	Blowout, pollution	Drilling moratorium OCS Orders (2)
Bay Marchand platform B Gulf of Mexico	1970	Drilling, producing and workover	Simultaneous operations	11 wells burning, fatalities	Inspection (PINC) SCSSV
Ekofisk platform Bravo North Sea	1977	Producing and workover	Simultaneous operations	Blowout large spill	NPD guidelines for simultaneous operations
Alexander Kielland North Sea	1980	Floating accom- modations platform	Fatigue cracking	Capsized large loss of life	NPD - Concept Safety Evaluation
Piper Alpha platform North Sea	1988	Drilling, producing and construction	Simultaneous operations	Fire and explosion, large loss of life	Cullen report Formal Safety Assessment



BRIEF REVIEW OF THE OREDA PROJECT

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ABSTRACT

The OREDA Project, established in 1981, has become one of the main sources of equipment reliability data for Oil & Gas Exploration and Production activities. In its first phase, the project produced the Handbook of Offshore Reliability Data. The data collected in the second phase was made available to OREDA members in the form of a computerized database system. Today, OREDA has entered into its third phase, and the project scope has been extended to include new equipment classes and detailed maintenance-related information. OREDA has thus extended its applicability from safety and reliability assessment to maintenance and operations optimization. The quality of the information collected has also increased dramatically since the first phase of the project.

Following a summary of OREDA Project highlights, the review briefly describes the need for reliability data in E&P operations. The scope of the OREDA Phase II data base is reviewed using the equipment class "pumps" as an example. Finally, some thoughts on the future of OREDA are given.

NOTE: The views expressed herein does not necessarily represent the views of all OREDA Project members.

1. Brief History of the Oreda Project

In the OREDA Project, a number of oil & gas companies make data from their maintenance records and log books available for in-depth analysis by their competitors. When OREDA was founded in the early eighties, this concept was generally considered impossible, for a number of reasons. Firstly, most companies had a general skepticism towards giving other companies access to their internal files. Secondly, there was a fear that revealing details on the reliability of equipment could cause difficulties with the manufacturers of the equipment involved. And finally, the industry had not yet fully accepted the many benefits which quantitative assessments of reliability, safety and maintenance brings to E&P operations.

Despite widespread skepticism, a pre-project had been launched in 1980, with the purpose of identifying data requirements for risk and reliability studies, and the adequacy of existing failure and repair statistics within company records. The results of the pre-project were promising, and a number of oil & gas companies decided to join the first formal phase of the project, running from 1983 to 1984.

The purpose of Phase I was clearly defined: To collect data from offshore production and exploration activities, and compile them into a Handbook of Offshore Reliability Data. The data collection exercise was indeed a tough job for those involved, but the Handbook turned out to be a great success. More than 1000 copies were sold world wide.

Following Phase I, a thorough review was made of the problems OREDA encountered in its first phase. One company decided to leave the project, but the remaining 7 members decided to launch OREDA Phase II in 1987. The scope of the project was adjusted as follows:

- Data should only be collected on **production-critical** equipment
- Emphasis should be on **quality** rather than **quantity**
- The data should be installed in a PC-based system
- Accessibility should be restricted to OREDA member companies

The results of Phase II was a PC-based system with 1623 inventories and 8424 failure reports, supplied with basic application programs for data analysis.

We are now almost one and a half year into Phase III of the project. All companies who participated in Phase II are still members, and 3 more companies joined the organisation in 1990. Phase III has adopted the following objectives:

- Increased commitment to data quality and relevance
- Increased number of equipment inventories, in particular safety related
- Inclusion of a new Maintenance Database
- Cooperation with manufacturers of critical equipment
- Significant software improvements
- World-wide marketing of the OREDA Software
- Cooperation with other organizations
- Preparation for partially automated experience transfer in Phase IV

The ten Phase III participants are:

BP Petroleum Dev. Ltd. Norway

Norsk Agip A/S

A/S Norske Shell

Norsk Hydro A/S

Saga Petroleum A/S

Den norske stats oljeselskap A/S (Statoil)

Total Oil Marine p.l.c

Elf Aquitaine

Phillips Petroleum Co. Norway

A/S Norsk Esso

2. The Need for Reliability Data in E&P Activities

Equipment failure is of major concern in E&P operations, as well as in most other industries. Equipment failure is one of the main reasons for:

- Investment in redundant equipment (instead of single train options)
- Larger facilities (e.g. living quarters and support structures)
- Equipment modifications
- Safety hazards during operations
- Large production losses
- High maintenance costs
- Increased cost of engineering activities

Since the recent oil crises, cost containment has been universally accepted in the oil & gas industry. With the advancement of reliability engineering and project management methods, simple and reliable concepts have also gained substantial ground. In fact, even the objective to minimize total cost over the life of the plant is now seriously being considered by many companies in the industry. The trends are therefore very interesting from the reliability and maintenance specialist's point of view, representing not only methodological challenges, but a substantial challenge in terms of data availability and data quality.

In most OREDA member companies, maintenance optimization and reliability studies have become an integral part of engineering design and plant operation. High quality data are needed:

- To select the most suitable manufacturers and models
- To identify dominating failure modes
- To understand the failure mechanisms involved
- To optimize maintenance strategies and maintenance parameters
- To make cost-efficient decisions on modifications and replacement
- To pinpoint areas of excessive maintenance workload
- To enable comparison of operational performance with other operators
- To provide manufacturers with required feedback for future improvements

Very few of these tasks can be achieved with reasonable accuracy without sufficient availability of high quality reliability and maintenance data, a fact well known to the OREDA sponsors.

The consequences of using poor data could be manifold, ranging from inaccurate or misleading assessment of risk to costly over-design and ineffective use of risk reducing measures. Figures 1 and 2 illustrate some possible characteristics of the data quality problem.

Figure 1 is an illustration of a lifetime trend in failure frequency for one particular equipment. The data is specific and not of generic type, but can still be misleading if the estimate of failure frequency is based on mean value over the observation period. **Trend analysis and equipment specific data** is required to identify the substantial reliability improvement seen in such cases, and the reason for the improvement. How often is this type of data available to the analyst?

Figure 2 is an illustration of the distribution in failure frequency of different valves performing the same function. An analysis based on averages (or weighted averages) is bound to be misleading, whatever the purpose of the study. How often is this type of generic data still used as basis for important engineering and operational decisions?

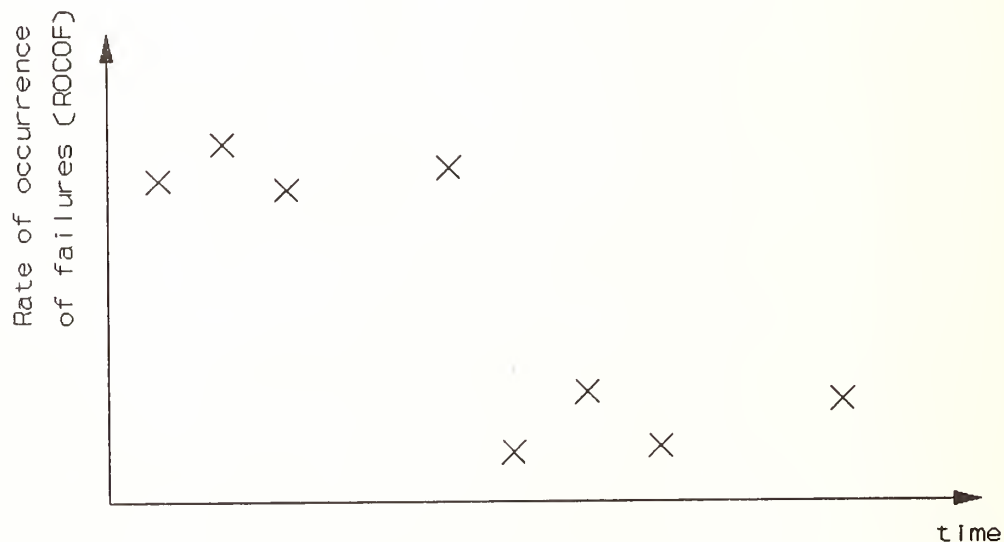


Figure 1: A shift in failure frequency

3. OREDA Data Collection Procedures

Commitment to data quality means that detailed and unambiguous data collection procedures have to be developed and agreed upon. Among the most important lessons OREDA learned in the previous project phases, are:

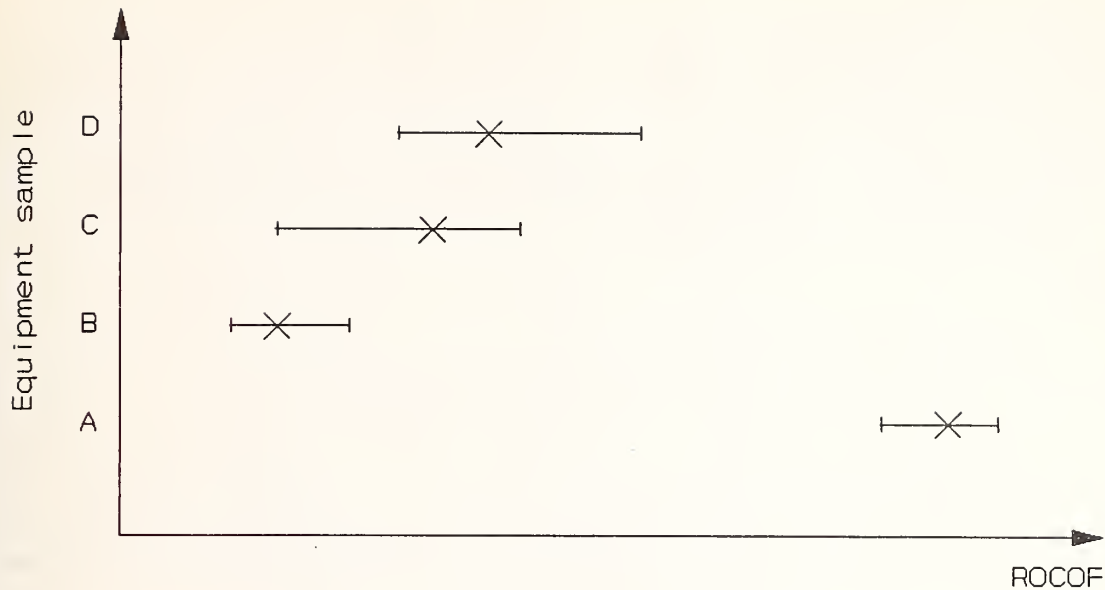


Figure 2: Variability in failure frequency among individual samples

- 1) A well defined format for data collection is essential
- 2) "On-line" guidance to the individual data collector on procedure interpretation is required
- 3) No compromises must be accepted with respect to data completeness and correctness
- 4) Operator's personnel must be available to answer questions
- 5) Data quality is expensive - in particular when data is collected from free format records

To further ensure the required data quality in Phase III of the project, the following requirements have been adopted:

- Equipment shall not be included in the inventory if the manufacturer has released, or is about to release, a new model with significantly improved reliability. This constraint extends to auxiliary equipment within the system boundaries
- Failure events shall not be added to existing inventories if the dominant failure mode(s) are associated with auxiliary equipment, and if replacement of the auxiliary equipment with other models or makes are likely to improve reliability performance significantly
- Data shall only be collected for equipment models currently

considered in new projects by one or more of the OREDA Participants

- Longer observation periods - if possible complete life cycles - shall be preferred to a larger number of shorter observation periods
- All equipment shall be uniquely identified and assessed for relevance and availability of data before data collection can start within each equipment class

4. Oreda Database Inventories

The Phase II database has the following inventories:

SYSTEM TYPE	NUMBER OF INVENTORIES	NUMBER OF FAILURE REPORTS
PUMPS	278	3152
COMPRESSORS	50	1639
GAS TURBINES	109	2611
VESSELS	329	438
HEAT EXCHANGERS	170	118
VALVES	645	427
SUBSEA EQUIPMENT	42	39

Additional Phase III inventories are:

- Expander/recompressors
- Electrical generators
- Fire & gas detectors
- Instrument switches/process sensors

An increased amount of data, of higher quality and relevance, will be collected in Phase III.

5. Oreda System Breakdown

The following definitions apply:

SYSTEM: Typically corresponding to Tag numbers

SUB-SYSTEM: An assembly of units that provides a specific function required for the system to achieve its intended performance

MAINTAINABLE ITEM: An item that constitute an assembly of parts that are normally the lowest indenture level during maintenance

Some examples illustrate this breakdown:

	<u>Example</u>
Level I: System	Pump
Level II: Subsystems	Starting system Drive unit Gearbox or drive Pump Control & monitoring Lubrication system Miscellaneous
Level III: Maintainable items	Tank Pump Filter Cooler Valves & piping Unknown

This level of detail is required in most cases for detailed systems optimization and operational considerations.

6. Inventory Data

The Inventory Report, uniquely associated with each database item, has the following general information (compulsory fields preceded by asterisk ("*")):

- * Report number
- * Reported by (name and date - dd/mm/yy)
- * Checked by (name and date - dd/mm/yy)
- * Source (or source reference)
- * Installation name
- * Item name
- * Company tag number
- * Company sub-tag numbers (if any)
- * Taxonomy code (coded)
- * Function (coded)
- * Manufacturer/supplier/package vendor
- Manufacturer of control system
- * Model/type
- * Redundant subsystems
- * Operating mode (coded)
- * Operational time (hours) (& calculation method if estimated)
- * Calendar time (hours)
- Number of demands/starts

- * Date installed (dd/mm/yy)
- * Dates of major replacements (replacement options coded)

In addition, each equipment class (system) has a number of specific data associated with them. As an example, the pump-specific inventory datafields are listed below:

- * Type of driver (coded)
- * Fluid handled (coded)
- Fluid corrosiveness/erosiveness (coded)
- * Power (Kw)
- Utilization of capacity (% of normal operating/design capacity)
- * Suction pressure (barg)
- * Discharge pressure (barg)
- Speed (RPM or strokes/min)
- Number of stages
- Body type (coded)
- Shaft orientation (coded)
- Shaft sealing
- Transmission type (coded)
- Pump coupling
- * Environment (coded)
- * Maintenance program (coded)
- * Instrumentation (coded)
- Pump cooling
- Bearing (coded)
- Bearing support (coded)
- Additional information

Note that a large number of the data elements are important in maintenance optimization, as well as in design optimization. Other entries are provided in order to identify the equipment when working on a generic level.

Also note the high number of compulsory fields and the many coded entries. Compulsory fields and coded entries are a "must" if high database quality shall be maintained.

Examples of coded entries in the inventory report with particular importance to maintenance optimization are listed below.

MAINTENANCE PROGRAM TYPES

Periodic parts replacement. One or more parts of the item is replaced with a new or completely overhauled item

Minor periodic service with limited extent of opening

Periodic inspection/opening of limited extent

Major inspection/overhaul of comprehensive extent with extensive disassembly and replacement of worn and/or life-limit parts

Periodic functional test

Condition monitoring

INSTRUMENTATION DATA - PUMPS

Data on the extent and type of instrumentation within a system boundary is important when comparing data from different operators, and when merging data into generic figures. OREDA include the following instrumentation details:

Process parameters: Temperature/Vibration/Flow/Speed/Pressure

Application: Trip/Control/Indication

Options: Critical, Single channel, Simplex, High integrity
 protection, Redundant

6. Failure Event Report Form

The standardized Failure Report Form is shown below. The high number of compulsory and coded entries is a characteristic also of this part of the database.

- * Report number (default sequence number)
- * Inventory report number (default)
- * Reported by (name and date - dd/mm/yy)
 Source
- * Failure mode, system level (coded)
- * Subsystem(s) failed (coded)
- * Failure descriptor attributes (Euredata classification)
- * Maintainable item(s) (one or more - coded)
 Repair activity (coded)
- * Failure detected date (dd/mm/yy hh:mm)
 Active repair time (hours)
 Downtime (hours)
- * Restoration manhours (hours)
- * Method of observation (coded)
 Additional information

Correlations have been developed, using statistical regression, to convert manhours to active repair time where the latter is unknown. These correlations are normally very accurate when used on single, individual installations. The active repair time is used both for dead-time calculations and in systems availability assessments.

Examples of coded entries in the Failure Report with particular importance to maintenance optimization are listed below. The observation method data is also valuable when considering measures to prevent certain failure modes from occurring.

REPAIR CODES

Examples

Restore	Repack, weld, tighten, plug, reconnect
Replace	Replace a worn-out bearing
Modify	Install a filter with a smaller mesh diameter, replace a sensor with another make
Adjust	Align, set and reset, calibrate, balance
Refit	Polish, clean, grind, paint, coat
Combination	
Unspecified	

OBSERVATION METHOD

Periodic preventive maintenance/inspection

Functional testing

Condition monitoring

Alarms and trips

Manual observation

Unknown

7. The Future of OREDA

The OREDA Project is gaining increased support in its own environment - the Oil & Gas Exploration and Production industry. The majority of North Sea operators have already joined the organization, and the policy shift apparent in Phase III makes cooperation with other industries an interesting option. Ongoing negotiations with a major American group of companies involving exchange of technology and software is a direct result of this new policy. Recently, a Work Group within the Oil & Gas Industry E & P Forum recommended its members to consider joining the OREDA project.

Other important achievements in the next few years could be in the following areas:

- Increased cooperation with equipment vendors
- Enhancement of OREDA's capabilities to handle hydrocarbon leak and ignition data

- Increased capability for standardized, coded failure reporting in computerized maintenance management systems
- Built in error checking at different levels - both in the maintenance systems and in OREDA

The work carried out by the oil & gas industry in the OREDA Project will continue to be of significant importance - to ensure safe and reliable operations, as well as to assist in the continuing effort to optimize the operations of the facilities.

DATA COLLECTION ON HYDROCARBON LEAKS AND IGNITIONS THE E&P FORUM APPROACH

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ABSTRACT

This paper describes: the objectives and approach of an Exploration and Production (E&P) Forum study aimed at providing the oil industry with data on hydrocarbon releases and ignition; and methods to improve these and other high priority data.

1. Introduction

This paper serves as a theme paper to the Working Group on Experience Data Bases and Case Study Analyses at the above Workshop. It is based on a proposal prepared by Technica for the Exploration and Production (E&P) Forum in London (U.K.). Based on this proposal, Technica has been awarded the contract to develop Guidelines for Data Collection on Hydrocarbon Releases and Ignition, and to set up an initial data base for such information. These Guidelines will be available in the fall of 1991.

2. Objectives

The objectives of the E&P Forum study are to provide the oil industry with reliable and well documented frequency data on hydrocarbon (HC) releases and ignition, as well as to provide methods to continuously improve these and other high priority data through collection and analysis of oil companies' internal experience records. Hence, there are two key deliverables from the study:

- a. Guidelines for Data Collection: to enable E&P Forum members to collect HC release and ignition data, and other high priority data, on a format compatible with OREDA.
- b. QRA Data Base: a compilation of presently available frequency data on HC releases and ignition for use in Quantified Risk Assessment (QRA) studies.

3. Approach

Any data collection scheme to obtain high quality frequency data must aim to find the right balance between the feasibility of obtaining information and the efforts required to collect it on one side, and on the other side the use and benefits from applying the data in probabilistic analyses. There will invariably be a potential conflict between the reporting unit, wishing to minimize the efforts required in collecting the information, and the risk analyst, wishing to have available detailed, reliable data obtained from a wide experience base. A

key part of this study must be to find the right balance, based on an agreed level of ambition between E&P Forum members and a thorough understanding of the critical data requirements in QRA studies and how frequency data quality will affect the results from such studies.

3.1 Areas of Particular Importance

There is a significant difference between collecting reliability data (e.g. OREDA) and leak/ignition data for a process unit. Reliability data can be extracted from Maintenance Information Systems (MIS) in which repair intervention actions are recorded for maintenance optimization, spares planning, etc. Hence, very rigorous reporting systems are usually in place for this purpose with most operators. Reliability data collection is therefore a matter of utilizing information which already exists, originally recorded for other (main) purposes.

Leak and ignition data collection will mainly be based on special records, established for the particular purpose of recording such events and monitoring their frequency of occurrence. Hence the type of failure mode ("external leak") is always well defined, but the records may not reflect the criticality of the event. This is in most cases determined by the leak rate. Consequence calculations in QRA studies require leak rates to be specified in kilograms per second, but this parameter can not be observed when the leak occurs. Consequently, qualitative categories like "minor leak", "major leak" and "rupture" are used to describe the event, and this information is later transferred into quantitative categories when performing data analysis in a QRA context. The uncertainty associated with leak rate estimates is therefore considerable in present QRA data bases.

Sensitivity studies have demonstrated that the risk results can be very dependent on the hole size distribution, i.e. the fractions of all leaks from a particular process segment which fall within a certain leak rate category. This study should aim to reduce the uncertainty in this area, by exploring ways in which leak rate categories can be determined with higher accuracy. The recording and analysis of gas detector responses could provide a way forward: by linking gas readings to a simplified gas dispersion consideration, it may be possible to "back calculate" the rate of HC release.

Another aspect which distinguishes leak and ignition data collection from reliability data collection is the fact that a significant proportion of the events are caused by human intervention, and do not result from equipment failures per se. Maintenance intervention, modification works, etc. contribute perhaps more than 50 percent of the significant leaks, and are also an important source of ignition. This is another reason why maintenance records are an unreliable source of information for HC leaks and ignition. However, these records do provide information on the level of human intervention, which may be used to analyse the effect of such activities on the frequency of leaks and the probability of ignition.

Just as it is important to quantify the leak rate, it is also necessary to establish a cut-off criterion for leaks to be reported. Very minor leaks from process equipment happen all the time. Many minor leaks are not picked up by detectors, but are identified by process operators and other platform personnel

who hear the sound of a release. A recent survey in the Norwegian sector carried out for the Norwegian Oil Industry Association (OLF) and the OFS offshore workers union revealed that only 69 (25 percent) out of a total of 272 gas leaks had been reported to the Norwegian Petroleum Directorate (NPD). Most of the 272 leaks were picked up by the gas detection system. This result clearly indicate the need to agree on common criteria for when a gas release should be reported. The very small leaks may not be of interest in QRA work, since they are too small to have a major hazards potential. Data collection and analysis must therefore ensure that such small "bleeds" are left out or accounted for separately.

The E&P Forum study must also address the recording of equipment inventories, i.e. the number and size of equipment containing hydrocarbons. Typical examples are the length and diameter of piping and risers, the number of centrifugal gas compressors, etc. Two basic approaches are available: a "parts count" approach in which each operator would have to record the number of each equipment/component class, or a "modularised" approach in which inventory information is kept at an integrated level, i.e. gas compressor train, first stage separation, etc. The parts count approach provide more detailed information with better scope for detailed data analyses, but this approach is also the one requiring somewhat larger efforts from each operator. We anticipate that the Work Group may nevertheless prefer this approach, since compatibility with OREDA is desirable (ref. sample from OREDA III Data Collection Guideline circulated from E&P Forum).

An ignition probability is required in risk analysis to calculate the frequency of fires and explosion based on the leak frequency on a platform. Ignition probability can be defined in different ways, depending on how the value is used in the analysis.

In early risk analysis, the ignition probability has often been made a fixed value, based on the leak rate. The value could be dependant on leak location on the platform to account for the presence of more or less ignition sources (hot work, rotating equipment, etc.). If explosions were included in the analysis, then a separate probability had to be included for late ignition.

A different approach is to make ignition probability a function of gas cloud size (a larger gas cloud will engulf more potential ignition sources). This approach has the advantage that the real mechanisms of ignition (i.e. that the gas reaches an ignition source) can be described more realistically. Relevant design features of the platform can then also be included in the analysis in a more consistent way, especially the ventilation regime.

From the moment that a leak occurs, gas will start spreading through a module. The gas cloud caused by a leak is therefore not of a constant shape and volume, but changes over time. The ignition probability will therefore vary with time as well. The size of the gas cloud will have an effect on the magnitude of the explosion pressure when ignition occurs.

The ignition modelling has therefore direct impact on the results of a risk analysis when explosion modelling is taken into account.

It is obvious that not everybody has the tools or capacity to perform an in-depth

analysis of explosion risk. However, a choice can be made to develop a database which permits a more advanced analysis to be performed. At the same time a derived result may have to be developed that can be used in simpler analyses. A number of example runs for a typical platform could be performed to provide a set of data for such a simple analysis.

3.2 Data Base Development

The setting up of a QRA data base for HC leak frequencies and ignition probabilities, based on presently available data will provide a very good starting point for establishing the data collection Guideline. Most of the data base work should therefore be done up front of the Guideline work, as indicated in the sequencing outlined in the enquiry document from E&P Forum.

The simplest approach to providing a QRA data base for E&P Forum members would be for Technica to present its standard failure data handbook. However, we are convinced that the E&P work group members would like to take advantage of the opportunity to share their experience data, and to undertake some analyses to enhance the understanding of inventory release and ignition mechanisms.

We see the most important sources of information to be the following:

1. In-house Technica sources:
 - a) TEDARES (Technica's Data Reference System)
 - b) BLOWOUT (Technica's blowout data base)
2. Confidential sources (with a very good chance of obtaining access for this project):
 - c) E&P Forum members in-house data sources
 - d) OLF's Gas Release Data Base
 - e) NPD's Riser & Pipeline Data Base
 - f) NPD's Production Upsets Data Base
 - g) OREDA
3. Sources in the public domain:
 - h) Worldwide Offshore Accident Databank (WOAD)

This list does not preclude the inclusion of other relevant sources in the study.

The initial activity will be to collect and review leak and ignition data from the above sources. We would at an early stage work with the E&P Forum Work Group members to obtain access to the confidential sources, and to establish adequate procedures for maintaining confidentiality requirements which may be imposed.

A HC inventories taxonomy will be developed, based on common offshore systems design. We would aim to establish a taxonomy which is structured in accordance with the Work Group members' systems classification schemes, in order to match as far as is practicable the experience records for leak and ignition incidents. The taxonomy developed here will also be the basis for the data collection

Guidelines to be established in this study.

A draft structure for the HC taxonomy is given below:

1. Drilling/Completion (operations)
2. Well systems (including interventions in the production phase)
3. Flowlines & Well Testing
4. Separation
5. Dehydration
6. Gas Compression
7. Metering
8. Blowdown & Flaring
9. Risers & Pipelines (including pigging units)
10. Crude Storage
11. Offshore Loading
12. Misc. Production Systems (e.g. condensate injection, drain systems, etc.)

A possible modification to this taxonomy structure would be consider "generic" items like piping segments, instrument connections, valves, flanges, etc. separately from the above items. This would be necessary if a parts count approach to estimating leak frequencies for a particular platform concept is required. The above taxonomy items would then be used for special items only, e.g. item #7 would include orifice plates, whereas valves and instrument connections used in metering stations would be included under the generic classes. A decision on the best taxonomy structure will be made in discussions with Work Group members, taking into account the results of the data analysis as well. The aim must be to establish a taxonomy which is suitable for QRA purposes and is practical for data collection purposes.

The collected data will be analyzed to identify the most important parameters influencing the leak frequencies and ignition probabilities. It will be important to be aware that higher leak frequencies are often associated with particular equipment problems, and that the problem can be fixed once it has been brought to the operators attention. An example of such a problem is the use of inappropriate gaskets, causing numerous leaks before the gaskets were replaced by a different type. Knowledge of this sort of problems will be particularly important when analyzing Work Group members' data files.

The data analysis will also aim to establish, if possible, simple correlations between leak and ignition data and high-level design parameters, e.g. number and type of platform modules, natural vs. mechanical ventilation, etc.

The ignition probability is a function of leak size and more particularly of the size of the gas cloud resulting from the leak (see 3.1). Ideally one would therefore want to know the exact release rate for each historic leak, the leak direction, ventilation characteristics, module description, etc., to be able to simulate all parameters and find their significance for the ignition probability. However that would be a task of too great an extent to produce results within the time frame for this exercise.

Rather than to use a brute force technique in which a multitude of data is

collected, we suggest concentrating the efforts on areas where the fastest results can be produced. This suggested approach is based on the fact that a leak rate is easier to estimate for an ignited leak than for an unignited one. In addition, in risk analysis one is mostly interested in ignited leaks rather than unignited ones.

The way to find realistic ignition data will therefore be to analyze a number of historical fires in more detail. Given that the accident descriptions are reasonably detailed, it should be possible to estimate the leak rate based on the fire size (for ignited releases it is more likely that a detailed accident report is available than for unignited leaks). For explosions one could spend some time to analyze the descriptions of gas detector recordings and also make a better founded judgement of leak size. With maybe 20 to 50 accident descriptions one would therefore expect that a reasonably realistic leak size distribution can be developed for ignited releases.

In order to be able to develop a frequency of ignited releases (by leak size) one needs to have a suitable platform population data set as well. We envisage therefore that E&P forum makes a list available of platforms where the level of accident reporting over a specified period is good. For those platforms (or a selection of platforms from the available population) accident descriptions of ignited releases will be analyzed as indicated above. The platforms must be classified according to a suitable scheme, in order to make a proper description of the available population. The classification is likely to take into account factors like the amount of processing on the platform (e.g. No. of separation stages/trains, compression, etc.) and the ventilation regime on the platform (mechanical vs natural).

From the sources on leak frequency data, it will be possible to obtain a reasonable estimate of the leak frequency for each platform class. With a suitable ignition model, the frequency distribution of ignited leaks can now be used together with the leak frequency for deriving:

- the hole size distribution
- the ignition probability per leak size

The methodology is thus expected to cover the two factors that contribute most to the uncertainty in risk analysis data.

The HC release frequency and ignition probability data will be presented in the form of a document, tailored to the use in QRA studies. This document will be the best available source of such data in the offshore industry. It will contain leak frequencies, hole size distributions and ignition probabilities for the taxonomy items.

The data base will meet the following requirements:

- Data from public sources will be traceable.
- Confidential data supplied by E&P members and other companies will not identify the data source (i.e. generic data).

- The data will be presented in a format which makes future updating possible once data from E&P members are routinely reported and analysed.

3.3 Data Collection Guidelines

The objective of the E&P Forum initiative is to ensure that future reporting from members will result in a high quality QRA data base. Since it is commonly recognised that present experience records do not provide an adequate basis for deriving such high quality data, the E&P Guidelines for data collection should aim to improve the current standard of HC release and ignition incident reporting. The Guidelines should also address other high priority data such as F&G detection, fire water systems, safety valves, blowdown systems, etc.

The OREDA Data Collection Guideline provides a very useful input to this part of the work. These Guidelines have evolved since the first phase of OREDA in 1983, and are therefore based on considerable experience collecting reliability data. It is at the same time important to keep in mind the differences between leak and ignition incident reporting and reliability data collection, ref. Section 3.1 above. We envisage the Guidelines would be developed in three stages:

- 3.3.1. Taxonomy Definition
- 3.3.2. Inventory Data Collection
- 3.3.3 Incident Data Reporting

Each of these are discussed below.

3.3.1 Taxonomy Definition

The taxonomy for the Guidelines will be based on the taxonomy developed for the initial data base on HC leaks and ignition, but extended to include other high priority items which do not relate to leak and ignition events by themselves. The taxonomy should as far as is practicable follow the OREDA taxonomy structure. This will be particularly relevant for the priority items which generally relate to component categories similar to OREDA, and for which data can be collected from maintenance information systems. It may also be useful to revisit the initial OREDA taxonomy from 1983, which contained about the double number of items to those presented in the OREDA Handbook. Those discarded were items for which no reliability data could be found.

An outline taxonomy for HC inventory items is given in Section 3.2 of this proposal. This would initially be detailed out with reference to E&P members' incident reporting systems and to the OREDA taxonomy. As discussed in Section 3.2, it will be important at this stage to agree on the taxonomy structure: we believe the most appropriate approach would be to separate out generic equipment categories like flanges and piping segments, and to reserve the special categories for items such as orifice plates, pig receivers, pressure safety valves, etc. It should be noted that the final data base could be made in such a way that high-level leak frequencies and ignition probabilities on a per module or per system basis could be derived automatically from pre-determined, generic modules or system configuration (note spreadsheet analogy). This would be very useful for early stage QRA purposes, when little detail about system

configuration is available.

3.3.2 Inventory Data Collection

We envisage that the inventory data collection scheme for the E&P QRA data base could largely be based on the OREDA system, i.e. with a two-level approach: one set of general information, applicable to all items, and one set containing specific information relating to each individual taxonomy item. The two sets would be developed to be fully compatible with OREDA.

There is some additional information which is relevant to leaks and ignition incidents, and which should be considered for inclusion in the Guideline. This relates to the local conditions in the area where the equipment is located:

- Module/Area geometry and volume
- Ventilation conditions
- Distance to safe areas and hot surfaces or open flames
- Gas detector type and location
- Volume of hot work, modification works, etc.

The latter information on activity levels is important since it is a fact that very many significant HC releases occur as a result of human intervention and not as result of spontaneous equipment failures. It is in our experience not straightforward to collect this type of information, and we need to agree with the Work Group whether collection of this information should be limited to a "per platform" basis rather than a "per module/area".

3.3.3 Incident Data Reporting

This part of the Guideline should also take the OREDA system as a starting point, in order to ensure compatibility. The main difference as far as HC release events is concerned is that the failure mode is predefined: "external leak". Whereas the OREDA failure report concentrates on the failure mode and the repair activity, the E&P report will have to address the incident itself and its consequences in much more detail.

Apart from the information required by OREDA (which we will not repeat here), we propose to consider the following information as part of the reporting format:

Leak Description:

- equipment/part leaking
- rate (preferably estimated as kg/s)
- duration
- means for isolating the leak (closing valve, empty inventory, etc.)
- cloud size
- means for detection (visual, noise, smell, detector)
- gas detector readings (inside/outside area)
- HC medium (could be inventory information)
- production shut-down time (if any)
- time of the day
- number of people present in the area

- operation in progress in the area (wireline, hot work, etc.)
- wind direction and speed (natural ventilation)
- ventilation rate (mechanical ventilation)

It will be a particular challenge to establish principles for determining the leak rate. As discussed previously, the leak rate can not be observed, and must therefore be derived from other parameters. Possible options include gas detector readings and leak hole size, from which a more accurate leak rate in kg/s may be determined. The feasibility of using such an approach must be discussed with the Work Group.

It is of interest to record the number of people present in the area when the leak occurs, since most QRA work combines leak consequences with the number of people present to estimate the number of casualties in the area. An average personnel distribution is commonly used for this purpose, but this may not be appropriate if more than half of the leaks are caused by human intervention.

The wind direction and speed should be recorded when a leak occurs in a naturally ventilated module, since the ventilation rate through the module will be determined by these factors (and the module geometry recorded as inventory information).

Leak Causes

Hardware causes of releases may be classified as in OREDA, using the Failure Descriptor. It may be appropriate to add some information about the leak path, since this will improve the understanding needed to assess the leak rate.

Human factors related causes may be classified at different levels of detail and root cause back-tracking. We would propose to avoid as far as is practicable simply using "human error" to describe an incident, since this is not a piece of information which tends to focus on constructive mitigating measures. It would be preferable to employ a cause classification scheme relating to e.g. "Inadequate procedure", "communication error", "violation of procedure", "inadequate labelling", etc. Technica will use its Human Factors expertise to establish proposed classifications, based on a review of incident data.

Ignition Description

- time delay
- ignition point (relative to leak source)
- overpressure
- explosion suppression agent (e.g. halon, if used)
- fire duration
- fire extinguishing method/agent

Ignition Source

- leak induced
- static electricity
- hot surface
- open flame

- faulty EX equipment
- gas in safe area
- hot work
- other human activities (e.g. smoking)

The incident reporting form will be produced in a format compatible with OREDA.

APPENDIX II

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