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Application of Risk Analysis to Offshore Oil and Gas Operations— Proceedings of an International Workshop

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Glossary of Acronyms
Used in These Proceedings

ABS	American Bureau of Shipping
ANSI	American National Standards Institute
API	American Petroleum Institute
API-RP	API Recommended Practice
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
BAST	Best Available Safe Technology
CSE	Concept Safety Evaluation
DAE	Design Accidental Event
EIS	Environmental Impact Statement
FAA	Federal Aviation Administration
FMEA	Failure Mode Effect Analysis
FTA	Fault Tree Analysis
HAZOP	Hazard and Operability Study
HSAC	Helicopter Safety Advisory Board
ISSC	International Ship Structure Congress
LRFD	Load and Resistance Factor Design
JONSWOP	Joint North Sea Wave Observation Project
MMS	Minerals Management Service
MODU	Mobile Offshore Drilling Unit
NBS	National Bureau of Standards
NPD	Norwegian Petroleum Directorate
OCS	Outer Continental Shelf
OREDA	Offshore Reliability Data Project
OTC	Offshore Technology Conference
pdf	Probability Density Function
QA	Quality Assurance
SNAME	Society of Naval Architects and Marine Engineers
TLP	Tension Leg Platform
USCG	United States Coast Guard

ABSTRACT

The proceedings of an International Workshop held at the National Bureau of Standards on March 27 and 28, 1984 are presented. The purpose of the workshop was to examine the application of risk analysis in offshore oil and gas operations. The proceedings include: an executive summary, an introduction, and summary reports and recommendations of four Working Groups: Standards, Codes, and Certification; Concept Evaluation and Design; Operation and Maintenance; and Logistics and Support. Also included are theme presentations on current practice in the United States, Great Britain, and Norway, and on current risk assessment methodologies.

Keywords: Codes; drilling platforms; gas production; marine engineering; ocean engineering; offshore platforms; oil production; petroleum engineering; probability risk analysis; regulations; shipping; standards.

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EXECUTIVE SUMMARY

On March 27 and 28, 1984, an International Workshop on "Application of Risk Analysis to Offshore Oil and Gas Operations" was held at the National Bureau of Standards (NBS), Gaithersburg, Maryland, U.S.A. The workshop was organized by NBS and sponsored by the Technology Assessment and Research Branch of the Minerals Management Service (MMS). It was attended by an invited group of experts from industry, government agencies, the engineering profession, the construction industry, labor unions, and public interest groups.

The purpose of the workshop was to examine the utilization of risk analysis in offshore oil and gas operations. First, various aspects of present practice were discussed by four theme speakers. Subsequently, four working groups convened and developed position papers and recommendations.

Dr. Floyd Tuler from Worcester Polytechnic Institute outlined the task of the Working Groups as follows:

Group I should deal with the application of risk analysis and reliability engineering in the formulation of standards, codes, and certification requirements. Risk analysis could be used as a basis for specifications and recommended practices and is in some instances required in the approval procedure for projects.

Group II should deal with the application of risk analysis and reliability engineering techniques to planning, siting, construction, and maintenance of offshore facilities.

Group III should deal with the application of risk analysis to the design, operation, and maintenance of offshore production systems.

Group IV should be concerned with risk analysis and reliability engineering techniques in logistics and support facilities.

The following guideline was suggested for working group discussions and reports: consider actual experiences; identify barriers to implementation; identify appropriate analysis techniques; identify data needs; identify opportunities for using risk analysis; identify research needs; list references.

Dr. Tuler also summarized some of the conclusions of a study he is conducting on behalf of MMS to examine the possibilities and limitations of using risk analysis in managing offshore safety. The conclusions of the study are that:

1. Development of offshore activities in the Gulf of Mexico has been gradual; use of risk analysis will become more important for new environments and new concepts.

2. Risk analysis can focus attention on problem areas where R&D is needed.

3. Risk analysis can put discussion of safety on a more rational basis.

The following limitations to risk analysis were identified:

1. Risk analysis tends to focus on catastrophic events and ignore routine events.

2. Consequences that can be quantified tend to assume exaggerated importance compared to those that remain qualitative.

3. There is a perception that risk analysis will lead to more stringent standards. However, there are examples where risk analysis leads to relaxation of requirements.

The full text of the working group reports is presented in Section 2 of this report. The reports are summarized below.

Working Group I, Standards, Codes and Certification

1. State of Practice

Many U.S. Government agencies require or employ risk analysis. During the mid-1970's, MMS commenced requiring use of API RP 14C, Analysis, Design, Installation, and Testing of Basic Surface Safety Systems in Offshore Platforms. USCG implemented a similar requirement in 1979 to apply to MODU's. The most comprehensive requirement was issued by NPD in 1981. Working Group I found some resemblence to the NPD requirements in the "Requirements to Verify the Structural Integrity of OCS Platforms" issued by MMS in 1979, which requires consideration of accidental loadings that must be quantified. API RP 2A, Recommended Practice for Planning, Designing and Constructing Offshore Platforms, also recommends risk analysis for platform sites for which "environmental conditions have not been codified."

2. Problem Areas

In Failure Mode and Effect Analysis (FMEA), unless due care is exercised failure, hazards, downtime, and defects tend to be merged in the single yardstick of "impact", thus obscuring contributing factors.

Human factors such as negligence or the value of human life are difficult to quantify. Even if data are generated, they may not be convincing.

Quantitative reliability analysis is limited by inadequate data bases and deficiencies in modeling. Existing hard data must be supplemented by engineering judgement.

- Probability density functions are difficult to obtain and enormous inaccuracies result when very small numbers at the tails of these functions are obtained by extrapolation.

- Modeling of system reliability considering component interaction requires further study.

- Problems of start-up failures and aging are generally not accurately addressed and the assumption is made that any system that did not fail is as good as new.

- The frequently used assumption of statistical independence of the variables can lead to gross errors.

3. Data Acquisition and Research Needs

Better and more reliable data are needed.

- Data on frequency of loss, exposure, and consequences of loss are needed.

- A Marine Board Committee on safety recommended that MMS establish an OCS safety information system for acquiring comprehensive event and exposure data, calculating frequency and severity of events, and analyzing trends.*

There is need to train practitioners in risk analysis and to educate the public.

4. Opportunities for Application

In the Gulf of Mexico operations, for which extensive experience exists, design methods should be improved by reliability-based procedures. Risk analysis would be very useful for novel design concepts in less known environments. Qualitative, as well as quantitative analyses are appropriate for these situations.

The use of risk analysis in the U.S. voluntary consensus standards is increasing and will further increase in the future.

Working Group II, Concept Evaluation and Design

1. State of Practice

The integration of specific discipline-oriented studies into a single risk projection is difficult in offshore engineering because of the varying qualities of the different data bases. In spite of this fundamental difficulty, a number of examples of effective uses of reliability analysis in offshore design problems are highlighted in the Working Group report: before design (e.g., selection of design wave heights), during design (e.g., gravity structure foundation penetration criteria), during construction (e.g., reliability analysis of underdriven piles), and during operation (e.g., inspection strategies of platforms). It is pointed out that: (1) most of the studies conducted

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*As pointed out by J. L. Rankin, Regional Director, Gulf of Mexico OCS Region, MMS, the Minerals Management Service has established an "Events File" containing detailed information on accidents that occurred and were reported in the Gulf of Mexico OCS. In addition, a semi-annual accident report is published by MMS (Editors' Note).

so far pertain to unusual projects in frontier areas, both geographically and conceptually; (2) these studies were not comprehensive or technically rigorous; and (3) the studies were not developed to a level suitable for routine application.

2. Problem Areas

These were identified as follows:

- Organizational and communication problems.
- The present state-of-the-art in reliability analysis and, in many instances, the lack of sufficient data preclude the use of rigorous analyses.
- The possible perception that reliability can be sterile and meaningless, if used strictly for satisfying regulations, rather than to aid the design decision process.

3. Research Needs

These were identified as:

- Data acquisition
- Technological improvements to reduce modeling uncertainties
- Reliability theory
- Development of procedures, including quality control procedures, aimed at reducing risks due to gross error

4. Opportunities for Implementation and Application

Reliability analysis should be used creatively as a tool for innovative design and decisionmaking, rather than merely as a means of obtaining numbers with possibly dubious physical significance.

Working Group III, Operation and Maintenance

1. State of Practice

The working group report notes that risk analysis should not be viewed as an all purpose tool. Rather, it is one of many tools that may be helpful in identifying and solving some safety problems, particularly for simple components or for subsystems, as opposed to entire facilities. The application of risk analysis is likely to be a useful tool in nonroutine, frontier problems. As far as the design stage is concerned, risk analysis can be used in two principal ways:

- To assist in project development or for initial evaluation by operators of various economic and safety aspects of the design. This is typically done, for example, in the U.K. Sector of the North Sea.

- To demonstrate compliance with statutory numerical targets of risk, as is the case in the Norwegian Sector of the North Sea.

In operation and maintenance, risk analysis may be employed to assist, where appropriate, in developing operating procedures in the form of policy, safety manuals, procedure guides, and contingency plans. Safety procedures are procedures for periodically inspecting, testing, and reporting on all safety devices and redundant procedures. Individual companies are assisted by industry groups in the development of safety procedures. To ensure that safety procedures are properly implemented, continuous training of safety personnel is essential.

Some of the working group members felt that risk analysis may be of value in developing "man-machine" interfaces, which will make human errors less likely, in particular, errors leading to blowouts. However, even if such technological improvements were made, training, experience, and supervision remain the key factors in preventing blowouts.

The working group notes that safety management requires extensive use of redundant systems and safety devices. It also notes that need for extensive computerized systems to track the testing and maintenance of surface and subsurface safety devices.

2. Problem Areas

The application of formal risk analysis methods is associated with difficulties in:

- Obtaining accurate failure mode and failure rate data for the many components of a given system.

- Obtaining accurate probability distributions of losses resulting from system failure, given the absence of sufficient historical data.

- Obtaining operational history related to component failure and prior maintenance work.

- Assessing the influence of human factors, a task that becomes increasingly difficult as the amount of human interactions required for system operation increases.

3. Opportunities for Application

- Efforts to keep failure mode and failure rate data current with the evolution of technological developments, and otherwise supplement reliability data bases.

- Creating training opportunities to familiarize engineers with practical risk analysis tools, since engineers who are routinely involved in the operation and maintenance of facilities are in the best position to identify areas where these tools can be applied effectively.

- Improving training and management with a view to reducing the possibility that human errors might occur.

Working Group IV, Logistics and Support

1. State of Practice

It was noted that:

- Risk to be considered should include serious loss or damage, as well as operability and downtime considerations which are primarily economical.

- Estimated measures of risk are meaningless unless they are linked with acceptability criteria or used to compare alternatives.

- Information on the confidence limits of risk estimates should be retained.

Various methodologies and their application are reviewed, including:

- Theory of second order stationary random processes, which is widely used in the logistics and support field. Applications identified are work barge operability studies, voyage risk analysis for sea fastenings, production jackets, jack-up legs and mounts, tanker loading at offshore terminals, and real-time offshore crane operations.

- Markov process analysis, which is applicable to wind and wave climatologies, ice movements, and operational windows. Examples of applications include logistics and supply relative to the Hutton TLP, and real-time offshore crane operations.

- Queuing Theory, which may be applied to transportation and supplies to offshore platforms, tanker waiting times, and average idle time in offshore oil terminals.

- Time domain simulations (which could be coupled with Monte Carlo statistical methods), which can be used to incorporate nonlinear system elements and to introduce human operator input. Examples of applications are studies of probable oil spill trajectories.

- Monte Carlo statistical methods used in conjunction with other simulation techniques where random variables are incorporated.

2. Data Acquisition and Research Needs

Data needs are in three areas: joint probabilities, statistical data, and distribution of critical system events. Data needs include:

- Wave and sea states
- Ice floes, keels, windows, and accretion rates
- Visibility
- Environmental disturbances to navigation and communications
- Seamanship (i.e., speed vs. directional sea states)
- Capabilities (to cope with adverse conditions)
- Spills; cleanup capabilities vs. broken ice cover, dispersion rates and trajectories in the Artic

R & D needs include:

- Human factors (seamanship, capabilities, real-time feedback effects)
- Nonlinear problems
- Stability and capsize in a seaway
- Roll damping
- Drift forces (shallow water)
- Steep irregular wave fields
- Higher-order response theories
- Statistical decision procedure

3. Opportunities for Implementation

- Consideration of logistics and support during the design stage.
- Consideration of logistics and support as a subsystem in a more global risk analysis (emergency response and assistance, support craft and facilities as a source of hazard).

Barriers to implementation include: institutional barriers reflecting unfamiliarity with the probabilistic perspective (i.e., marine surveyors with specification type rules); the proprietary nature of data; lack of sufficient time during emergencies and salvage situations; and information that cannot be readily utilized by users and operators.

It was noted by the participants that the workshop promoted much-needed communications among practitioners. It was emphasized that the terms "risk analysis" and "risk assessment" are used without a clear definition of their specific meaning, and that risk analysis techniques are more easily applied when considering financial risks than when considering risk to humans.

In addition to the working group reports, much information was conveyed in invited theme papers and other contributions. The theme papers included: an overview of present practice in the U.S.; a review of safety and reliability assessment methodologies; and a review of the use of reliability analysis in the safety management of offshore development projects in Norway.

In addition, information was conveyed on an E&P Forum study of risk analysis in offshore exploration and on a project in which offshore reliability data are collected. These contributions are summarized and presented in Appendix I.

A list of workshop participants is included in Appendix II.

1. INTRODUCTION

The construction, operation, and maintenance of offshore oil and gas production facilities in hostile environments require innovative and frequently untried engineering solutions. The assessment of risk is, therefore, a key element in decisionmaking required for the planning, design, and operation of these facilities.

On March 26 and 27, 1984, an International Workshop on the Application of Risk Analysis to Offshore Oil and Gas Operations was held at the National Bureau of Standards, Gaithersburg, Maryland. The workshop was attended by an invited group of experts. It was organized by the National Bureau of Standards (NBS) and sponsored by the Technology Assessment and Research Branch of the Minerals Management Service (MMS), U.S. Department of the Interior.

The purpose of the workshop was to assess current practice. First, various aspects of the state-of-the-art were discussed by four theme speakers: Mr. F. P. Dunn from Shell Oil Company, Houston, Texas, gave an overview of current U.S. practice; Dr. David Slater from Technica, London, United Kingdom, discussed probabilistic risk assessment methodologies; Dr. Øystein Berg from the Norwegian Petroleum Directorate (NPD) discussed the Norwegian approach to management of offshore risk; Dr. Floyd Tuler from Worcester Polytechnic Institute introduced the topics to be discussed in the course of the workshop. After the presentations of the theme speakers, the workshop participants were organized into four working groups covering the following topics.

Working Group I - Standards, Codes, and Practice

Scope: Application of risk analysis and reliability engineering techniques in the area of standards, codes, and certification.

Chairman: Mr. Stanley Stiansen
American Bureau of Shipping

Working Group II - Concept Evaluation and Design

Scope: Application of risk analysis and reliability engineering techniques to the planning, siting, design, and construction of offshore oil and gas production facilities.

Chairman: Professor Fred Moses
Case Western Reserve University

Working Group III - Operation and Maintenance

Scope: Application of risk analysis to the operation and maintenance of offshore oil and gas facilities.

Chairman: Professor Adam T. Burgoyne
Louisiana State University

Working Group IV - Logistics and Support

Scope: Application of risk analysis in the exchange of material, energy, and personnel between the shore and offshore installations.

Chairman: Mr. Bruce Hutchison
Glosten Associates

Each working group prepared a summary report addressing the following topics:

1. State of Practice (experience in application)

2. Problem Areas

3. Data Acquisition and Research Needs

4. Opportunities for Implementation and Application

The working group summaries are presented in Section 2. Appendix I contains the text and a summary of the theme presentations and other written contributions. Appendix II contains a list of participants.

2. REPORTS OF WORKING GROUPS

INTRODUCTORY COMMENTS TO THE WORKING GROUPS

by

Floyd R. Tuler

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Worcester, Massachusetts

When we were picking a title for this workshop, we of course wanted one that would convey, as best as possible, the purpose and content of the meeting. After listening to the three lectures this morning, I think that we could have used the subtitle - "And how to reduce the probability that the BEST LAID PLANS OF MICE AND MEN OFTEN GO ASTRAY."

There can be no disagreement that everyone concerned with offshore operations wants better ways to anticipate and cope with their hazards. Designers, builders, operators, owners, insurers, workers, regulators, and neighbors would all prefer that the risks associated with these technologies be reduced to the lowest levels that can be achieved at reasonable cost. But disagreement might arise over what are the hazards, to what levels can they be reduced, and what is a reasonable cost for reducing them.

Risk analysis is a relatively new and promising approach which might be used to identify, analyze, and manage the hazards associated with complex technological projects such as offshore oil and gas operations. A full risk analysis of a design or an operating procedure requires a number of steps, as shown in figure 1.

First, an analysis is performed to identify the hazards, and the risks and consequences associated with these hazards. Next, based on acceptance criteria and other requirements, the risks are evaluated by asking the question - are they acceptable? That is, does the estimated level of risk meet the acceptance criteria and other requirements?

If the answer is NO - the design or procedure must be revised or the criteria or requirements could be modified. If the answer is YES, the design or procedure is acceptable and the activity proceeds to whatever the next step might be. The risk assessment is essentially a technical activity, and forms the major part of the concerns of Working Groups II, III and IV. The setting and definition of the acceptance criteria and other requirements is the concern of Group I. Before I discuss the specific tasks facing the working groups, I would like to take a few minutes to briefly summarize some important issues raised this morning as they relate to the deliberations of the working groups.

Pat Dunn, in his discussion of current practice in the U.S., highlighted a problem that we are all going to have with definitions. The working groups will need to make clear what they mean when they use these various terms.

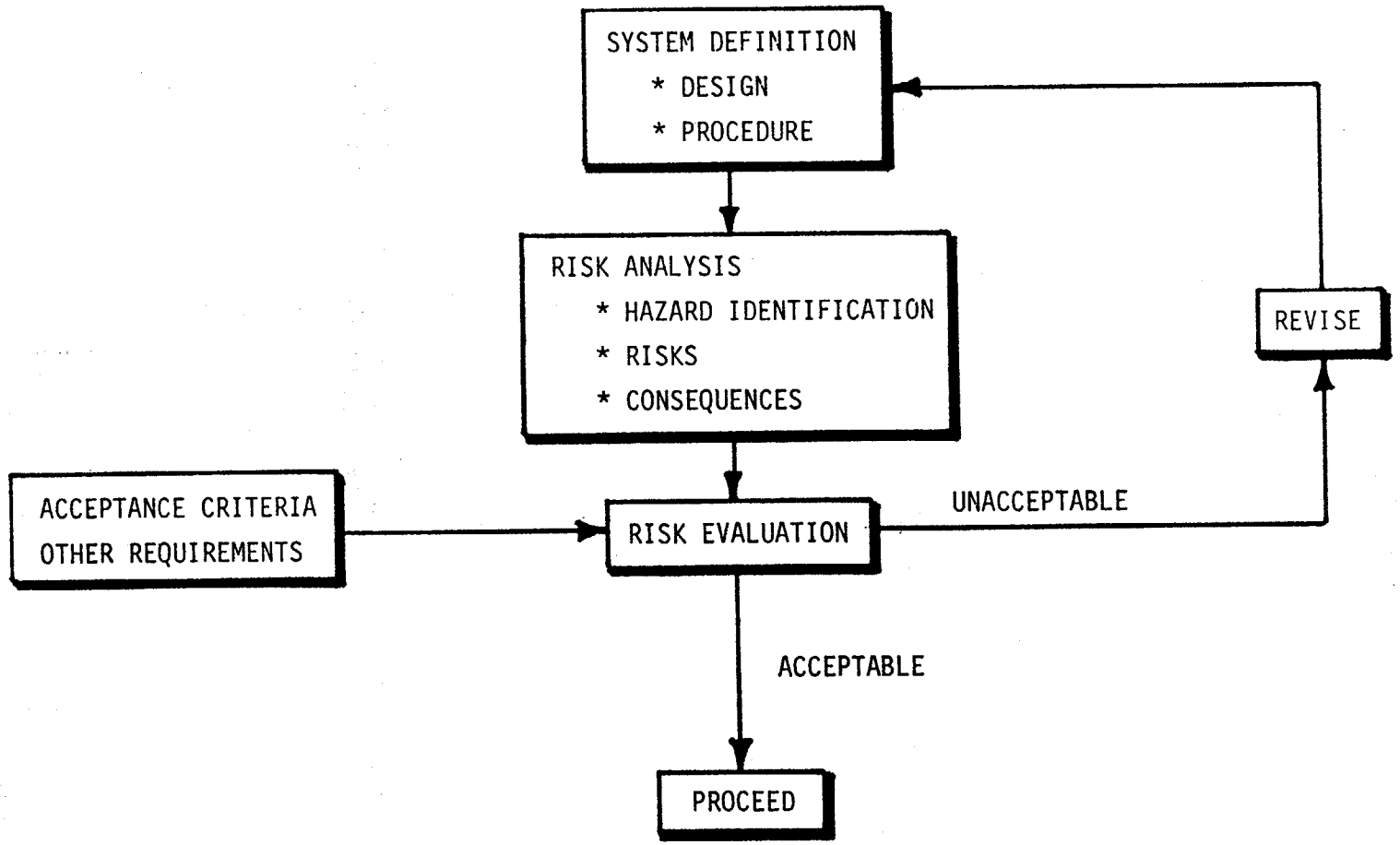

Figure 1 - Flow Diagram of Risk Analysis

There is an important distinction to be made between a reliability analysis which considers the failure of a component or subsystem subjected to an isolated event and a risk analysis which considers the interaction between components and subsystems subjected to a combination of events. Pat described some useful applications of reliability analysis, as shown in figure 2.

First, he gave us an example of the optimization of a structural design concept given uncertainties in both the loading conditions and the response of the structure. He also gave us some interesting examples of how reliability analysis has been used to develop API recommended practices for structural design and criteria for installations in the Gulf of Mexico, and how recommended API practices and specifications for well completion systems were based on an analysis incorporating the reliability of key components. In addition, he described how a formal risk analysis was used by manufacturers and operators as background for API recommendations on operation and maintenance of offshore cranes. These examples highlight two broadly different uses for risk analysis - and I'll have more to say about this later.

The next speaker, Øystein Berg, gave us an overview of the regulatory framework for offshore operations in Norway, and their specific use of risk analysis in the approval procedure for an offshore installation, (see figure 3). Ten different safety analyses were suggested for the early phases of the project when it is easier and less costly to influence the final results. Through these analyses the safety of an installation can be checked at three levels:

SERVICEABILITY CONTROL - or what might be called by some an availability study. This is concerned with reducing downtime.

COMPONENT FAILURE CONTROL - is concerned with structural, equipment, and component reliability.

These two risk evaluations are generally covered by existing codes, regulations, and practices.

The third type of safety evaluation - MAJOR ACCIDENT CONTROL - is concerned with analyzing the risks to the complete installation when an unfavorable event might jeopardize a large number of lives or cause severe pollution or major economic loss. The procedures and criteria for major accident control were not directly covered by existing codes and regulations in Norway, so a requirement was introduced for executing a concept safety study. The evaluation is based on specific design accident events, such as blow-out, fire, explosion, extreme weather, and combinations of these. Specific criteria for evaluating the risks are specified in guidelines so that although formal risk analysis is not explicitly mandated, it becomes the best method by which the risks can be identified for the evaluation. The aim of the concept safety evaluation is to establish an acceptance level to risk for the entire system.

The issues raised by constrasting the U.S. and Norwegian systems of safety management could keep Working Group I busy for months, I'm afraid, rather than the allotted time of less than one day.

OVERVIEW OF CURRENT PRACTICE (F. P. DUNN)

RELIABILITY ANALYSIS OF COMPONENT OR SUBSYSTEM

- OPTIMIZE STRUCTURAL CONCEPT
- DEVELOP RECOMMENDED PRACTICE
  - STRUCTURAL DESIGN CRITERIA
  - OFFSHORE CRANES

Figure 2 - Summary of Applications of Reliability Analysis from Paper by F. P. Dunn

MANAGEMENT OF OFFSHORE RISKS IN NORWAY (Ø. BERG)

RISK ANALYSIS REQUIREMENTS IN APPROVAL PROCEDURES

SAFETY MANAGEMENT FRAMEWORK

- SERVICEABILITY CONTROL
- COMPONENT FAILURE CONTROL
- MAJOR ACCIDENT CONTROL
  - CONCEPT SAFETY STUDY
  - EXPLICIT ACCEPTABLE LEVEL OF RISK

Figure 3 - Summary of Management of Offshore Risks in Norway from Paper by Ø. Berg

The last speaker, David Slater, reviewed the techniques for doing the full range of safety and reliability studies. Since we didn't have his paper in advance, we'll have to make do with the generic slide shown in figure 4. For the most part, the examples were for applications of the various techniques to operations in the North Sea. He stated that this is rarely a problem, and I hope that this point will be actively debated in the workshops. He also contrasted the use of analysis methods such as Hazard and Operability Studies and Failure Modes and Effects Analysis with the widely used API Recommended Practice RP 14C for setting minimum standards for surface safety devices. More than one of the working groups can address this issue.

For the last one and a half years or so I have been involved in a study for Sandia National Laboratories in cooperation with the Minerals Management Service, in which we examined the possibilities and limitations of using risk analysis in managing offshore safety. Two of my colleaques on this study - Chris Hill and David Cheney - are also here. The last major policy study of offshore safety, "Energy Under the Ocean," was done in 1973 and a lot has happened since then to make a review of the use of risk analysis for offshore projects worthwhile. Although the final report has not been completed, I can briefly summarize of some our conclusions as they may be relevant to the working groups:

- Development of offshore activities in the Gulf of Mexico, where we have most of our experience, has been evolutionary. Use of risk analysis becomes more important when new environments are encountered and new concepts are considered.

- Risk analysis can focus attention on problem areas where research and development are most needed.

- Risk analysis is a tool which can put discussions of safety on a more rational basis for all the interested parties. Publication of assumptions, methods, and results could help to allay concerns about offshore safety. Furthermore, recent legal developments indicate that there could be liability associated with not using state-of-the-art techniques.

We also identified some limitations of the use of risk analysis:

- Formal risk analysis tends to focus attention on the catastrophic events while ignoring the more routine events which in aggregate may also cause significant loss and damage. Thus, formal risk analysis should not be a substitute for other more traditional approaches to safety management.

- Risk analysis may be subject to the fallacy of "misplaced concreteness," in which the consequences that can be quantified take on an exaggerated importance relative to those that remain more qualitative.

- Finally, there is a general perception that risk analysis always leads to more stringent standards. However, there are examples which show that risk analysis can lead to a relaxation in specified requirements.

METHODOLOGIES FOR ANALYSIS OF SAFETY AND RELIABILITY

(D. H. SLATER AND R. A. COX)

CONCEPTUAL DESIGN SAFETY EVALUATIONS

HAZARD ANALYSES

STRUCTURAL RELIABILITY

SHIP COLLISION

Figure 4 - Summary of Methodologies for Analysis of Safety and Reliability from Paper by D. H. Slater and R. A. Cox

The details of these conclusions and our recommendations will have to wait a little longer for the completion and submission of our report.

I finally come to a discussion of the task of the working groups. The chairman for each group has prepared a position paper and you should have copies of these papers. In each case, these papers provide the background for the concerns of the working group. In addition, the earlier papers have substantive conclusions concerning the application of risk analysis to the topics of the respective working groups. It is up to the group at accept, reject, or modify the position paper and in particular the conclusions. I will discuss the scope of each working group, but you should realize that the boundaries between the groups are elastic and fuzzy.

The chairman of Working Group I is Stan Stiansen from the American Bureau of Shipping and the rapporteur is Charles Bookman, of the Marine Board (see figure 5). Working Group I is concerned with the application of risk analysis and reliability engineering techniques in the formulation of standards, codes, and certification requirements.

Risk analysis can play two separate roles in this area. As we heard in Pat Dunn's presentation, risk analysis and reliability analysis can be used to provide the basis for detailed specifications or for recommended practices. And as we heard in Øystein Berg's presentation, one or more risk analyses might be required as part of the approval procedure for a project. These two uses of risk analysis are intimately tied to the differences between performance standards and specification standards. Specification standards can represent the cumulative knowledge and experience of all those concerned with the particular technology. On the other hand, performance standards tend to encourage innovative solutions to specific problems, taking into account the particulars of each case.

The second working group has as its chairman Professor Fred Moses from Case Institute of Technology; the rapporteur is Professor Paul Wirsching from the University of Arizona (see figure 6). The concern of this group is the application of risk analysis and reliability engineering techniques to the planning, siting, construction, and maintenance of offshore structures. This scope is different than originally planned - construction, maintenance, and inspection of the structure are added concerns. Our speakers this morning highlighted what is one of the central questions for this topic. From one point of view, the reliability of components and subsystems is analyzed when they are subjected to isolated accidental events. In the other case, the safety of the total system is evaluated, based on consideration of the interactions between the components and subsystems when they are subjected to accidental events which may occur in combinations. Since there is already a large and growing activity in considering the total system safety, it would be particularly helpful here to amplify on some specific examples - giving details of the techniques used and the results.

Working Group III is concerned with the application of risk analysis and reliability engineering to design, operation, and maintenance of offshore facilities (see figure 7). By facilities I mean the production systems, which is again a

WORKING GROUP I

STANDARDS, CODES, AND CERTIFICATION

CHAIRMAN: STANLEY STIANSEN

RAPPORTEUR: CHARLES BOOKMAN

APPLICATION OF RISK ANALYSIS AND RELIABILITY ENGINEERING TECHNIQUES IN THE FORMULATION OF STANDARDS, CODES, AND CERTIFICATION REQUIREMENTS.

* AS BASIS FOR FORMULATION
* ANALYSIS REQUIREMENTS
* PERFORMANCE STANDARDS VS SPECIFICATION STANDARDS

Figure 5 - Working Group I - Standards, Codes, and Certification

WORKING GROUP II

CONCEPT EVALUATION AND DESIGN

CHAIRMAN: FRED MOSES

RAPPORTEUR: PAUL WIRSCHING

APPLICATION OF RISK ANALYSIS AND RELIABILITY ENGINEERING TECHNIQUES TO THE PLANNING, SITING, AND CONSTRUCTION OF OFFSHORE OIL AND GAS PRODUCTION FACILITIES.

* SYSTEM SAFETY/SUBSYSTEM RELIABILITY

OPTIMIZING REMEDIAL CONSTRUCTION STRATEGIES

ESTABLISHING DESIGN CRITERIA

SPECIFYING STRUCTURAL DESIGN PARAMETERS

Figure 6 - Working Group II - Concept Evaluation and Design of Structure

WORKING GROUP III

OPERATION AND MAINTENANCE

CHAIRMAN: ADAM BOURGOYNE

RAPPORTEUR: STRUAN SIMPSON

APPLICATION OF RISK ANALYSIS AND RELIABILITY ENGINEERING TECHNIQUES TO THE OPERATION AND MAINTENANCE OF OFFSHORE OIL AND GAS FACILITIES.

* DEVELOPING OPERATING PROCEDURES, POLICY, SAFETY MANUALS, PROCEDURE GUIDES, CONTINGENCY PLANS
* OPTIMIZING MAINTENANCE PROCEDURES AND SCHEDULING

Figure 7 - Working Group III - Operation and Maintenance of Production Systems

change in scope. Professor Ted Bourgoyne from Louisiana State University is the chairman, and the rapporteur is Struan Simpson of the E&P Forum in London.

In this area, applications of risk analysis could include the development of procedure and plans for safe operation of the installation and for optimizing maintenance procedures and scheduling to reduce downtime. Specific problems in using quantitative risk analysis in these areas have been pointed out by Ted Bourgoyne in this paper. These include:

1. lack of data for failure modes and failure rates of components,

2. not having accurate probability distributions for the consequences of a system failure, and

3. how to predict human errors.

Working Group IV is concerned with Logistics and Support. The chairman of this group is Bruce Hutchison from the Engineering consulting firm of Glosten Associates (see figure 8). The topics to be covered by this working group include the application of risk analysis in the movement of material, energy, and people between the shore and the offshore facility. The uncertain hazards of the offshore environment complicate considerably the setting of schedules and inventories under normal conditions. But the feasibility and optimization of the transfer of equipment and personnel needed to deal with an accidental event must also be considered. Optimization of windows of opportunity for both normal conditions and crisis conditions can greatly increase safety and minimize undersirable consequences and costs.

Finally, I would like to present to all the working groups a general list of guidelines and issues to be considered for your reports.

1. As much as possible in the short time that you have, you should share specific experiences with actual applications of risk analysis to offshore operations. These should include both positive and negative experiences - successes and failures. Just as the combined experience of a number of workers leads to the best choice for a component or operating procedure, combined experience will lead to the best use of risk analysis as a tool for safety management. We need a common understanding of the strengths and weaknesses of this tool. And without knowing what has been tried before and what the results were, it will be difficult to improve our ability to use risk analysis.

2. What are the barriers to implementation of risk analysis in your area? Are they technical barriers, such as insufficient data or inadequacies of the techniques, or are the problems organizational and institutional?

3. You should identify which analysis techniques are most appropriate for specific applications. (This is really a part of the first item.)

4. Every working group can look to the common problem of inadequate data. This particular barrier for the application of risk analysis is so important

WORKING GROUP IV

LOGISTICS AND SUPPORT

CHAIRMAN: BRUCE HUTCHISON

APPLICATION OF RISK ANALYSIS IN THE EXCHANGE OF MATERIAL, ENERGY, AND PERSONNEL BETWEEN THE SHORE AND OFFSHORE INSTALLATIONS.

* OPTIMIZING SCHEDULES AND QUANTITIES
* IDENTIFYING HAZARDS

Figure 8 - Working Group IV - Logistics and Support

that I have put it down as a separate item on this list. What kind of data are needed? And what should we do about it?

5. Can we identify opportunities for using risk analysis at present? How can we use risk analysis given the current data base and current methodologies?

6. What do we need to make the application of risk analysis more effective? What should our research priorities in your area be, short range or long range? What could we do if we had the answers from this research and development that we cannot do now?

7. Finally, we don't expect that you will produce an all encompassing bibliography; but specific references and knowing the bounds of proprietary information would make our proceedings and recommendations much more useful to those who will follow what comes from this workshop.

In conclusion, we want to thank you in advance for your participation in the working groups. We know that the time is short for dealing with the broad topic covered by this workshop; but the time is ripe and the opportunities are exciting for applying risk analysis to the problem associated with offshore operations.

Good luck in your efforts!

STANDARDS, CODES AND PRACTICES

REPORT OF WORKING GROUP I

1. INTRODUCTION

At the Mineral Mangement Service (MMS)/National Bureau of Standards Workshop on the Application of Risk Analysis to Offshore Oil and Gas Operations, a session was convened on "Standards, Codes, and Practices." The membership of the working group is attached. The interpretation of the working group of its charge was to investigate the application of risk analysis and reliability engineering techniques in the area of standards, codes, and certification practices. It includes the use of risk analysis in the formulation of standards, codes, practices, certifications, and regulations, the requirement in standards and regulations that quantitative risk analysis be employed, also, the voluntary use by industry of risk analysis to comply with standards and regulations.

1.1 DEFINITIONS

The working group found it necessary to define the terms risk analysis, reliability analysis, and safety analysis, in order to clarify meanings and uses of the terms during the discussions.

The consensus of the working group favored the definition that risk, R, involves the likelihood (probability) of an undesired event, F, and the consequences of the event, C, i.e.:

$$R = R(F,C)$$

Some working group members indicated the need to consider the setting in which the event probability and consequences were being considered, or the "exposure," E, as part of the expression of a risk.

$$R = R(F,C,E)$$

In this connection, exposure would be needed so the risk estimates can be related directly to specific activities being considered for safety action, standards, or regulations. It would also be needed to set priorities for safety action among such activities, and for locating the high risk subactivities for which further information might be needed. If exposure is included, risk would be expressed in terms of probable consequences per unit of exposure during the activity being analyzed, i.e., the probability of disabling injury per hour of drilling operation, or crane operation, or per hundred wells drilled, etc.

Risk analysis may take one of two forms at the top level. Qualitative risk analysis is any consideration of events that could lead to failure, and their consequences. Events are to be treated at a system level, rather than as isolated events. Quantitative risk analysis refers to any number of methods which provide a statistical foundation to the understanding of risk.

Safety analysis to assess risk was also discussed. The point was made that safety analysis methodically seeks to discover and assess potentially harmful interactions among system personnel, equipment, and procedures, and how "failures" of components (including personnel) are accommodated by the system to control the harm that could occur. With the consideration of exposure in the latter expression of risk, risk analysis helps satisfy the safety analysis need.

Some members of the working group suggested the need to delineate the very different nature of terms such as risk assessment, risk analysis, reliability analysis, safety analysis, and engineering analysis. However, the view which opposed this thought should be noted.

1.2 RISK OF OFFSHORE OPERATIONS

The conduct of any operation inevitably involves risk. The degree of risk varies with the task and types of risk generally always include property, personal injury, and damage to the environment. The offshore operations are no exception. Some of the risks in conducting offshore oil and gas operations may be generic as existing in any engineering system and some may be due to its unique nature related to its complex operating environment. Traditional thinking often regards experience in design, construction, and operation of offshore systems as the best safeguard against risks. The value of this contention can hardly be disputed as evidenced by the superior safety record of the oil and gas operations in the Gulf of Mexico. Yet losses have occurred partly due to omission to account in design for certain "unlikely" events but mostly due to the uncertainties in design variables, methodology, and the interaction of human elements. These incidents often lead to improvement of standards and practices to overcome the deficiency. The process is therefore corrective but in many cases lags occurrence of an identifying incident. It should also be noted that loss of one component or one subsystem is not necessarily self-contained. The loss may propagate and trigger other losses and may ultimately lead to the loss of the entire system, depending on the individual design.

Aside from the basic variables encountered in design (e.g., structural design), human factors must also be regarded as part of the system. In one source of statistics pertaining to offshore structures, human errors account for more than 85 percent of all losses. It is therefore logical to include human factors in risk assessment. Human errors may be present in the design, construction, inspection, maintenance, and operations of the offshore installation. Such errors can lead to component/system malfunction or damage.

It is particularly important to take risks into account in the development of technology for offshore systems especially under novel operating conditions. Unlike some fully tried and tested engineered systems such as an automobile system or a glycol dehydration unit where the basic subsystems and general configuration among all makes and years are essentially the same, the differences in offshore environments (usually geographic areas) dictate that past experience in one environment may not be automatically applicable with high confidence in another environment. For instance, experience drawn from the successful design of risers operating in 100 foot water depths may not be directly transferred to the design of risers for use in a tension leg platform in 1500 feet of water.

Additional investigation, engineering analysis, testing, and observations are necessary. The fact that there is more variability in offshore structures or that there is less experience associated with deeper waters requires that engineers and planners would be wise to mobilize all available means, including risk analyses, and probably be more conservative in their designs, and/or do more experimenting and testing.

2. STATE OF PRACTICE OF RISK ANALYSIS

2.1 ROLE OF STANDARD-MAKING BODIES

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, then they should be included as a part of the general formulation of the standards, codes and practices. On the other hand, these goals are presumably achieved when standards, codes, and practices or regulations already require engineering analysis sufficient to produce a safety record that appears to be acceptable to society. In order to justify additional requirements it must be shown that they will materially improve safety. 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 is accomplishable, is it cost effective.

2.2 USE OF RISK ANALYSIS

Risk analysis is employed in many applications in both the private sector and in the government. Within the U.S. Government, risk analysis is required or employed by the Materials Transportation Bureau of the Department of Transportation, the Consumer Product Safety Commission, the Nuclear Regulatory Commission, the Department of Energy, and the National Transportation Safety Board, to name a few. The purpose of this section is to review the use of risk analysis by regulatory bodies of the offshore oil and gas industry.

2.2.1 Requirements in Standards and Regulations

Engineering analysis has been inherent in codes of practice and regulations since their inception. Formal, explicit requirements in regulations for reliability analysis, safety analysis, and risk analysis have come into being more recently.

During the mid-1970s, the MMS commenced requiring the use of API RP 14C, "Analysis, Design Installation and Testing of Basic Surface Safety Systems on Offshore Platforms." This was followed in 1979 by the USCG implementing a similar requirement for industrial equipment on Mobile Offshore Drilling Units. The most comprehensive requirement for safety analysis, which presumes the use of some form of risk analysis, in the offshore is the "Guideline for Safety Evaluation of Platform Conceptual Design" issued by the Norwegian Petroleum Directorate (NPD) in 1981.

Several characteristics of the NPD guidelines are worth noting for their breadth of scope.

- Safety analysis is to be performed at the installation's conceptual design stage.

- Accidents to be evaluated include "...blow-out, fire, explosion and similar incidents, falling objects, ship and helicopter collisions, earthquakes, other possible water conditions, and relevant combinations of these incidents.

- No specific methods of approach have been specified except that the safety analysis "...should be carried out at a superior system level," and that "the intention is not to include calculation of residual risk," i.e., only qualitative analysis would suffice. However, as an order of magnitude guideline, "...the total probability of occurrence of each type of excluded situation would not, by best available estimate, exceed 10^{-4} per year...."

Some key points in the philosophical aspects of the NPD Guidelines can be readily observed. The NPD Guidelines recognize that in the conceptual design stage, the design is not adequately developed to apply detailed design requirements. It requires that the overall safety of a platform conceptual design be evaluated with respect to certain accidental conditions which could threaten the survival of the platform or the personnel. These are called "design basis accidents" and are required to be considered at the earliest phase of design.

Referring to the items of hazard analysis mentioned in the second item in the foregoing, one may find resemblance among other regulations. For example, in the "Requirements for Verifying the Structural Integrity of OCS Platforms" issued by the MMS in 1979, similar requirements are stated:

> "Considerations shall be given to accidental loading, and where such loadings are incorporated in design, they shall be quantified."

The requirements then proceed to exemplify some of the accidents which bear striking resemblance to the partial list given in the foregoing, with the exception of earthquakes and extreme weather conditions which are not regarded as accidents and are covered elsewhere in the MMS Requirements.

The intention of the MMS Requirements is to recognize the potential danger of such accidental events, and to require that they be taken into account in the engineering analysis. The particular logical tool employed by the engineer, which may include risk analysis, is not specified.

In the U.S. Coast Guard's regulations covering mobile drilling units, and, to some extent, compliant structures, certain requirements aiming at reduction of risks also exist. For example, requirements regarding hazard warning systems, structural arrangement and equipment to provide adequate escape means, etc., can be all grouped under the guiding principle of reduction of probability of

hazard occurrence and consequences. Classification rules in this regard generally are compatible with the MMS and the USCG requirements, where applicable.

The American Petroleum Institute's "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms," RP 2A, recommended that a risk analysis be performed to determine design environmental conditions for platform sites for which environemental conditions have not been codified. This risk analysis is to include "...the estimated cost of the platform designed to environmental conditions for several average expected recurrence intervals; the probability of platform damage or loss when subjected to environmental conditions with various recurrence intervals; the financial loss due to platform damage or loss including lost production, cleanup, replacing platform and redrilling of wells, etc. As a guide, analyses have indicated that the optimum average expected recurrence interval is several times the planned life of the platform."

A complete listing of relevant regulations and the governmental agencies accorded the mandate to regulate the U.S. offshore oil and gas installation has been compiled in a report entitled, "Safety and Offshore Oil," by the Committee on Assessment of Safety of OCS Activities, Marine Board, Assembly of Engineering, National Research Council in 1981.

2.2.2 Analytical Methods

There are numerous analytical methods employed in risk analysis. The methods described in this section exemplify what can be done in light of the present state of technology to satisfy the existing regulatory requirements under the overriding principle of reduction of risks and consequences.

A credible risk analysis requires a team effort. This team should consist of experts in hazard analysis, experienced designers, system analysts, platform managers, and those trained in estimating consequences. Most of the analytical models for risk analysis (e.g., event and fault tree techniques, and failure mode and effect analyses) are well known and have been successfully applied in other industries. The detailed knowledge of the particular project and the experience gained in similar past offshore projects that the team can assemble is the significant part of the risk analysis effort. As such, risk analysis should not be viewed as an exercise in probability and statistics but as an opportunity to marshall all resources (analytical, engineering, and management) to arrive at logical and rational decisions.

2.2.2.1 Analysis of Design Basis Accidents

The primary objective of this step is to identify the possible undesirable consequences of the chain of events that may follow a specific event. The following series of analyses are generally pursued.

- Event Selection. This step identifies consequences of a hazardous event. For example, in case of fire, explosion, and surface blowout, the possible consequences are the triggering of secondary fire or explosion under the most unfavorable wind conditions, elimination of escape routes and

equipment, reduction of escape time, destruction of valves, pipelines that handle hydrocarbons, etc.

- Event Design Loads. Determination of maximum accidental loads after the occurrence of identified events which may jeopardize the survival of the platform structure.

- Design Evaluation. Evaluation of the design concepts and recommendations of necessary revisions in design to enhance the survivability.

2.2.2.2 Failure Mode and Effect Analysis (FMEA)

The FMEA is intended to identify and examine all possible features of the failure modes and their effects on the major subsystems of an offshore installation. The basic features generally include:

- a list of the system components,

- a list of the functions of the components,

- execution of a functions block diagram identifying the components and their functional interdependencies can be considered as a desirable preliminary stage of FMEA,

- modes of failure which are considered for each component,

- probable causes of each failure,

- effects of each failure.

A rigorous probabilistic treatement of these items may not be within the present state of practice. However, engineering judgement may be exercised, leading to an "impact index" based on the frequency of the failure modes and their severity. The impact index so evaluated can be used to identify the most severe failure mode or modes. Note that severity in this context is measured by the consequences of the failure, including its cost both tangible and intangible, and by the acceptability of the failure event to the parties concerned.

The typical failure modes of concern are high severity, low frequency events. Low frequency, low severity failures are possibly inconsequential, while low severity, high frequency events are a nuisance and should ideally be designed-out.

2.2.2.2 Fault Tree Analysis (FTA)

The FTA is intended to integrate the elements that stand alone in FMEAs. However, the FTA need not be considered in relation to FMEA, since it can be conducted independently. It is also a convenient way to incorporate human error. The fault tree connects, by means of AND gates and OR gates, events which contribute to the undesirable event of interest. It is constructed deductively, beginning with a single specific undesirable event, and then systematically

identifying all known events which could cause or contribute to the occurrence of the undesirable event. If the probabilities of occurrence of the basic events are known, they can be used to estimate the probability of occurrence of the top undesirable event. Even if they are not known, the FTA still can be helpful to the analyst in identifying the critical paths in the system. Interactive software packages which help in constructing the fault tree and which carry out the subsequent probabilistic analysis are commercially available.

3. PROBLEM AREAS

The discussion on available methods of risk analysis is by no means complete. It simply demonstrates that within the state of technology, means of analysis to satisfy the risk assessment requires currently specified in codes and standards are available.

Having recognized this, it should be noted that, even within the scope of qualitative assessment, the situation is far from ideal and many problem areas exist. It would be pointless to argue the merits and shortcomings of the methods of analysis without an exhaustive compilation and thorough evaluation of available methods. It is not the intention of this paper to provide the final analysis in the identification of problem areas which remain the charge of the other work groups. However, for illustration purposes, a critique of a hypothetical risk analysis employing the methods and criteria mentioned in the foregoing are presented here.

3.1 INTERACTION OF DESIGN AND RISK ANALYSIS

One major difficulty the analyst may expect to encounter stems from human sources rather than from the process or equipment employed.

Risk analysis is, in general, employed in two ways by designers, analysts, and decisionmakers. At the concept design stage, risk analysis is used to describe risks at the system level, and to gain an appreciation of the feasibility of the concept from the standpoint of coping with risks. Risk analysis at the concept design stage is also useful in establishing design criteria. Risk analysis is employed in the detail design stage to obtain some degree of confidence that the system as proposed provides the level of safety desired, and to optimize the design to this end.

In both instances, the risk analysis is a distinct element of project engineering, similar in some organizational respects to the quality assurance function during construction -- separate from but a part of, the engineering activity.

3.2 QUANTIFICATION OF VARIABLES AND THEIR ROLES IN IMPACT RATING

The second difficulty relates to the simplicity of quantification in the FMEA example discussed earlier. By necessity, due to lack of more precise data, the complex issues like failure, hazard, downtime, and defect have been merged into a single yardstick called "impact". By obscuring the source of contributing factors, this oversimplified measure may not be very useful in providing guidance in prioritizing the various remedial actions. However, the basic idea of using

small number of parameters is sound. Since the term "impact" has been only conceptual heretofore and its definition has been avoided for the sake of generality, improvement within this approach is possible by the proper usage of the impact parameter. For example, if cost-effectiveness in design revision was the one issue that need guidance from this parameter, a system of cost rating in FMEA similar to the probability and effect rankings can be expressed in terms of prevention cost as a result.

3.3 QUANTITATIVE ANALYSIS

Problems in the area of quantitative risk analysis are much more deep-rooted and complex. Nevertheless, they can be grossly categorized into two major obstacles, namely, the questions of data base and probabilistic modeling.

3.3.1 Data Base

In order to address the issues of data base, the question of quantifiability of data should be placed in focus. There are data which result from scientific measurements usually referred to as "hard" data. For example, yield strength of a steel or the life of an electric relay can be statistically quantified so that the main question in this regard would be the population of the data pool used in the statistical analysis. Other commonly used terms are safety or design factor, bearing life, fatigue life, etc. Data of this sort are generally noncontroversial. Others may be quantifiable but, due to a variety of reasons such as cost of data acquisition or the relative young age of the product which precludes the existence of a sufficient data pool. Some, as a practical matter, may not be quantifiable with usable accuracy because life-dependence on specific site or application parameters gives a continum of populations -- values whose life depends on corrosivity, for example. For both the latter situations, engineering judgements are needed to supplement or even to replace data. In such a case, it is generally agreed that the uncertainty of data poses a greater problem than the bias. These are the areas in which standardization of practices through documents such as API RPs (Recommended Practices) provide tremendous assistance to safe operations.

Devices such as the Delphi method or its variations designed to cope with experts' disagreement are widely used but have yet to approach resolution of the issue. Finally, items such as human behavior (e.g., negligence-related to forgetfulness), human value and human life are extremely difficult to quantify and the data, if any, may stand indefensible.

In a report "Risk and Decision Making: Perspective and Research," prepared in 1982 by the Committee of Risk and Decision Making, National Research Council, the dilemma of lack of data of confidence in the data available was put in focus:

> "In the debate on how far to quantify, as in most long-standing debates, there are errors of two kinds in the balancing equation: a false sense of precision with numbers may give the impression that more is known than is really known; and a false sense of impression without numbers may give the impression that less is

known than is really known." "...If you do not use probabilities, then what do you do and how will it respond to policy needs?"

While a clear-cut solution of this dilemma is not available at the present, continued research appears to hold the key to the prospect of meaningful use of the quantitative risk analysis. One emerging approach uses the occurrence and frequency of timed events sets which are parts of a postulated or actual accidental process. Common events building blocks, with a consistent structure, are used for risk estimates, task design, task monitoring, and mishap investigation. Through observation of task performance and investigations, occurrence of critical, timed events sets identified in postulated and actual accidents can be measured and their influence on task outcomes recorded. The approach lends itself to Delphi, observations or experimentally developed frequency estimates.

3.3.2 Probabilistic Modeling

Regarding probabilistic modeling, potential problems are again numerous. Data, whether they are hard data or engineering judgements, are often not expressed in terms of probabilities of failure. For example, the term "mean time to failure" is quite popular. Translation between whatever measure being used in raw data to a probability requires a proper postulation of the probability density function (pdf). This must be made with extreme caution since the tail end of the pdf is generally most significant and potential inaccuracy is enormous in dealing with extremely small numbers through extrapolation techniques. Similar care must also be exercised in the probabilistic modeling of a system or subsystem. For example, the tendon string of a tension leg platform appears to be a system of individual segments connected in series (where the fatigue behavior of interconnecting joints may be critical). The collection of such strings that form a tendon group at a corner of the platform may be regarded as a system in parallel. The probabilistic modeling of the two cases evidently requires different treatment. Theoretical development of this kind has not reached a stage of gaining universal acceptance at this time.

Another issue in statistical modeling is the problem of start-up failures or aging. Not accounting for these would imply that the percentage of systems in operation at a given time which would fall in the next interval of time is independent of time. In other words, as long as a system has not failed, it is as good as new, an obviously nonconservative assumption. Certain items such as reduction in strength due to corrosion wastage can probably be quantified albeit crudely. It is not certain how others such as the remaining effectiveness of a warning system or the fatigue behavior of a structural system can be properly modeled to account for aging.

The hypothesis of statistical independence of random parameters which is so commonly made for the sake of convenience in analysis, is another potential source of gross error. Strictly speaking, as a starting point, the joint pdf of failure for all the components must be known and subsequent multidimensional integration would be required, a prohibitive proposition as it now stands. Without it, how failure would be properly represented statistically remains an outstanding issue. However, it is acknowledged that partial solution to such

problems exists in the structural reliability in that the correlation among component failures can be properly incorporated as is done in some analysis computer codes.

4. DATA ACQUISITION AND RESEARCH NEEDS

Assuming there are areas in which the need can be justified and given the numerous problem areas as discussed in the foregoing, perhaps one proposition that would meet universal agreement is the need for more reliable data, a better understanding, and better methods of risk analysis through further research. Evidently the type of data regarding the risks of failure depends upon the system under consideration and on the method of analysis employed. Therefore, a systematic synthesis of all possible situations expected to be encountered in a risk analysis would be necessary prior to drafting a plan for the actual gathering and analysis of data. In other words, the identification of data needed is in itself a research topic. Even so, the scope of such an effort is necessarily limited to addressing data needs with reference to existing approaches in risk analysis.

5. ASSESSMENT

In light of the foregoing discussion of the state-of-the-art, the working group offers the following points.

5.1 VALUE OF RISK ANALYSIS

Risk analysis is one of a number of analytical processes or tools which help to give an understanding of critical paths to system failure, and the consequences of failure. This understanding improves the ability to target design efforts and safety resources to the safety problems of greatest concern. One of its major contributions is in the description of interactions of the elements of the total system. To the extent that risk analysis can be done on a quantified basis, the potential of the analytical technique to aid in the iterative processes of engineering design and system safety is increased.

Interest in risk analysis arises because of the growing demand to demonstrate the validity of plans for achieving an acceptable level of safety performance. In any operation with potentially unacceptable safety or pollution risks, the parties who might be harmed, and their representatives in government, desire the party introducing the risks to assure that reasonable safety measures have been prepared, and they are likely to achieve the desired results. The value of risk analysis lies, partly, in satisfying these concerns. Risk analysis, like other approaches can address interactions among people and procedures, the handling of emergencies, and the range of consequences, as well as hardware and environmental behavior. By asking different questions, using different analytical methods, and expressing outcomes in different terms, properly performed risk analysis may discover kinds of safety problems that engineering analyses may not be seeking. Such a risk analysis would place equal emphasis on all conditions: operating, extreme environmental and accidental conditions. Risk analyses done in other industries (e.g., nuclear) have shown that the contribution to risk comes mostly from "smaller than design basis" events.

Risk analysis models may be used in availability and maintainability studies. Risk analysis results may also be used in identifying areas for safety training.

5.2 USE OF RISK ANALYSIS

Risk analysis may be beneficial for well-studied design concepts for which extensive experience exists. The design of such platforms (e.g., in the Gulf of Mexico) may be improved and mode consistent by using reliability-based design procedures (see, for example, The American Institute of Steel Constructions' draft Load and Resistance Factor Design Specifications and the reports of the American Petroleum Institute PRAC Project 81-22).

Risk analysis may be especially useful for novel design concepts in environments where knowledge and experience lack. The logical process of risk analysis would help identify important risks and combine the experience gained in other applications (e.g., Gulf of Mexico, North Sea) with the unique features of the particular project in a consistent manner. Qualitative risk analysis has been in use by the U.S. offshore oil and gas industry in these situations, especially for concept formulation and design, in developing standards and regulations, and in the iterative process of engineering design and design review. The U.S. offshore oil and gas industry also employs quantitative risk analysis on its own initiative, especially in cases where the magnitude of corporate investment or public interest makes it imperative that maximum safety precautions be taken.

The Norwegian Petroleum Directorate requires that formal safety analysis methods be employed to demonstrate that proposed concepts meet stated performance criteria. Thus, the NPD regulations are performance based. In fact, wherever NPD regulations depart from a performance approach, requirements are set forth as guidelines. The issue before this working group then narrows to the question of the extent to which quantitative risk analysis should be relied on in U.S. standards and regulations. The answer to this question is found in the way U.S. standards and regulations are developed.

The engineering profession, which serves both industry and government, has long recognized the need to provide self regulation and guidance to ensure the maintenance of professional standards of design and construction. The engineering profession and industry have historically joined together in voluntary actions to produce a wide range of consensus standards. Many organizations participate in creating these documents -- USCG, MMS, industry organizations such as API and ABS, as well as professional societies like ASME and other standards writing organizations.

Where feasible, standards are performance based, to allow for technological development and innovation. For its part, government has relied to a great extent on industry self-regulation, and has incorporated standards by reference in the regulations governing OCS operations. Thus, the extent to which risk analysis is relied on today in industry standards and government regulations is a reflection on the extent to which risk analysis has been incorporated into standard engineering practice. Its use is growing in both instances. However, it should be noted that some in the working group hold the view that not enough risk analysis is incorporated into engineering practices or taught to engineers

at present, and that this may hinder application of risk analysis to projects in the future.

5.3 NEED FOR IMPROVED UNDERSTANDING

There is a need to develop a lexicon of terminology and methods concerning risk analysis, so that practictioners can communicate with one another, and so that the results of different investigators are comparable. An effective way of promoting consistency between different risk analyses is for the industry to develop a set of acceptable procedures; such a procedure guide identifies acceptable methods for performing various tasks of risk analysis, suggests data sources, and compiles experience and insights gained in recent risk studies. It would aid the oil company manager to plan a risk analysis in terms of manpower, schedule and costs and would also make him cognizant of the type and use of risk analysis results.

Some of the reluctance of engineers to employ risk analysis to a greater extent is a reflection of a popular lack of understanding and misconception concerning the nature or risk, risk analysis, and risk assessment. The need for education about risk analysis is real, and is a matter for priority attention. The professional community also requires a sounder view of risk analysis and more accessibility to knowledge and information in this regard.

There is some evidence that more extensive use of quantitative risk analysis and improved understanding of how the results can be used can lead to a relaxation of specific regulations. Thus, risk analysis is very supportive of performance based regulation.

Regulatory agencies have to reach an accommodation on criteria for acceptability of the operators, the standards setting bodies, and the general public. Over time, with improved understanding the divergent viewpoints concerning acceptability converge, but they do so slowly. Risk analysis may help the regulatory agencies make and justify tradeoff decisions that are their responsibility, yet, more than risk data are needed to bring about the convergence of views about what constitutes an acceptable risk. As demonstrated by the U.S. experience with nuclear power, operating experience must demonstrate that the estimates were reasonably trustworthy and did not misrepresent the experience. Confidence in the analysts is imperative for the convergence to occur, as it has to a large degree in the field of hazardous materials transportation.

5.4 LIMITATIONS ON THE USE OF RISK ANALYSIS

Risk analysis is a logical process of bringing together everything the risk analysis team knows about a major facility. It reduces a complex problem into components for which we may have combinations of data, models, and experience. The exercise of engineering judgement is best done at the component level throughout the analysis. Risk analysis does not preclude the use of engineering judgement. In fact, it calls for a visible and defendable use of judgement. Modern risk analysis in the Bayesian statistical framework is founded on such a use of experience and expert judgement.

Some doubts have been raised as to the capability of risk analysis to identify risks that traditional engineering practice cannot identify. This may be so for simple and well-studied concepts. The collective experience of the industry has, in fact, over several applications, recognized these significant risks. However, for complex and novel projects, an unstructured approach has less chance of identifying dominant risks. The analytical tools exist for this purpose and it behooves the industry to take full advantage of them.

Human error is nearly always present in events which lead to accidents, and which are described through risk analysis. Human performance can be described statistically. Significant progress has been made in the study of human reliability in other industries. Operator performance under different stress conditions is being studied probabilistically. Techniques are also available to judge the significance of gross design, construction, and inspection errors. Nevertheless, much work remains to be done in this area.

The ability to quantify risks depends on the availability of safety data, including data on frequency of system and component failures, data relative to exposure, and data on consequences of failure. Creation of broad data bases is a task that is larger than any one project or company. Such data would need to be assembled. The working group notes two contructive developments.

1. A reliability data base on equipment in use in the North Sea is nearing completion (OREDA project).

2. The safety data situation in the U.S. has recently been assessed by the Marine Board (Safety Information and Management on the OCS, 1984). The committee authoring the report recommended that the Minerals Management Service establish an OCS safety information system for acquiring comprehensive event and exposure data, calculating frequency and severity rates, and analyzing trends.

As described above, lack of understanding is a barrier to further use of quantitative risk analysis in the U.S. This problem needs to be addressed at the national level.

A number of limitations have been reviewed. Some are inherent in the analytical tools. Others, such as lack of data, can be remedied. Still others are due to misapplications of analytical tools by the analysts, or misinterpretation (misuse) of results.

5.5 DEVELOPMENT IN THE STATE OF PRACTICE OF THE OFFSHORE OIL AND GAS INDUSTRY

Industry needs to gain experience and understanding in risk analysis. Greater familiarity will come with increased use, because risk analysis improves our understanding of system level interactions and critical paths to failure, hence it can be used to improve safety.

As the use of risk analysis becomes more widespread, industry standards, etc., will need to be revised to provide for the use of risk analysis as an alternate analytical technique. This is, in fact, already occurring. An instance cited

by some working group members is the draft reliability-based specification for steel structures by the American Institute of Steel Construction.

5.6 DEVELOPMENT IN THE STATE OF PRACTICE OF GOVERNMENT

The following problem area cited by the working group requires immediate attention.

- Need for lexicon of terminology and risk analysis methods.
- Need for data on frequency of loss, exposure, and consequences of loss. (A related matter is the possibility of making company-sensitive risk studies more widely available in an anonymous fashion.)
- Need for training of practitioners.

The top level intent of the Norwegian approach is to require formal system safety planning. The Norwegian approach strives to get industry to develop and implement a plan to achieve an adequate safety performance level, and requires industry to demonstrate an adequate supporting safety analysis for government review. In other words, risk analysis provides a way to conform to the government's safety analysis mandates.

Elements of the U.S. Departments of Energy and Defense are approaching the achievement of adequate safety performance in a somewhat similar, nonregulatory way. Regulatory agencies within the U.S. Department of Transportation have used risk analyses in the evaluation of alternative state and municipal regulatory actions. Consistent with the fabric of the U.S. regulatory system, offshore risk analysis will enter into offshore oil and gas standards and regulations coincident with the extent of its acceptance and use by industry. There is no reason to depart from the historical practice in the regulation of offshore oil and gas of incorporating industry-developed standards into government regulations by reference. As industry includes risk analysis in it industry-developed standards, government should continue to reference such standards in its regulations. Over time, risk analysis will be used increasingly, in concert with the experience base, in setting standards and regulations, and in demonstrating compliance. The only reason to depart from historical practice would be if, in the future, the safety record is deemed unacceptable, and a government requirement for additional risk analysis offered some hope of improvement. In view of the apparent good overall safety performance record of the industry, any government consideration for the use of risk analyses should be carefully scrutinized to assure that its use is limited to particular areas where its benefits outweigh its costs. For example, large potential losses, new technology, high-risk areas of operations, or repetitive safety problem areas could be likely candidates for its use.

There is no rationale in the U.S. for establishing quantitative levels of performance at this time. U.S. regulators have to keep in mind the diverse conditions in the U.S., which have led to a two-track engineering design and regulatory system (as refleted in RP 2A and the Verification Program) to address both less complex installations for shallow water in the Gulf of Mexico and all

other systems. Quantitative risk analysis is already being applied selectively on projects in the "all other" category because of the magnitude of the risks involved.

6. CONCLUDING REMARKS - OPPORTUNITIES FOR IMPLEMENTATION AND APPLICATION

The foregoing discussion can now be summarized in simple terms. The operation of an offshore oil and gas installation involves numerous risks. Therefore, minimizing risks by identifying risks of loss, reducing their probabilities of occurrence and alleviating their consequences provides an attractive framework for increasing the safety of offshore installations. Presently, standards and codes that deal with safety of offshore structures have begun to identify the issues of risk and there are reasons to believe that standards and regulations may play an increasingly significant role in risk analysis. Another constructive development is the use of risk analysis in the development of standards which have a deterministic format.

The state of practice in standards and regulations remains largely at the level of performance-oriented requirements compliance with which may be fulfilled by qualitative risk assessments. This would require that the treatment of failure be approached at a system level. In other words, consideration of events that are part of the accidental loss-producing process should be carried out for the entire process, rather than being viewed as isolated events during the design process. On this basis, even a qualitative description at the system level can succeed in identifying unacceptable interactions that must be changed at an early stage of design, given the state-of-the-art. In this manner, conformance with existing requirements in standards and regulations cast in their present limited scope is possible.

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CONCEPT EVALUATION AND DESIGN

REPORT OF WORKING GROUP II

SCOPE

The scope of Working Group II is the application of risk analysis and reliability engineering techniques to the planning, design, construction, inspection and maintenance of offshore oil and gas production structures. This group did not consider topside facilities or support activities.

GENERAL COMMENTS

Risk is the potential for the realization of unwanted negative consequences of an event. A complete risk analysis should contain two components - a risk determination which includes event identification and quantitative estimation of probabilities and risk evaluation which presumes a level of acceptability and includes value judgements.

Risk determination for complex structures such as used in the offshore industry, has three components:

Hazard--Vulnerability--Consequences

A hazard is a natural or man-made phenomenon that may induce unwanted events and may include storms, mudslides, fire, collision, dropped objects, excessive operating demand, poor fabrication, etc.

The impact of a hazard depends on the vulnerability or whether the system's capacity is exceeded by the demand of the hazard. If demand exceeds capacity, damage occurs. The consequences depend on the system exposure in terms of lives, property, and environmental losses. A complete risk analysis should incorporate uncertainties in hazard (severity and frequency), vulnerability (for both serviceability and major damages) and consequences (tangible and intangible.)

It has been difficult within offshore developments to quantify overall risks because the uncertainties include many natural phenomena (wind, wave, soil properties, etc.). Published applications have focused on utilizing risk analysis to promote rational trade-offs between alternatives in a decision framework. It is widely accepted that there is no risk-free operation especially in technically innovative developments. But as one author aptly put it in the title of his paper, "No Risk May be the Greatest Risk of All."

In the context of offshore structures, risk applications have been referred to as structural reliability analyses that include the following steps. Relevant load (demand) and strength (capacity or resistance) random variables are identified. Performance data, and relevant informatiion for each variable is then collected. Data can be either qualitative or quantitative. In the next step, probabilistic descriptions for demand and capacity are constructed. Then, various levels of probabilistic techniques may be used to compute or

estimate risks. Basically, reliability analysis is an attempt to assign a measure of safety which reflects the uncertainties in the analysis. Subsequent applications may apply economic and other trade-offs to arrive at an appropriate design decision.

A general reference for offshore reliability methods is "Application of Reliability Methods in Design and Analysis of Offshore Platforms" by the ASCE Committee on Reliability of Offshore Platforms, Journal of Structural Engineering, ASCE, Vol. 109, No. 10, Oct. 1983.

1. STATE OF PRACTICE

Considerable probabilistic analysis is done in offshore engineering within individual disciplines such as oceanography, marine soils, weld quality, etc. It can be shown (in reliability theory) that treating each topic in isolation and independently assigning design values to each variable produces reliabilities which may vary considerably from project to project. The integration of these specific discipline-oriented studies into a single risk projection is needed but it is difficult in offshore engineering because of the varying qualities of the different data bases. Some integration has nevertheless been carried out for specific projects and also more generally for the development of structural design specifications.

There were many examples reported at the workshop on the effective use of reliability analysis in offshore design problems. Four categories of application were identified, 1) before design, 2) during design, 3) during construction, and 4) during operation. A brief description follows:

Before design.

1) Gulf of Mexico wave forces and selection of design wave heights. In this early study, the reliability techniques were used to establish rational design criteria for wave loadings. The analysis included existing performance data.

2) Gulf of Alaska design earthquake and wave height conditions. This development is similar to the Gulf of Mexico wave force study except that it also considered regional seismicity and the possible interactions within the criteria selection process of these two hazards (wave and earthquake).

3) Canadian EIS, design ice loads. Risk and reliabiltiy techniques were used in the determination of reasonable design ice loads for fixed production structures in the Canadian Beaufort Sea. One operator in the Beaufort Sea had used deterministic methods to establish ice loads due to ice flow impacts. The design loads were reviewed using reliability analysis and it was found that they were overly conservative.

4) Ice forces and resistances reliability - A reliability study for the Beaufort Sea examined various types of structures and compared alternatives based on cost and risk.

5) Troll development (offshore Norway). Again, alternatives were compared using risk analysis to evaluate the best structural concept.

6) Hutton TLP analysis. Studies have been reported using system reliability methods to compare various structural forms related to this innovative concept.

7) API-LFRD specification development.

8) API fatigue reliability study.

During design.

1) Hibernia development - used risk methods to compare gravity based versus floating structures.

2) Troll alternatives - detailed design criteria development.

3) Foundation factors of safety for Southern California platforms in an intense earthquake zone.

4) North Sea gravity structure foundation penetration criteria.

During construction.

1) Reliability analysis of underdriven piles for a Gulf of Mexico structure.

2) Criteria established for tow routes on transocean tows, i.e., Atlantic vs. Pacific, etc.

During operations.

1) Sitting jackup drill units in Norton Sound and Lower Cook Inlet.

2) Inspection strategies for North Sea platforms.

3) Remedial construction - In this early example, one company utilized reliability analysis to select remedial strategies for modifying existing structures.

4) Damage to structure caused by dropped pile. This study and several similar ones have utilized reliability methods to evaluate damage tolerance. Among the considerations are system capacity, repair schedules and further inspection alternatives.

5) Platform damage repair alternatives in the Cook Inlet.

Many of the examples cited above are for unusual applications such as projects in frontier areas with regard to both geography and concept. Most of these special studies were not comprehensive or technically rigorous, but for the most part used for economic and safety decision analysis. It would be a mistake

to assume that any of the studies is developed to a level suitable for routine application.

One important characteristic of the work is the involvement by designers in the trade-off studies. In all cases, the consequences of failure were established and incorporated in the design of the overall system. In this regard, the following priorities were noted, a) safety to the personnel involved, b) minimize risk to environment, c) and minimize the economic risk. In some instances, the studies recommended further data gathering to fill in the major uncertainty gaps or else control mechanisms during operation to reduce risk consequences.

The studies discussed seemed to be characterized by a willingness to admit to large uncertainties especially in modeling new phenomena. Such large gaps in the technology could still be treated by reliability techniques because the studies were not inhibited by any risk target goals. Also, the studies were generally conducted in a design rather than a verification situation. The work was performed either by design oriented engineers also knowledgeable in structural reliability theory or by designers assisted by experts in this area. In summary, reliabiltiy analysis has to be used with the reason and within its range of applicability and limitations.

2. PROBLEM AREAS

The following barriers to implementation of reliability analysis in offshore construction can be identified.

1) Organizational and communication problems. This is at the top of the list. Within the oil companies as in other industries, there is a wide range of familiarity with reliability methodology and the aims and application of risk analysis. There can be substantial differences in how reliability results could be interpreted. There are also problems with integration; companies and design teams have different risk management perspectives.

2) The present state-of-the-art and the available information preclude the use of rigorous reliability analysis.

   a) Often there is simply not enough data available to perform a detailed reliability analysis.

   b) In some cases the theory has not yet been developed. For example, there is a need of good system reliability methods. Most studies concentrate on well-defined damage modes usually involving a single event. The system risk involves the complex interrelationships and correlations of different events. Failure event models are needed for identifying and defining redundancy and incorporating inspection, quality control, and quality assurance resources in the risk assessments.

   c) Engineering judgements must be made with regard to the methodology of analysis and also with regard to professional modeling uncertainties.

d) Human Errors - Many if not most reported failures are due to hazards and events which are not traditionally considered in the design or conception stage. In particular, human errors are frequently responsible for major catastrophies but these are often difficult to model or even identify before the accident event. Recent studies on quality assurance have begun to report statistical data on human errors in design, inspection and construction. In additon, guidelines are beginning to emphasize creation of damage scenarios in which possible hazards are identified at the project conception stage.

3) Motivation can be a barrier to implementation. For example, mandatory imposition of reliability methods has tended to produce solutions to satisfy the regulations rather than aid the design decision process. This could inhibit initiative and creativity and lead to exercise in formalistic nonsense.

4) There is an issue of exceptions, i.e., what one thinks is going to be the result of the analysis and how it will be perceived by others. In most studies, reliability (or risk) represents a convenient measure of safety. It has only a limited accuracy in an actuarial (statistical) sense, since only the relative (not absolute) risks between different hazards may be correct. In order to permit precise utilization of risk as a trade-off criterion between a variety of different concepts, all aspects of control or construction activities would need more accurate risk assessment. This requires considerably more data as well as improved reliability techniques than are now available.

In summary, reliability analysis is still in an evolutionary stage, especially for evaluating new concepts with significant technological uncertainties. Because of the limitations cited above, there was considerable concern expressed that a risk analysis, as part of a certification process, would be counterproductive. While the operator has the obvious responsibility to ensure public safety, the control mechanism must be meaningful. At this stage, reliability analysis simply has not been refined to the point where meaningful computations of probabilities of failure can be performed. There is concern that some interpretations of regulations such as the new NPD requirements, will contribute to the "paralysis by analysis" syndrome. Discussions at the Workshop indicated, however, that in fact the NPD requirements may be interpreted with a practicality that balances economy and constructive safety strategies. An additional problem, however, is that excessive efforts to compute reliability would dilute manpower and may in fact decrease safety by directing effort from all the <u>design</u> safety issues to only those that are amenable to reliability <u>analysis</u>.

3. DATA ACQUISITION AND RESEARCH NEEDS

The previous section described limitations in current risk studies and emphasized that reliability must be viewed as a dynamic quantity ever-changing during a project's lifetime. Reliability is not a single target at which we aim but rather a process by which we identify areas for investigation and control. Possible responses include allocation of material and human resources within the system, such as redundancy, inspection, quality assurance, and damage mitigation.

Within this scope there are specific research needs for studies on:

1) Data; some examples are: statistics on soil behavior and foundation capacity, fatigue including initial flaw distributions and probability of detection, environmental descriptions, e.g., joint distributions of wave height, period, directionality, current, wind, etc., ultimate strengths (not deterministic) of systems, etc.

   With regard to data, many of the effective applications of reliability analysis are unusual, and it is not easy to anticipate the data needs.

2) Technological improvements to reduce modeling uncertainties. Example include soil structure interaction and design factors associated with seismic analysis and fatigue. In more typical applications it is possible to use experience (e.g., Bayesian updating methods) to reduce the modeling error. In other cases, modeling error can only be identified and reduced by experimentation.

3) Reliability theory. This would include (a) system reliability models to assess redundancy (b) load combinations, i.e., multi-hazard loading probability models and (c) applications of control concepts to mitigate damages.

4) Gross errors and blunders. This could be addressed by the expansion of quality assurance procedures to address hazards which in fact may be the most common contributors to risk. Use of Bayesian decision tools and expert system philosophy could assist in these controls.

A question was raised as to what would be the best effective mechanism to do the research. Industry pooling of experiences and data certainly would be helpful but this approach has been impeded by practical legal problems. In the past, the Marine Board has provided support for projects for synthesizing data. The Interagency Ship Structures Committee also supports some projects, but it is a small effort. The American Petroleum Industry has also funded reliability oriented projects such as the LRFD and the fatigue project. These have been good vehicles for disseminating probabilistic information. In addition, there are the professional groups such as the ASCE offshore reliability committee and conference and workshop proceedings.

4. OPPORTUNITIES FOR IMPLEMENTATION AND APPLICATION

This item is clearly the most difficult since risk analysis should avoid becoming simply another acceptance hurdle. That is, a program which one accepts in theory but doesn't like because it impedes progress while having little to do with the design concept. The primary goal of structural reliability analysis is to use reliability methods as a design and decision tool for assisting in rationally making necessary and inherent trade-offs. Demonstration projects of risk analysis are needed in which costs as well as benefits are expressed and the flexibility rather than the rigidity of risk analysis is emphasized. Opportunities need to be taken to assess trade-offs in concepts, design criteria, redundancy, material selection, design veification, inspection scheduling, etc.

Implementation projects should account for the differences between: (a) projects with significant historical performance experience and hence updated (Bayesian) parameter estimates, and (b) those projects with significant innovation which need to emphasize quality assurance including concept risk evaluation.

In summary, demonstration projects illustrating the implementation of risk analysis should contain the following ingredients:

A. Willing participation of owners, designers, regulators and/or researchers.

B. Realistic applications including examples in frontier areas as well as the more developed offshore areas where there exists a considerable body of experience.

C. Potential for trade-offs between design, material, inspection, and insurance costs.

Specific efforts to facilitate implementation include the following:

1) Improved communication. The people that need to be convinced of the usefulness of risk analysis can only be converted over a long period of time. Projects such as those sponsored by the API, industry cooperative studies, and government research programs have all been very effective in promoting reliability analysis in this regard.

2) Design specification changes. Although this aspect is covered in Group I it is clear that such efforts also help motivate the reliability studies on concept evaluation.

3) A review situation which encourages rather than retards innovation should be maintained. Third party reviewers should also be encouraged to perform their own risk analysis, but within the same framework and goals as the producer.

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OPERATIONS AND MAINTENANCE

REPORT OF WORKING GROUP III

INTRODUCTION

The term "risk analysis" has recently come into wide usage, but it is important to note that the meaning attached to this term varies according to its application and that a standard definition which would encompass its wide scope would be cumbersome. In this paper, the term "risk" will be used to refer to the likelihood of occurrence of events which would have adverse consequences upon the safety of people, the environment, or economic resources. In order to specify risk, one must specify the undesirable event being considered, the likelihood of occurrence of this event in a given area over a given period of time, and the likely consequences of the event in terms of value or degree of losses which might be incurred. The likelihood of occurrence of the undesirable event can be expressed qualitatively, (e.g., rare, occasional, frequent) or expressed quantitatively as a normalized frequency or probability. The consequences of an event can also be expressed qualitatively (e.g., severe or minor) or quantitatively (e.g., economic loss, fatality rate, or incidence of ill health). The term "risk analysis" will be used to describe the process of identifying undesirable events and characterizing the causes and effects of "hazards". A "hazard" is a substance, situation, or event, which has the potential to cause harm directly or initiate a sequence leading to harm. Hazards could include chemical spills, the release of harmfull or explosive vapors, falling objects, leaking valves, etc. The effects of the hazards are determined by estimating the consequences to people, the environment, and the economic resources of the investors.

The term "risk assessment" will be used to refer to the whole process of risk analysis and the evaluation of the results of the risk analysis against technological capabilities, economic costs, and social or political criteria. Thus, risk assessment involves the systematic identification and evaluation of undesirable events by means of analytical techniques. The results are expressed in terms of probabilities and are thus not absolute, requiring interpretation before determining if the risks are acceptable. This interpretation tends to be subjective unless there are hard criteria which are established by laws, regulations, or industry concensual standards. Usually specific criteria do not exist in great detail, particularly in dealing with complex systems. Nevertheless, the risks inherent in alternative courses of action may be compared in a relative sense. Additionally, risks associated with a discrete action may be deemed too high to be acceptable according to prevailing standards. If a risk appears to be too high, the introduction of design or other changes to lower the potential losses to a more acceptable level is then subject to re-analysis using the same techniques. This is called the "iteration process" and characterizes risk assessment methodology. The overall risk assessment process is illustrated in figure 1.

The term "reliability" is often used in risk analysis as a measure of the probability that a component will perform a required specific function.

COMMON CAUSE ANALYSIS - The Common Cause Analysis method is used to determine correlations between 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 judgement.

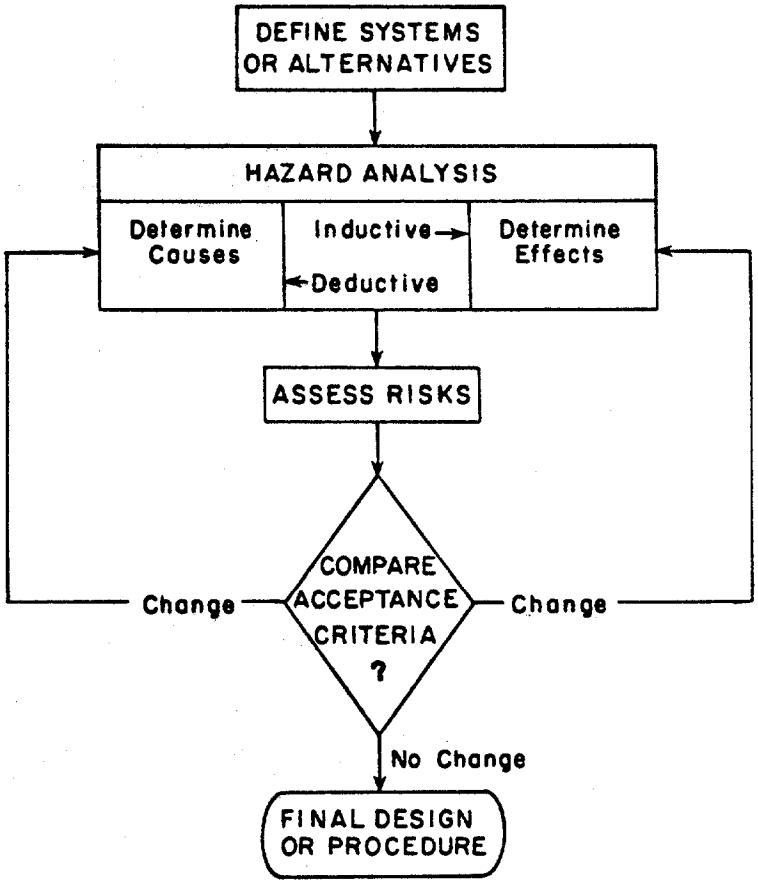


Figure 1. Risk Assessment Process

Reliability is determined as one minus the probability of occurrence of the event leading to system failure. Thus, reliability analysis techniques are similar to those used in risk analysis.

Although all risk assessment methods are variations of the classical approach shown in figure 1, there are many variations which 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)
(4) Event Trees

The common variations used for risk analysis include:

(1) Event Trees
(2) Fault Trees
(3) Reliability Diagrams
(4) Markov Diagrams
(5) Monte Carlo Simulations
(6) Common Cause Analysis

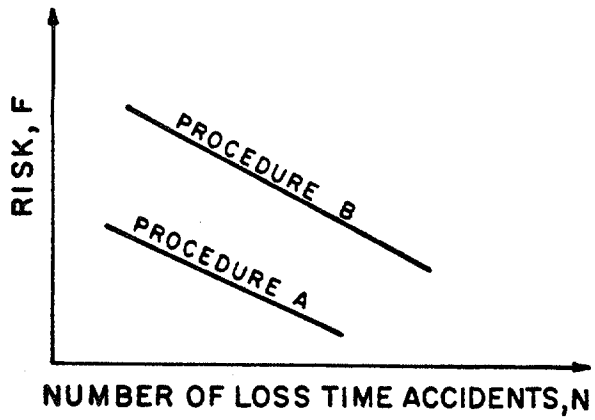
A given risk assessment study may involve the use of several of these procedures. Note that event trees are used both for hazard identification and risk analysis. A detailed description of these risk assessment methods is beyond the scope of this paper. However, a summary description of each technique is given in Appendix A.

TYPICAL RISK ANALYSIS RESULTS

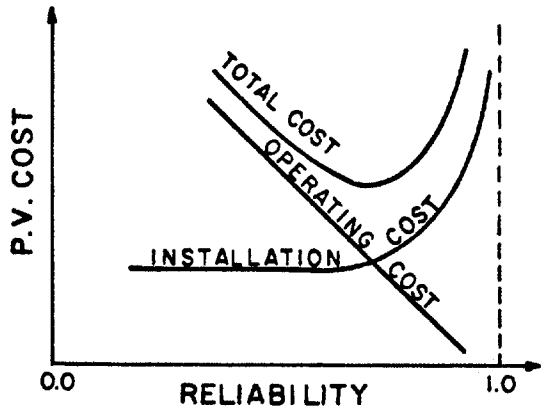
Once a risk analysis has been completed, it may be summarized in graphical form to assist in interpretation of the results. The most comon graphical formats used are shown in figure 2a – an example of a risk profile of several alternatives being considered. In this type of representation, risk expressed as a normalized frequency or probability, F, is plotted versus the corresponding number, N, of occurrence of losses. Figure 2b is an example of a cost versus reliability curve for a given operating system. High reliability has a high initial investment but a low maintence cost while a low reliability has a low initial investment but a high maintenance cost. Figure 2c is similar to figure 2b, but cost is plotted versus risk rather than reliability. This figure illustrates that the lowest economic cost may still result in unacceptable risk to human lives and design or other modifications may be initiated. Figure 2d is an example showing cumulative probability plotted versus present value profit.

STATE OF PRACTICE

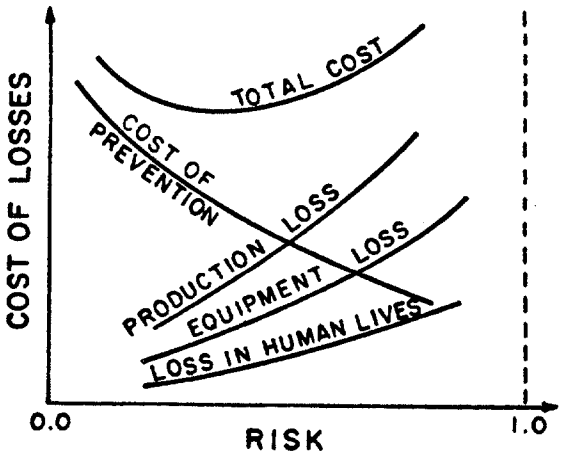
DESIGN - A large number of risk assessment techniques have been presented in the literature. Several of these techniques have been used in a variety of applications in the design and operations of offshore oil and gas facilities.



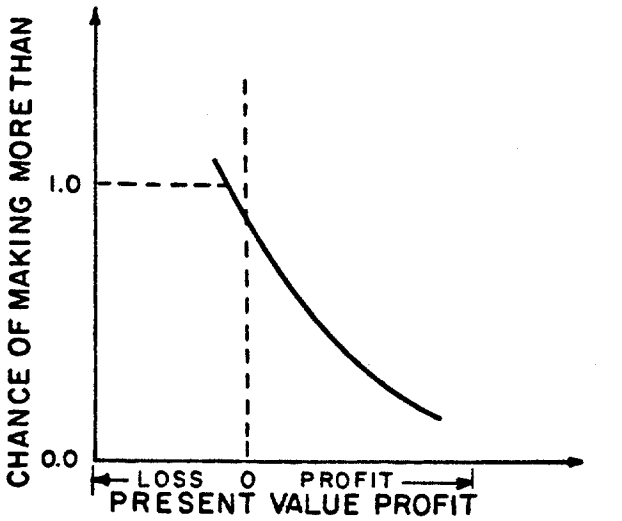
a) Risk Probability vs. Number of Losses



b) Cost vs. Reliability



c) Cost of Losses vs. Risk



d) Cumulative Probability vs. PVP

Figure 2. Typical Risk Analysis Results

They are thought to be most effective when integrated into the design phase of a project having novel components, or when directed towards evaluating alternative solutions to a problem which has been identified, and which is amenable to solution by risk analysis. Risk analysis does not yield the solution to all safety problems. It is a tool which can be helpful in identifying and solving some safety problems, but it is by no means an all purpose tool.

A significant number of examples of the application of risk analysis to offshore oil and gas operations had been carried out by members of the working group, including such problems as selection of alternative well completion methods, diverter failure analysis, oil spill risk analysis, and risk analysis of welding operations. The applications with which members of the group had personal experience were most often addressed towards components or subsystems, more limited in scope than an entire facility, and were not considered to be a routine design procedure.

In the Norwegian Sector of the North Sea, about a dozen rather specific studies have been completed to date, all commissioned by operating companies, but in many cases primarily for submission to the Norwegian Petroleum Directorate as project safety evaluations. Subjects have included major integrated drilling, production, and quarters platform with steel and concrete structures, small riser platforms, a major water injection, drilling, and quarters platform, and advanced deep water concepts.

In the UK Sector of the North Sea, risk analysis are conducted by operators primarily to assist in project development and as a means for internal evaluation of economic and safety factors. Unlike Norway, there is no requirement to demonstrate that numerical targets of risk have been met, but the operator has a legal responsibility to ensure that best engineering standards have been achieved. This is subject to verification by a certifying authority. Risk analysis is not required as the basis of statutory consents as is the case in the Norwegian Sector of the North Sea.

In current routine design practice in mature areas such as the Gulf of Mexico, standards which include API 14C are generally used. Maturity is defined here in terms of proven practice. Even in an area such as the Gulf of Mexico, a "frontier" may be experienced from the standpoint of new application. An example would be operation in deep water. Consequently, "frontier" is defined in this paper in terms of practice rather than geography. Risk analysis is considered to have greatest potential in frontier areas of endeavor.

OPERATIONS AND MAINTENANCE - An approach to safety management in operations and maintenance of offshore oil and gas facilities is illustrated in figure 3. As new systems are developed and introduced, risk analysis procedures may be employed to assist in developing operating procedures in the form of policy, safety manuals, procedure guides, and contingency plans. However, the most essential ingredient to the development of safe operating procedures is past experience, and sufficient imagination to recognize the kinds of hazards present in a given project. In mature areas of domestic offshore operations, such as the Gulf of Mexico, an effective hazard identification process has been performed

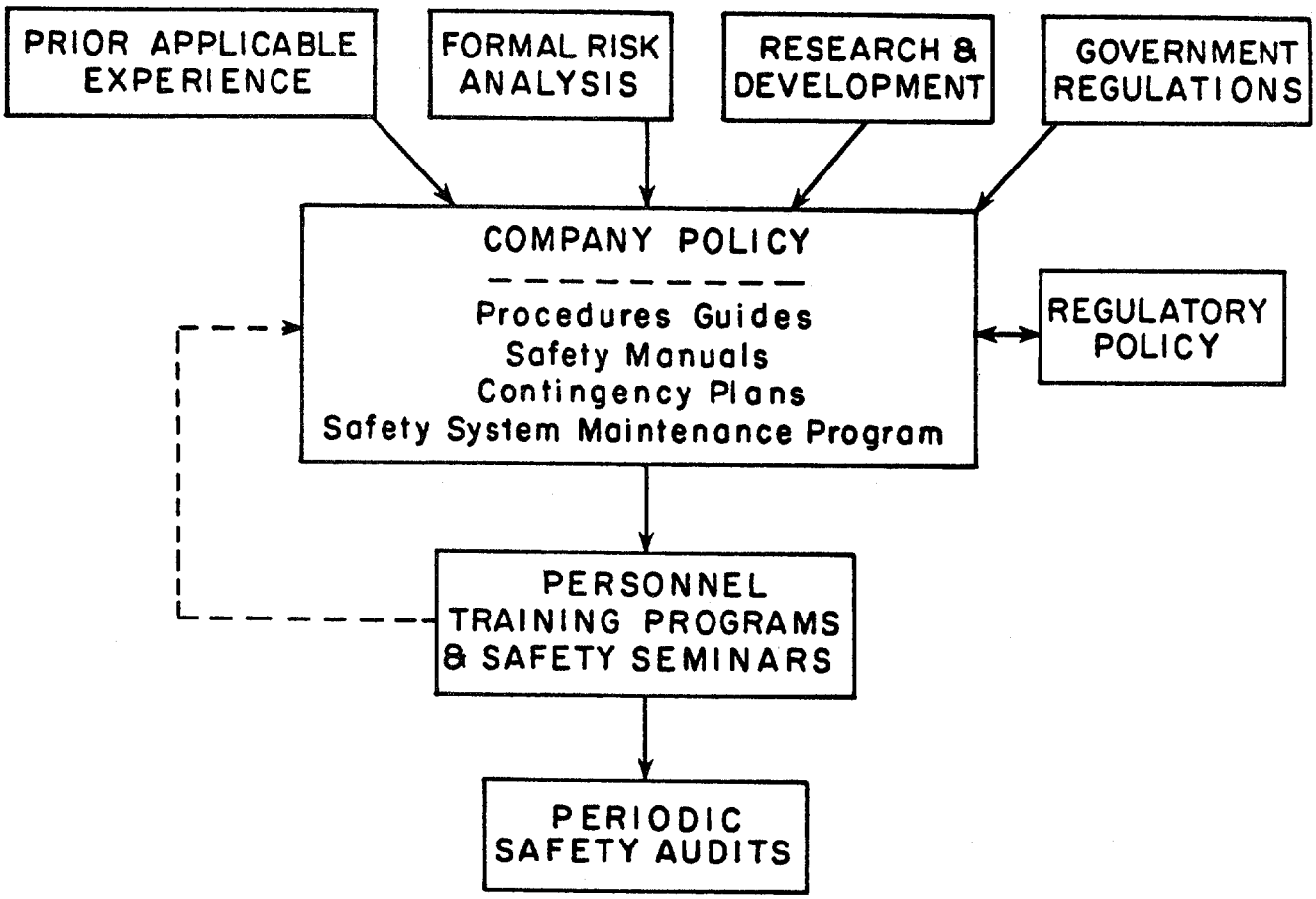


Figure 3. Risk Management for Novel System

through the collective thoughts and experiences of many experienced engineers, operations supervisors, and managers working in this environment. Appropriate policy and procedures have been incorporated into safety manuals, procedures guides, an contingency plans. The safety procedures developed generally include comprehensive procedures for periodically inspecting, testing, and reporting on all safety devices and redundant systems.

Individual companies are assisted by industry groups such as the American Petroleum Institute, the International Association of Drilling Contractors, and the Offshore Operators Committee in pooling resources of many companies in the development of appropriate policy and engineering procedures. This is further reinforced by government regulations enforced by the Minerals Management Service, the Occupational Safety and Health Administration, and the Coast Guard. In current practice, routine safety management is achieved through enforcement of appropriate policies and procedures. Independent safety audits are sometimes performed by company safety groups. Government agencies can also assist in maintaining a safer work environment by inspection on visits to ensure compliance with government regulations.

Generally speaking, the greatest problem faced in controlling risk is not the development of the appropriate safety procedures, but their implementation through continuous training of field personnel to keep them abreast of these procedures. Thus, considerable effort must be continuosly directed towards conducting appropriate training seminars. These schools also stimulate discussion among employees about hazard recognition and occasionally provide feedback to the safety personnel concerning new problems and the need for procedural changes.

Offshore oil and gas operations can be broken into the two main areas of drilling operations and production operations. Generally these functions are handled at the field level by different suborganizational groups within a company with higher level commonality to ensure safety of the overall operation. The division of responsibility and specilization permits engineering and operations expertise to be more effectively focused. Industrywide risk management policy and published procedures as well as government regulatory agencies reflect this typical organization.

Although the machinery and processes used in offshore drilling and production operations are quite different, the same general types of hazards are present and include:

(1) loss of containment through leaks, ruptures, overflows, etc.
(2) explosions
(3) fires
(4) hazardous solids, liquids, and gases
(5) heavy machinery
(6) high voltage electrical power
(7) structural failure or sinking vessel

These hazards result in risks of personal injury or loss of life, loss of equipment or entire facilities, loss of oil and gas production and environmental damage. Each person working on a given offshore unit must be given broad training with respect to all of the hazards present, and intensive training concerning the hazards associated with his particular area of specialization.

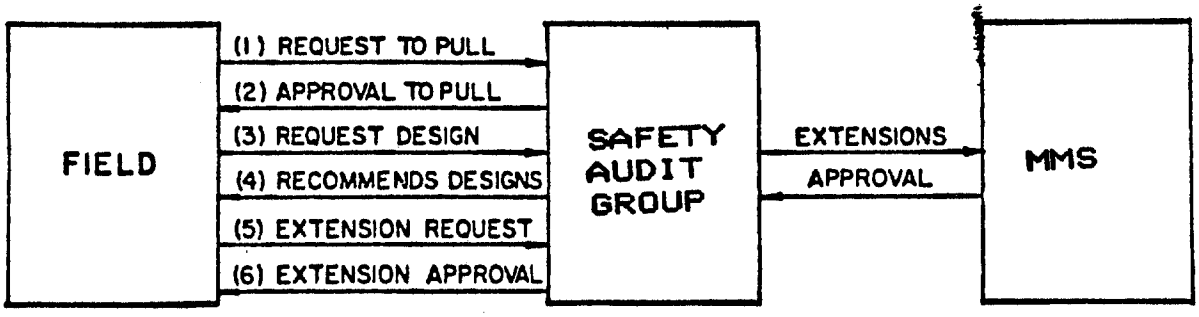
A blow-out is the most catastrophic undesired event which could lead to the most severe losses in all of the categories listed above. Extensive engineering effort is devoted to the area of blow-out prevention in drilling and production operations. However, blowouts continue to occur, and can usually be traced to a sequence of human errors. Some members of the working group felt that risk analysis may be of value in developing improved "man machine interfaces" which will make human errors less likely. However, even if substantial technological improvements are made in existing blow-out prevention equipment, effective training, experience and supervision are likely to remain the key factors in a successful blow-out prevention program.

Safety management in oil and gas operations generally involve the extensive use of redundant systems and safety devices. Adherence to API guidelines (API RP14C) requires two levels of protection beyond good process design. Extensive computerized programs are generally required to track the testing, maintenance, and reporting of the needed surface and subsurface safety devices. One company alone reports over 13,000 safety devices located on 111 platforms in the Gulf of Mexico, which require 120,000 tests to be performed each year.

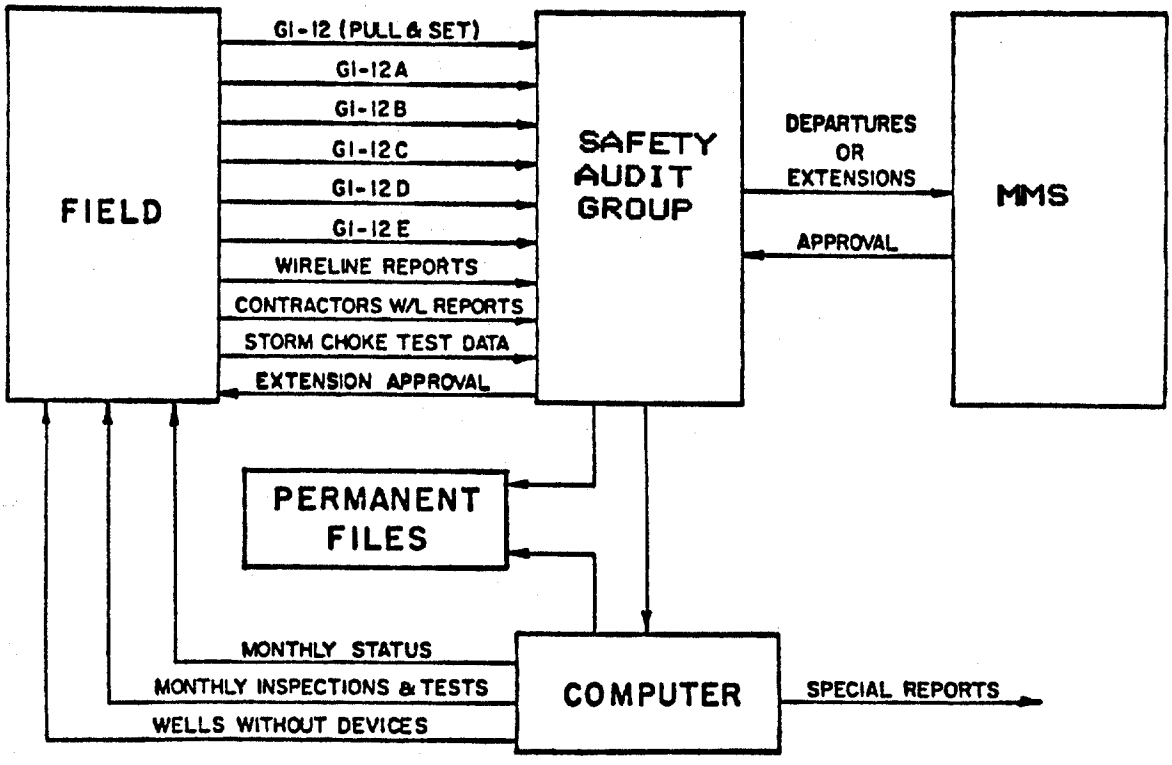
A complete description of offshore safety management activities is beyond the scope of this paper. However, in order to provide an example of current offshore inspection and maintenance practices on safety devices, a few of the more important safety systems will be described. Example organizations and procedures for testing and maintaining these safety devices will be presented.

SUBSURFACE SAFETY VALVES - Subsurface safety valves are designed to close the well below the surface to prevent a blow-out in the event the entire surface safety system is lost due to destruction of the production facility by fire, ship collision, etc. Thus, subsurface safety valves are the last line of defense against blowouts in producing wells. The design of certain types of these devices must be matched to the producing characteristics of the well to ensure a functional system. Occasionally, these devices must be removed to allow remedial well work below them, or because the well characteristics have changed and they need to be replaced. As an example subsurface safety device movement authorization procedure is shown in figure 4. Note that a special safety audit group is used to monitor and approve the removal of these valves. This same group:

(1) maintains a daily audit of wells temporarily without a subsurface safety valve.
(2) handles all communications with regulatory agencies
(3) performs all safety valve design work in accordance with API recommended procedures (API RP14B).
(4) monitors the results of all field tests run to verify a proper design.
(5) provides inspection, schedules such as the example of table 1.



(a) Verbal Procedure



(b) Written Procedure

Figure 4. Subsurface Safety Device Movement Authorization Procedure

PAGE 1

SUBSURFACE SAFETY DEVICE
INSPECTION SCHEDULE
AUGUST • 1983

INCLUDES DATA THRU 6/30/83

G.I. 16 FIELD

THE INDICATED ACTIONS MUST BE PERFORMED ON THE FOLLOWING WELLS ON OR BEFORE THE DATE INDICATED
IF ANY OF THE WELLS LISTED WERE INSPECTED DURING JULY NO FURTHER ACTION IS REQUIRED.

S	799	BB	1	NO. 1	8/13/83	SCSSV TEST
S	799	BB	3	NO. 1	7/11/83	SCSSV TEST
S	799	BB	4	NO. 1	8/28/83	SCSSV TEST
S	799	BB	5	NO. 1	8/15/83	SCSSV TEST
F	34	J	13D	NO. 3	8/17/83	TEST DEVICE
F	34	K	14	NO. 1	7/11/83	TEST DEVICE
F	31	L	6	NO. 1	8/18/83	INSPECT DEVICE
F	31	L	9	NO. 1	8/24/83	INSPECT DEVICE
F	31	L	13	NO. 1	8/11/83	TEST DEVICE
F	31	L	13T	NO. 3	8/11/83	TEST DEVICE
F	31	L	14	NO. 1	8/ 2/83	TEST DEVICE
F	31	L	14T	NO. 3	8/ 2/83	TEST DEVICE
F	31	L	17	NO. 1	8/ 6/83	TEST DEVICE
F	31	L	19	NO. 1	8/ 7/83	TEST DEVICE
F	31	L	20	NO. 1	8/ 6/83	TEST DEVICE
F	31	L	20D	NO. 2	7/20/83	TEST DEVICE
F	31	L	21	NO. 1	8/27/83	PULL DEVICE AND SET PLUG*
F	31	L	24	NO. 1	7/ 2/83	TEST DEVICE
F	31	N	8	NO. 1	8/12/83	TEST DEVICE
F	31	N	9D	NO. 2	8/12/83	TEST DEVICE

NOTE
*SET PLUG - TYPE AND STATUS REPORTED IN THE CONTROL HISTORY INDICATES THAT THE WELL HAS NOT BEEN PRODUCED FOR 6 MONTHS.
ANY WELL THAT WILL REMAIN SHUT-IN FOR SIX (6) MONTHS WILL HAVE A PUMPTHRU DEVICE SET.

Table 1 - Example Inspection Schedule

(6) provides safety device histories such as the example of table 2.
(7) provides reliability data by maintaining failure reports such as the example of table 3.

SURFACE SAFETY VALVES - Surface safety valves are located on all wells and at other strategic places to stop flow in an emergency. Various sensors are used to detect a hazardous situation and automatically close the appropriate safety valves. A schematic of a typical surface safety valve system is shown in figure 5. API recommended procedures (API RP14C) requires that a safety analysis function chart (SAFE), such as the example shown in figure 6, be prepared showing the safety devices located on each system component. Periodic tests are performed on each surface safety valve and on each component designed to activate each surface safety valve. As in the case of the subsurface safety valves, detailed computer records of test results and required maintenance work are maintained.

The surface and subsurface safety valve for each well must be approved by the Minerals Management Service for offshore service. This entails qualifying the valve under API Spec 14A for subsurface safety valves and API Spec 14D for surface safety valves. The API subcommitee which develops these specifications meet several times a year and are continually updating requirements to reflect new developments.

PRESSURE RELIEF DEVICES - All pressure vessels and piping are protected by pressure relieving devices if the possibility exists to exceed the maximum allowable working pressures. As with the previous safety devices discussed, these devices are periodically tested to ensure operation at the proper set pressures. Testing is generally done in accordance with ASTM Code UG 126.

FIRE PROTECTION SYSTEM - Firefighting systems are installed on platforms in accordance with API RP 14G. Extensive inspection, maintenance, and testing of this equipment are also performed. Reporting procedures similar to those discussed above also applies to this equipment.

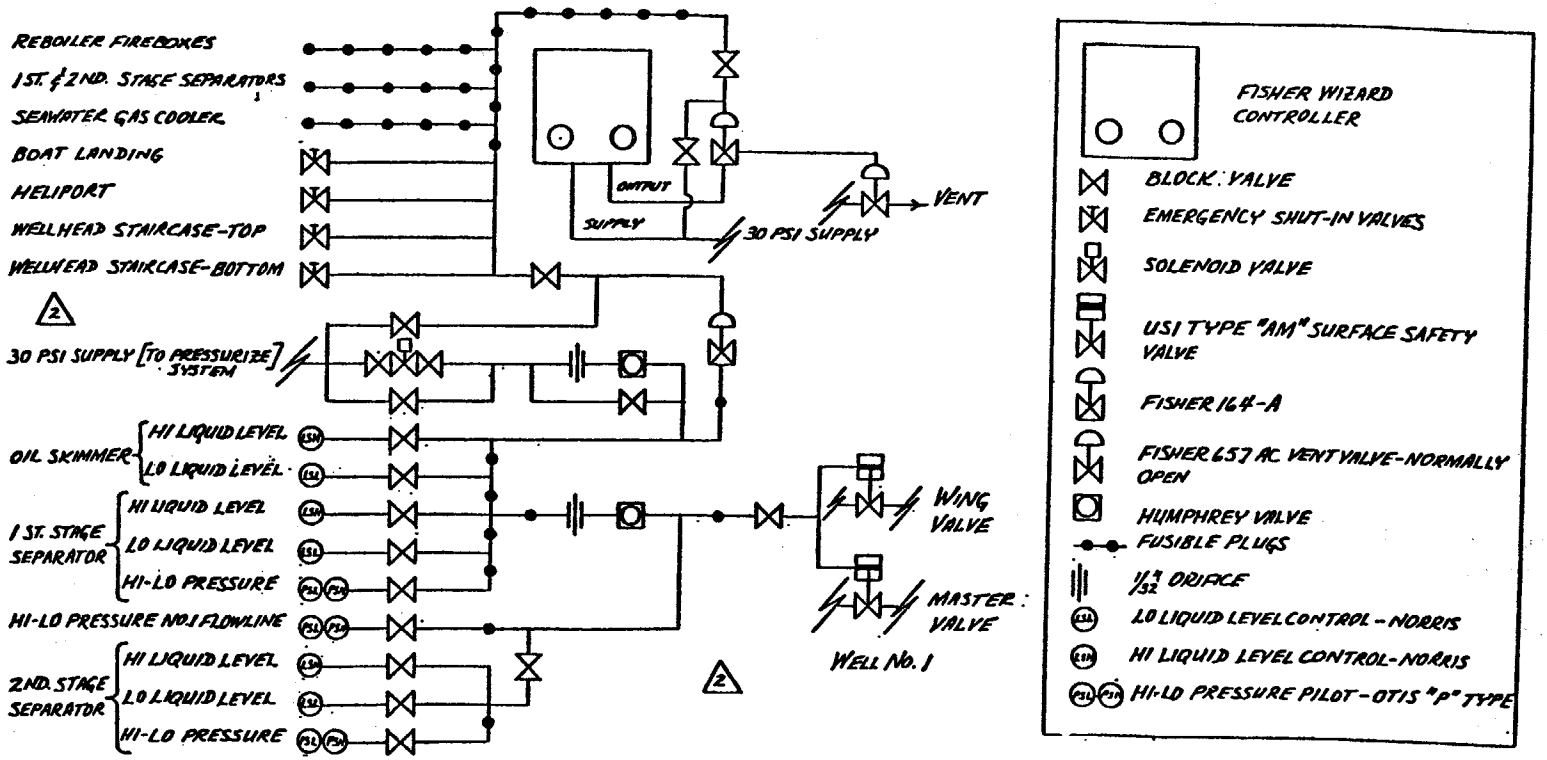
HAZARD DETECTION SYSTEM - Flame, heat, smoke, and gas detectors for specific hazardous gases are generally located in potentially high hazard areas. Fire detection systems are installed in accordance with the National Fire Protection Association standard for automatic fire detectors. Periodic testing of this equipment is also required.

The above systems are just a few illustrative examples of the types of systems employed. Many additional systems are also present.

PROBLEM AREAS

Formal risk analysis methods have been and will continue to be one of the many tools used for managing risks in offshore oil and gas operations. However, applications of formal risk analysis methods in a selective fashion can be of greater value in frontier areas where it is necessary to speculate on the likely outcome of alternative approaches to field development. Qualitative analysis is necessary in the absence of data to arrive at some possible answers to the

Fig.5 - Typical Surface Safety Valve System



NO.	REVISION	BY	DATE
		CHKD	APP'D
1	ADDED EMERGENCY BLEED-DOWN SYSTEM	—	7-24-70
2	ADDED ADDITIONAL BLEED-DOWN STATIONS AND ELIMINATED NO. 2 & 6 WELL STATIONS	R&C	9-6-82

FOR BIDS —
FOR APPR —
FOR CONST —
DRAWN R&C 9-6-82
CHECKED R&C 9-6-82
APP'D —

SURFACE SAFETY SHUT-IN SYSTEM

AFE NO. —
FILE CO. —
SCALE NONE UNLESS OTHERWISE NOTED
DWG NO. P-MC-B-400
SH NO. P-1-2

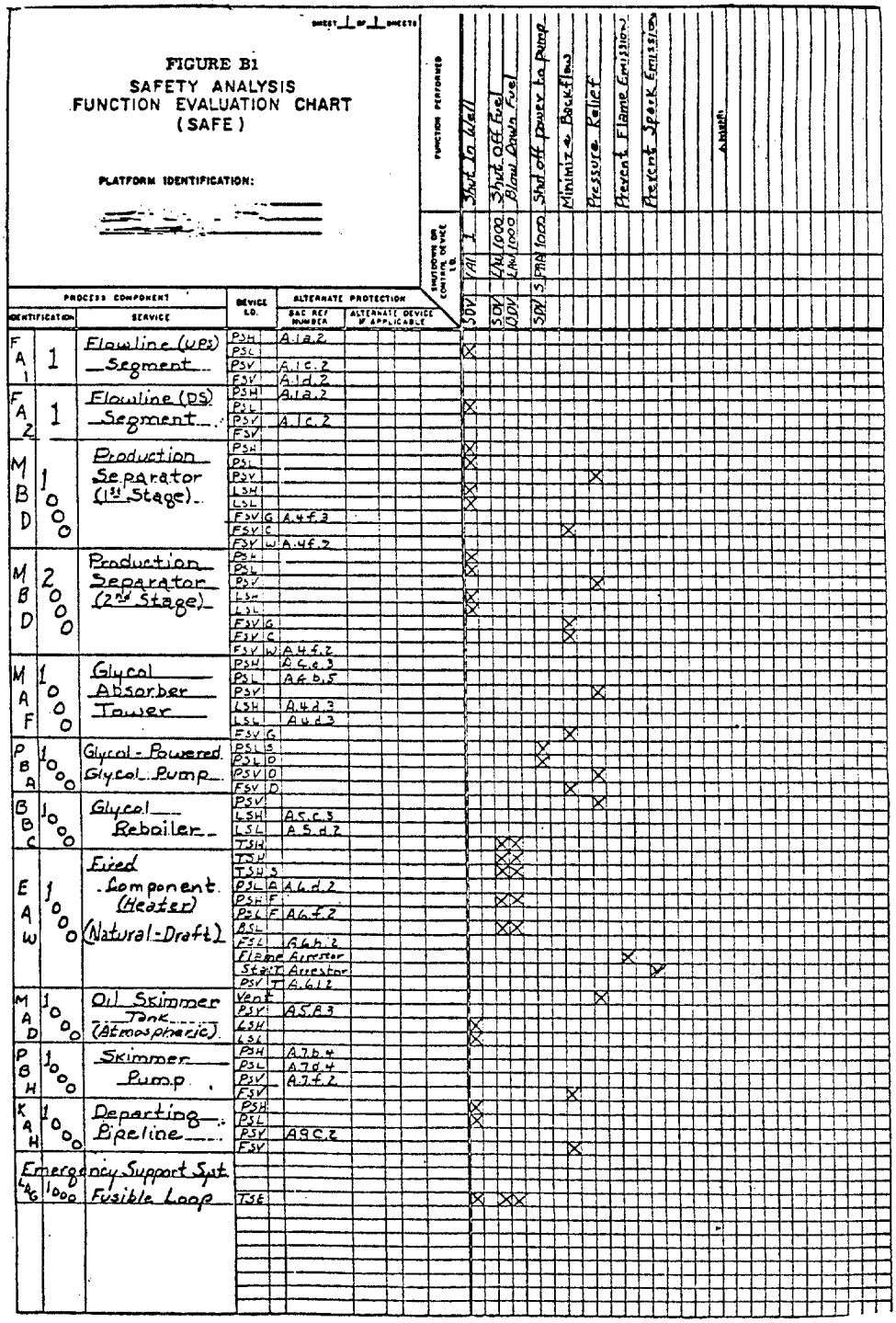


Figure 6. Typical Safety Analysis Function Chart

JUL 18, 1983
SUBSURFACE SAFETY DEVICE HISTORY

INCLUDES DATA THRU 6/30/83

W.M. 73 FIELD

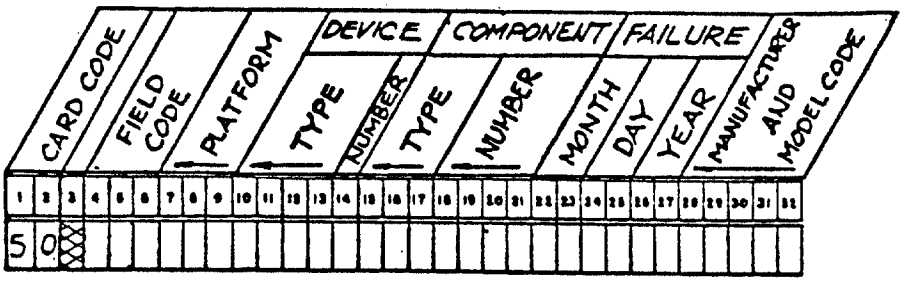
LEASE	WELL	STRG. NO.	TYPE	STATUS	DATE	SEQ	ACTION	SET AT (FT.)	VALVE TYPE	VALVE SIZE	BEAN SIZE (SERIAL NO.)	NO. OF SPACERS	NIPPLE TYPE	MANDREL TYPE	EQUAL. SUB	NOM. TUBE SIZE (IN)	INSPECT OR TEST EXM.	FED
F 1083 A	9	1	OIL	FLOWING	2/25/83		TEST	460	OTIS DK	3.00	2443		OTIS X	OTIS X	SCSSV TEST-O.K.		2	
F 1083 A	9	1	OIL	FLOWING	4/25/83		TEST	460	OTIS DK	3.00	2443		OTIS X	OTIS X	SCSSV TEST-O.K.		2	
F 1083 A	9	1	OIL	FLOWING	6/25/83		TEST	460	OTIS DK	3.00	2443		OTIS X	OTIS X	SCSSV TEST-O.K.		2	
F 1083 A	10	1	UNPER		3/16/83		PULL											
F 1083 A	10	1	UNPER		3/23/83	1	SET	1500	PUMPTHRU	2.00				OTIS W	OTHER	2.00		6
F 1083 A	10	1	UNPLR		3/23/83	2	TEST	1500	PUMPTHRU	2.00				OTIS W	PLUG TEST--O.K.			6
F 1083 A	10D	2	OIL	FLOWING	2/13/83		PULL											
F 1083 A	10D	2	OIL	FLOWING	2/14/83		SET	1600	OTIS J	2.00	18/64	9		OTIS D	OTIS H	2.00		6
F 1083 A	10D	2	OIL	FLOWING	3/16/83		PULL											
F 1083 A	10D	2	OIL	FLOWING	4/12/83		SET	1600	OTIS J	2.00	16/64	11		OTIS D	OTIS H	2.00	3	6
F 1084 A	11	1	OIL	FLOWING	2/11/83		PULL											
F 1084 A	11	1	OIL	FLOWING	2/12/83	1	SET	438	OTIS DK	* 2.00	DK21832R		OTIS X	OTIS X		2.00		2
F 1084 A	11	1	OIL	FLOWING	2/12/83	2	TEST	438	OTIS DK	* 2.00	DK21832R		OTIS X	OTIS X	SCSSV TEST-O.K.			2
F 1084 A	11	1	OIL	FLOWING	2/28/83		TEST	438	OTIS DK	* 2.00	DK21832R		OTIS X	OTIS X	SCSSV TEST-O.K.			2
F 1084 A	11	1	OIL	DEAD	3/ 7/83		PULL											
F 1084 A	11	1	OIL	DEAD	3/21/83		NONE								SECTION 3.2 WAIVED			
F 1084 A	11	1	OIL	GAS LIFT	3/24/83	1	SET	979	CAMCO PC	1.25	2442		OTIS X	OTIS X	OTHER	1.25		2
F 1084 A	11	1	OIL	GAS LIFT	3/24/83	2	TEST	979	CAMCO PC	1.25	2442		OTIS X	OTIS X	SCSSV TEST-O.K.			2
F 1084 A	11	1	OIL	GAS LIFT	5/24/83		TEST	979	CAMCO PC	1.25	2442		OTIS X	OTIS X	SCSSV TEST-O.K.			2
F 1084 A	11D	2	UNPER		3/ 8/83		PULL											
F 1084 A	11D	2	UNPER		3/19/83	1	SET	500	PUMPTHRU	2.00				OTIS W	OTHER	2.00		6
F 1084 A	11D	2	UNPLR		3/19/83	2	TEST	500	PUMPTHRU	2.00				OTIS W	PLUG TEST--O.K.			6

Table 2 – Example Safety Device History

Table 3. Example Safety Device Failure Report

SOUTHEASTERN DIVISION - OFFSHORE

FIELD: _____



CIRCLE ONE CODE	
33	SERVICE TYPE

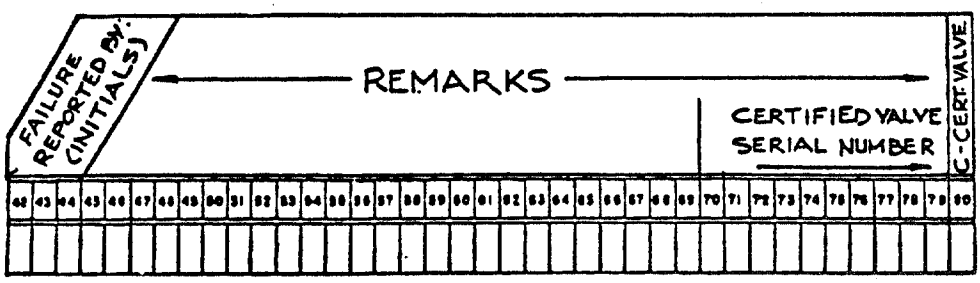
C - CONTROL FLUID
E - ELECTRICAL
G - GAS
H - HEAT TRANSFER FLUID
O - OIL/CONDENSATE
R - GLYCOL
T - TEMPERATURE/FLAME/HEAT
W - WATER
Z - OTHER

CIRCLE ONE OR TWO CODES FOR EACH CATEGORY

CIRCLE ONE CODE		35-36		37-38		39-40	
34	FAILURE MODE		FAILED PART(S)		FAILED CONDITION(S)		CONTRIBUTING CONDITION(S)
A - FAILS TO OPEN		A - BALL/GATE/FLAPPER		A - BENT		A - FOREIGN MATERIAL	
B - FAILS TO REMAIN OPEN		B - BEAN		B - BROKEN		B - HANDLING	
C - FAILS TO CLOSE		C - BEARING		C - COLLAPSED		C - SEALANT	
D - FAILS TO REMAIN CLOSED		D - CONTROL SYSTEM		D - DAMAGED		D - LUBRICANT	
E - LEAK INTERNAL		E - CYLINDER		E - DENTED		E - WATER	
F - LEAK EXTERNAL		F - DIAPHRAM		F - PLUGGED		F - HYDRATES	
G - OUT OF TOLERANCE		G - ELECTRICAL SYSTEM		G - PUNCTURED		G - SAND	
H - FAILS TO OPERATE		H - EQUALIZING SYSTEM		H - RELAXED		H - SCALE	
J - PREMATURE OPERATION		I - FLOAT		I - STUCK		I - PARAFFIN	
K - FAILS TO REMAIN LOCKED		J - FLOW TUBE/LINER		J - WARPED		J - OVERPRESSURE	
Z - OTHER		K - HOUSING		K - WORN		K - OVERTEMPERATURE	
		L - LINKAGE		L - CUT		L - IMPROPER ASSEMBLY	
		M - LOCK		M - SAND CUT		M - IMPROPER INSTALLATION	
		N - MANDREL		N - FROZEN		N - IMPROPER MAINTENANCE	
		O - ORIFICE NOZZLE		O - LOOSE			
		P - PISTON/POPPET		P - BURNED		P - FAILED TO EQUALIZE	
		Q - CAGE				Q - CORROSION INTERNAL	
		R - SEAL INTERNAL(O-RING)		R - BUILD-UP		R - CORROSION EXTERNAL	
		S - SEAL EXTERNAL(PACKING)				S - DRIFT	
		T - SEAT				T - VIBRATION	
		U - UNKNOWN		U - UNKNOWN		U - UNKNOWN	
		V - SPRING				V - SWOLLEN	
		W - PILOT OPERATED VALVE					
		X - STEM/SHAFT				X - CARBON DIOXIDE	
		Y - SENSING ELEMENT				Y - HYDROGEN SULFIDE	
		Z - OTHER		Z - OTHER		Z - OTHER	

CIRCLE ONE CODE	
41	ACTION TAKEN

A - REPAIRED
C - ADJUSTED/RESET
E - SERVICE/CLEAN/LUBE
H - DEVICE REPLACED
X - DEVICE ELIMINATED
Z - OTHER



REPORT PREPARED BY:	EXXON SUPERVISOR:

classic risk question of "what if ?" Quantitative risk analysis for offshore oil and gas operations is hampered by difficulties in:

(1) obtaining accurate failure mode and failure rate data for the many components of a given system;
(2) obtaining accurate probability distributions for losses resulting from a system failure in the absence of historic data;
(3) obtaining operational history related to component failure and prior maintenace work;
(4) assessing the influence of human errors.

When failure mode and failure rate data are available, they may not apply accurately to local conditions or to the application under review. For example, a recent paper by Engen and Rausand published reliability data for surface controlled, subsurface safety valves in the North Sea. Failure rate data are presented for four different valve types. However, the authors caution that a meaningful comparison of the failure rate data of the different valves cannot be made because operating conditions vary greatly among the various fields and operators. The presence of corrosive fluids, hydrogen sulfide, sand, flow rate variations, etc. was not accounted for in the study and would greatly alter valve performance. It was also pointed out that many failed valves showed evidence of human error, such as operating the valve under a high differential pressure. These difficulties would prevent a meaningful comparison of failure rates of individual valve types. However, it would not prevent an order of magnitude risk analysis from being made.

An effort must be made to keep failure mode and failure rate data current with new developments. Manufacturers are continually modifying their products in attempts to improve reliability or reduce costs. Also, equipment is being placed in increasingly hostile environments.

The causes of most accidents or failures can be attributed to human error at one or more stages in the concept, design, fabrication, and operation of the system of interest. The accurate modeling of human error factors in formal risk analysis becomes increasingly difficult as the complexity of the system increases and as the amount of human interaction required for system operation increases. This problem makes risk analysis most easily applied to less complex subsystems which have a high degree of automation.

OPPORTUNITIES FOR APPLICATION

Risk analysis procedures can be applied to each phase in the operations and maintenance of offshore oil and gas facilities. In current practice, the techniques are most useful when moving into a new operating environment or when applying new unproven technology. In these situations, it provides a systematic framework to evaluate alternative operating procedures and contingency plans. Used in this context, it is a valuable tool for developing appropriate policy and safety procedures.

Gierstad and Norge have presented a summary of offshore reliability data obtained from a joint project by seven companies operating in the Norwegian sector of the North Sea. This OREDA study will produce a handbook of generic

reliability data which should aid in the application of risk analysis by supplementing the data base of individual companies.

Many engineers involved in offshore oil and gas operations are not familar with the various risk 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 problems in the operations and maintenance of offshore oil and gas facilities are in the best position to see areas where these tools can be effectively applied.

A question not fully answered by the working group is whether the furtherance of formal risk analysis methods is the most effective means of improving offshore safety and loss control. As previously indicated, the majority of accidents (85-95%) are caused by human failure, rather than equipment or hardware failure. Correction of this situation requires effective line management of people. In other words, line management must be trained in good leadership techniques.

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APPENDIX A

PRELIMINARY OR GROSS HAZARD ANALYSIS - A Preliminary Hazard Analysis is usually the first step in a risk assessment procedure. Using this method, established checklists and forms are used to list all of hazardous materials, situations, events, potential accidents, human errors, etc., that can be identified. Previous experience of similar installations is systematically incorporated into the special forms or 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 the items considered on the forms. The preliminary analysis is inductive (starting with possible causes and proceeding to the possible losses) while the gross analysis is deductive (starting with the possible losses and proceeding to the causes). Safety manuals can generally be regarded as 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 which has had 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 Modes, Effects, and Criticality Analysis (FMECA) is used to identify the weakest links in the design. These methods are inductive in that they start with all of the possible failure modes of each component in the system and proceed to determine the effects or consequences of these failure modes. As with the other hazard identification methods, the last step involves identifying corrective action for control of the hazards identified. This method can be extremely time consuming and applications are relatively limited for complex systems with substantial redundancy.

The FMEA and FMECA techniques are particularly useful in analyzing hardware failures but rapidly lose credibility in analyzing the human failure factor which can become much more difficult to forecast or predict.

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 which can be trced through the system. Each operation or system leads to two paths of known probability (success or failure). The failure path at 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 standard 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 "and" gate

symbol. When an event has several possible independent causes, 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 which will lead to the top event. Single basic events which will lead to the top event 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 which 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 which will result in an open composite circuit. When a combination of open switches that will cause system failure are 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 which will prevent system failure are called a "tie-set" and the minimum 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. It is extremely complex, is practical only on a high speed computer, and in general is 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 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 are obtained that can be used statistically to determine the composite events which are most likely to occur and their corresponding probability.

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LOGISTICS AND SUPPORT

REPORT OF WORKING GROUP IV

PREFACE

Discussions in the working group concluded that the risks to be considered include both major accidents with serious loss or damage involving men and/or materials; and operability/downtime type considerations, where the losses may be primarily economic, involving loss of time and cash flow. The types of risk analysis perspectives that may be applied range from the limited scope involved in project or task decisions and management, to quite global risk management perspectives where the logistics and support fleet might be viewed as one subsystem in the management of risks associated with an entire field.

In general it was felt that simply developing estimated measures of risk is inadequate and meaningless. The estimated risks must be subjected to a judgement process wherein they are determined to be unacceptable/acceptable; better-than/worse-than some alternative. Flowing out of this process either explicitly or implicitly is a decision/action process. The generalized rational approach appropriate to this process would be to impose a statistical decision procedure over the risk analysis.

Another broad observation which particularly applies to the domain of logistics and support is the lack of an overall unifying domain of responsibility. This is a basic reflection of the usual commercial arrangements in this sector of operation but it poses a considerable obstacle to the application of risk analysis techniques to many projects.

A last general observation, which applies broadly to all engineering activities, not just risk analysis, is the need to retain that information bearing on the confidence limits of our estimates. Judgements concerning the meaning and significance (or lack of meaning or significance) are primarily lodged in these measures of the dispersion of certainty rather than in the expected values.

LOGISTICS AND SUPPORT

Logistics and support activities comprise virtually all of the infrastructure of a working offshore oil and gas field exclusive of the platforms and working platform superstructures. Even the platforms and their superstructures were transported to their working site in a logistic operation. Included in support activities are services such as firefighting, spill containment and cleanup, towage, salvage and search and rescue. Thus when considering the application of risk analysis methods, logistics and support activities are among the most pervasive aspects of offshore oil and gas production.

Foremost among the logistic activities is the transportation of the product of the oil/or gas field. This activity encompasses marine pipelines, offshore terminal and tanker loading facilities, tankers and tank barges, and storage facilities.

The movement of personnel, equipment and supplies incorporates consideration of supply vessels, tugs, barges, floating cranes, crew boats and helicopters. Many of these vessels perform important support roles in response to platform accidents and emergencies so any risk analysis performed at a sufficiently global systems level must consider the availability, deployability and response times associated with many of these logistic and support entities.

EXAMPLE APPLICATIONS

A number of example applications of risk analysis to logistics and support activities were shared and discussed during the sessions or Working Group IV. Most occasions to apply these methods seem to have originated either as an aid to internal decision processes or at the request of marine surveyors on behalf of the insurance industry. A brief listing of some of the example applications follows together with annotation concerning methods used, and commentary.

Work Barge Operability Studies
Method used: Theory of Second Order Stationary Random Processes (Probability and Frequency Domains)
References: 1,2,3,4,5,6

A number of studies of this type were discussed. Applications were typically to crane barges, dredges and pipe laying barges. The studies were used variously to select optimal principal dimensions for new equipment, select the best available existing equipment, determine number of work units required and estimate project schedule and cost.

Arctic Ice Window - Wet Tow vs. Dry Tow
Method Used: Monte Carlo Simulation (Probability and Time Domains)

A Monte Carlo simulation study was performed to examine voyage duration, required departure date and risk of shut-out for the delivery voyage of an Arctic Island. Alternatives compared were wet tow and dry tow deliveries. Processes subject to variability for both delivery alternatives were wind, current, and Arctic ice window opening. Additionally the wet tow was subject to uncertainty in stillwater towing resistance.

Logistic and Supply Relative to Hutton TLP
Methods Used: Markov Network Analysis (Probability and Time Domains)

As a weight sensitive design the storage requirements for drilling supplies are very critical. Richard Van Hooff indicated that a Markov network analysis of the logistics and supply capabilities that could be provided assisted in determining the acceptability of reduced drilling supplies storage capability.

Voyage Risk Analyses for Sea Fastenings, Production Jackets, Jack-Up Legs and Modules
Methods Used: Theory of Second-Order Stationary Random Processes (Probability Domain and Either Frequency or Time (Domain)
References: 1,7,8

Numerous examples exist where either frequency or time domain risk studies have been applied to voyages, usually by barge but also in the case of rigs, wet towed on their own hulls. Time-domain methods have been used where significant nonlinear response mechanisms are at work, otherwise frequency domain analysis is usually employed. The critical processes about which these studies are usually concerned are usually wave-induced dynamic structural loads involving sea-fastenings, fatigue sensitive joints on jackets, jack-up rig legs guides, and internal outfit on production modules. Such studies involve consideration of spatially and temporally varying wave climatologies.

Tanker Loading at Offshore Terminals
Methods Used: Theory of Second-Order Stationary Random Processes

Examples were presented where reliability and risk analyses were used in evaluating the dynamic and operating characteristics of proposed offshore terminal designs. Primary factors studied were weather limits on hook-up and product transfer, and avoidance of such casualties as failure of loading hoses or mooring hawsers.

Real-Time Offshore Crane Operations
Methods Used: Theory of Second-Order Stationary Random Processes and Markov Processes (Probability, Frequency and Time Domains)
References: 9

Real-time feedback and operations optimization systems have been employed to improve the operations of offshore cranes operating under exposed weather conditions, especially when employed in heavy lifts of high value. Such systems employ precomputed motion operators, real time sea state and motion monitoring, simulator and optimization elements. Field experience with these systems has been quite positive.

Mooring System Design Studies
Methods Used: Theory of Second-Order Stationary Random Processes (Probability Domain and Frequency and/or Time Domains)

Mooring arrangements for work barges and other support vessels working in close proximity to each other and/or to fixed platforms have been studied to determine required geometry, elasticity and strength.

Oil Spill Simulation
Methods Used: Time Domain Simulation and Monte Carlo Statistical Methods (Probability and Time Domains)

Studies have been conducted to estimate probable trajectories for oil spills under various conditions of wind, current, and oil flow rates (as for instance in the case of blowouts). Such studies have been used as an aid in assessing the threat to beaches and other marine resources posed by potential oil pollution sources.

APPROPRIATE TECHNIQUES

Many of the techniques appropriate to risk analysis, as applied to logistics and support activities, have been briefly cited above with the example applications. A more complete compilation of appropriate methods follows.

Theory of Second-Order Stationary Random Processes -

Of all the techniques to be discussed, the theory of second-order stationary random processes has been most widely applied to problems concerning logistics and support activities. The prevalence of this technique derives from suitability of the theory for studying linear systems (e.g., work barges and support vessels) subject to excitation derived from a random field (i.e., wave field). When combined via the probability calculus with wave climatologies, the method yields quantitative measures of risk and operability in the selected environment. References: 1,2,8

Markov Process Analysis -

Many logistic and support activities can, from an appropriate perspective, be regarded as Markov processes. (A popular example of a Markov process is the "random walk".) Wind and wave climatologies, ice movements, the occurrence and duration of "operational windows" are all examples which may be fruitfully subjected to Markov analysis.

Queuing Theory -

Queuing models are closely associated with Markov processes. Such models may be applied to logistics and supply problems such as the transportation of supplies to an offshore platform, or the adequacy of an offshore oil transfer terminal. For instance, such questions as average tanker waiting time before loading and average terminal idle time of an offshore oil loading terminal would be appropriate queuing theory issues.

Time Domain Simulations -

Many processes are most easily addressed by direct time domain simulation. In the realm of dynamics the usual reason for resorting to time domain simulation is the desire to incorporate nonlinear system elements, (e.g., nonlinear mooring forces). Other motivations for time domain simulation include the ability to introduce human operator input (real time simulation, such as some maneuvering studies) and systems whose complexity is most easily addressed in the time domain, e.g., very complex networks. Time domain methods are at their most powerful when coupled with Monte Carlo statistical methods (following discussion). Typical problems addressed by time domain simulation are nonlinear dynamics, maneuvering, nonlinear wave hydrodynamics, oil spill trajectories and logistic network performance.

Monte Carlo Statistical Methods -

Monte Carlo statistical methods form a powerful adjunct to other simulation techniques where the simulation incorporates random variables. The Monte Carlo method simply involves repeated trial runs of the simulator culminating in the assemblage of response statistics, much as one might collect repeated data from a physical experiment. The insight provided into nonlinear process statistics is similar to that provided for linear systems through frequency domain analysis.

Three other techniques were discussed by the working group. These were HAZOP studies, exercise, and model testing. Model testing is a powerful method, to be considered especially where nonlinear phenomena are suspected of being important. Excercises are conducted both at full-scale and in simulations. Full-scale exercises, particularly of emergency response systems, are valuable both as a management and training tool, and as a source of data for data analytical risk analysis procedures. Lastly, the HAZOP methods of analysis were suggested as an appropriate means of identifying problems required further study.

DATA NEEDS

Data needs, and research and development needs (to be discussed in the following section) are quite closely related. Three main themes dominate the data needs for risk analysis as applied to logistic and support activities; these are: 1) Joint probabilities, 2) Statistical dispersion (variability) information, i.e., retention of more than just mean trends, and 3) Better definition of system "capabilities" by which it is meant the distributions representing criteria for critical system events. The data needs identified by the working group are summarized in the following list:

Wave Data -

Joint climatological statistics for period[1], height (significant), principal heading angle and key parameter(s) for directional spreading.
Directionality: better data on directional spreading functions.
Independence parameters: independence period and distance, for wave climatology processes.
Persistance: better and more complete data on sea state persistance.
Better wave data for newly emerging areas of operations, and particularly for logistics and support, better wave data along supply routes leading to operations area.

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[1] Concerning the wave period, it is particularly important that work establishing climatological data base be very clear and precise in their definition of the period statistic presented.

Ice -

Ice floes and cover, spatial and temporal distribution statistics.
Ice keels, frequency of occurrence and draft for operating areas.
Ice windows, persistance data.
Ice accretion rates on equipment and superstructure under various environmental conditions.

Visibility -

Joint probability with respect to other key environmental conditions.

Environmental disturbances to communications and navigation.

Seamanship -

Markov transition matrices for heading and speed vs. directional sea state, wind ice, visibility, slamming, acceleration, etc.

Capability -

What causes shut-down of crane operations?
What causes cessation of supply delivery?
Under what conditions can personnel be transferred?
What causes speed or heading changes? (see Seamanship above)

Spills -

Cleanup capabilities vs. broken ice cover.
Dispersion rates and trajectories for new areas such as the Arctic.

RESEARCH AND DEVELOPMENT NEEDS

Research and development needs fall under three main headings, those being: 1) human factors, 2) nonlinear problems and 3) statistical decision procedures. Problems and topics in each of these areas are listed below.

Human Factors -

Seamanship: To what factors and processes does a skilled seaman respond, and what are those responses? What is the typical variation in seamanship responses?

Capabilities: what factors and processes result in the shutting down of crane operations? ... supply transfer operations? ... dredging operations? ... personnel transfer? ... etc.

Real time feedback effects - impacts of forecasting and monitoring (note that those effects need not occur through a human interface process). Prospects for further implementation of feedback and monitoring. References: 9,10

Nonlinear Problems -

Numerous nonlinear problems exist and only a few examples are presented here. However, the development of widely accepted higher order models for the irregular wave field and corresponding theories of response will greatly enhance our practical mastery of nonlinear hydrodynamic interactions.

Stability and capsize in a seaway:
Subharmonic resonance
Water on deck

Roll damping:
Interaction between shed bilge eddies and incident wave field

Drift forces:
Shallow water cases

Steep irregular wave fields:
Hydrodynamic and statistical modeling

Higher order response theories:
The natural corollary to higher order models of the wave field

Statistical Decision Procedures -
Development work is needed to introduce appropriate statistical decision procedures into both operations planning and real-time operations decision generation. Such work is particulary necessary as an adjunct to further implementation of real time monitoring and feedback systems.

OPPORTUNITIES FOR IMPLEMENTATION

In addition to the applications of risk analysis and management techniques to those problems for which it is currently applied (and the growth in such applications) three thoughts were discussed which may point to future opportunities for implementation. These three ideas were:

1) Consider logistics and support at the field and platform development/ design stage - not as an afterthought. In particular:

   a) Consider logistic issues as they apply to platform and production system module delivery to the field.
   b) Utilize systems approach to define available/required support and interaction of such support with design.

2) Consider logistic and support capabilities as a subsystem in more global risk analyses.

   a) Logistic and support capabilities during emergency response and assistance.
   b) Logistic and support craft and facilities as a source of hazard

and 3) Consider logistic and support as an integral part of overall project optimization.

BARRIERS TO IMPLEMENTATION

Most of the barriers to implementation are institutional in character and as such probably reflect the relative unfamiliarity of a wider user public (including many engineers) with the probabilistic perspective. Specific citations of this type would include marine surveyors with static rules and codes of the specification type.

Other barriers to implementation include the usual lament concerning proprietary data, and the frequent lack of a unifying framework of responsibility concerning logistic and support activities.

Two other barriers deserve mention. The first is time during emergency or salvage situations. Only pre-planning, pre-analysis and experience can be brought to bear in an emergency situation, there is usually no time for sophisticated real time analysis. The second and not unrelated problem is that much of the information provided to user/operators is unusable, having been generated to satisfy the engineers and regulatory requirements; not as real aides to an operator in an emergency.

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Written comments (dated June 8, 1984) on the Working Group IV (Logistics and Support) position paper, by Mr. Robert C. Phillips.

"There are a number of consultants and research groups working on formal risk analysis methods who are advocating a much wider application of formal risk analysis to offshore oil and gas operations, believing that it will be possible to make better and safer decisions, and thereby save money. There is considerable skepticism from industry and others. The risk analysis advocates utilize many of the precepts and ideas propounded in the late 60's and 70's by operations research analysts. However, many of these methods have been considerably refined since that time. These risk analysis methods attempt to quantify risk and the assessment of risk mathematically. However, the assessments are often very rough due to the lack of detailed statistical data on one or more of the important factors. That is, the answer may be correct within one or two orders of magnitude. While this type of analysis is useful for certain purposes it may not meet the needs of an operating manager or design engineer. Further, it may not be practical to obtain the detailed statistical data that formal risk analysis requires to give better answers. First the necessary data has not always been precisely defined by the risk analysis proponents and secondly, the acquisition of such data may be far too expensive, particularly where it involves the statistics of human behavior.

Another problem in the practical application of risk analysis is that the methods usually develop probabilistic assessments. However, risk is not only highly subjective among individuals, it also is subjective to considerable change in the same individual, particularly one who is not trained in such assessments, may apply very different risk criteria in assessing personal risk and business risk.

Several positive results occurred as a result of the workshop:

- It promoted much needed communication between the practitioners of formal risk analysis and the potential users of this discipline.

- It emphasized that many people are using the terms risk analysis and risk assessment without clear ideas as to the specific meaning of the terms.

- It emphasized that formal risk analysis techniques work better when considering financial or property type risks (easily quantifiable subjects), than when considering human factors and risk to humans (not easily quantifiable).

The Group IV position paper recognizes some of these points, particularly noting the "relative unfamilarity of a wider user public (including many engineers) with the probabilistic perspective." Actually, the problem may be broader than noted in the position paper. The evaluation of risk requires not only a knowledge of probability and the probability perspective but an understanding of risk criteria. Actually, the user must have considerable knowledge of formal risk analysis methods if he is to have confidence in the results of such sophisticated analyses. He may not be as skilled in applying the techniques and in developing the assessment, but he must have a reasonable good understanding

of what he is receiving from the formal risk analysis, in order to depend on it. The operations research analyst working with the government (particularly in the military) had continuing problems in establishing credibility with the operating managers due to the lack of understanding between the two groups.

Another problem with the use of formal risk analysis is briefly mentioned in the Group IV position paper in the preface. That is, there are few consensus standards on acceptable risk criteria. Since the subject is not too well understood by large numbers of people there has been no substantial effort to establish such criteria. When human health/safety is involved, the emotional and political aspects are so pronounced that it becomes extremely difficult to establish any realistic risk criteria.

One observation that might be made from the workshop is that there is a substantial need for additional treatment of risk analysis and risk criteria in all college curricula if society is to cope adequately with the advances in all fields of technology. Otherwise, society will be unnecessarily burdened with unrealistic restrictions and regulations generated by fear and by purely emotional judgements."

Chairman's Closing Remarks:

The position paper developed by Working Group IV elicited written comments from Mr. Robert C. Phillips of the Travelers Insurance Group which I have chosen to include (above) as part of the working group report. Additionally, Mr. Henry Chen of SOHIO phoned in some comments to me which largely parallel the sentiments expressed in Mr. Phillips written comments. Additionally Mr. Chen expressed the opinion, widely held within the working group, that the application of risk and reliability studies should not be mandated by regulation.

In closing I would like to emphasize a few points which, while treated in the position paper, perhaps deserve review, particularly in consideration of the comments received. First I wish to emphasize again the importance of including measures of confidence in risk and reliability work. The inclusion of confidence limits can substantially address the concerns expressed in Mr. Phillips' opening paragraph.

Second, I would observe that probability is the natural and preferred language for discussing risk. If probabilistic assessments are unfamiliar to the user public, then it points to an inadequacy within our educational and training systems (as Mr. Phillips so ably observed) rather than an inadequacy in the language of expression.

There is a distinction to be drawn, in many opinions, between measures of risk (by which I mean the probability of some event or consequence) and the judgement or evaluation of a risk or consequence. Assume that in a given problem the risk of a particular innocuous structural failure is 0.0001, and that in a separate problem the risk of the loss of a human life is also 0.0001. The risk in both instances is identical but we would all judge the consequences very differently. If we strive (as recommended under research and development needs) to develop statistical decision processes which can structure and formalize the judgement of these disparate consequences we will again find the probability calculus to be a worthy and suitable language for expressing our results.

Lastly, I wish to observe that risk analysis procedures are being successfully applied within the offshore oil and gas industry as a means of reasonably addressing engineering and operational issues of limited scope. Such applications typically involve the application of those methods described in the position paper as second-order stationary random processes and usually pertain to responses to waves. Without consideration of exposure periods and wave climatology such methods fall short of what could be regarded as a risk analysis. However, with consideration of exposure and wave climatologies a risk analysis is obtained. Such methods have found particular application in the areas of logistic and support activities because often very brief exposures are involved.

I would like to take this opportunity to express my thanks to the participants in Working Group IV for their contributions to the general discussion and to the working group report. I would also like to thank the Minerals Management Service for sponsoring, and the National Bureau of Standards for organizing, this workshop on the application of risk and reliability analysis to offshore

oil gas operations. The workshop has engendered a most worthwhile exchange of perspectives and information.

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APPENDIX I

THEME PRESENTATIONS AND OTHER CONTRIBUTIONS

INTRODUCTION

The first part of the workshop was dedicated to theme presentations by invited speakers. In addition, some of the workshop participants contributed valuable information. The theme papers and contributions are presented in this Appendix and summarized in the following section.

SUMMARY OF PRESENTATIONS

Mr. F. P. Dunn, from Shell Oil Company, presented an overview of current practice in the U.S. in exploration, field development, and operation and maintenance. The importance of voluntary industry standards was stressed. The standards are also incorporated in government regulations (MMS and USCG). Formal reliability analysis was used in many instances to provide a rational basis for the industry standards. American Petroleum Insitute (API) Standard API 2A on Offshore Structures is in the process of being changed to a reliability based format. At times, industry resorts to reliability analysis to arrive at optimum solutions, as in the case of exploration drilling structures for Harrison Bay in the Beaufort Sea. The point was made that risk analysis is not necessarily a panacea, and that many accidents are caused by engineering or detailing deficiencies which would not be prevented by risk analysis.

Dr. David Slater, from Technica, London, U.K., reviewed various safety and reliability assessment methodologies applied to offshore installations and the practical applications of these methodologies in the North Sea. Methodologies discussed were: Conceptual Design Safety Evaluation; Hazard Survey/Hazard Inventory; Process Safety Design Checks; Hazard and Operability Study/Failure Modes and Effects Analysis (HAZOP/FMEA); System Reliability/Fault Tree Analysis; Event Tree Analysis; Cause-Consequence Diagram; Structural Reliability Analysis; Simulation Techniques; Risk Assessment; Construction Audit/Pre-Construction Check; and Safety Audit.

Dr. Slater noted that in the North Sea at least four full risk analyses were performed in behalf of industry, and about a dozen concept evaluations were carried out for the Norwegian Petroleum Directorate (NPD). HAZOP has recently been very widely used in the North Sea because of its advantages over API Standard RP 14C which, even though it is simpler to apply than HAZOP, does not provide much information. He also noted that reliability analysis is used to verify target reliability levels in production, to evaluate failure frequencies in complex plants as part of a risk analysis, and to evaluate the effectiveness of protective systems.

Dr. Øysten Berg, from NPD discussed the safety management of offshore development projects by NPD. Offshore oil and gas production in Norway is regulated in accordance with a Royal Decree dated October 3, 1975, which will be updated in the near future as a result of revisions following the "Alexander Kielland" accident. Effective control of safety is assured by "internal control" systems, in which industry is responsible for enforcing the implementation of the safety regulations in their own operations. The regulations require a "conceptual safety evaluation" which must document that the initial concept chosen for the field development will result in acceptable safety. A system reliability

analysis has to be performed considering all "design accidental events" (DAE's, or most unfavorable situations) which can be envisioned. "Improbable" accidental events are excluded from consideration; an "improbable" event is defined as one which by the best available estimates has a probability of occurrence of less than 10^{-4} per year. "Adequacy" is measured by the ability of main support structures, escape ways, and shelter areas to remain functional or partly functional during the DAE's considered. Considerable R&D was sponsored by NPD between 1978 and 1983 to facilitate the implementation of their safety requirements.

In addition to the theme presentations, the following information was conveyed:

Mr. Struan Simpson of the E&P Forum, discussed their study of the relevance of risk analysis initiated in 1981. The survey conducted to date, which considered methodologies and typical application in offshore projects, indicates that risk analysis has been used in a wide range of projects, from assistance to engineering design through safety evaluations for project management and statutory agencies. While industry recognizes the value of risk analysis, it is evident that these analyses supplement the primary engineering and management processes, rather than being a primary decisionmaking tool. It was also stated that risk analysis cannot identify hazards that are not inherent in the basic engineering design models and considerations. Thus, risk analysis supplemented, but did not replace conventional engineering and management practices. Further studies will consider the impact of risk analysis on exploration and production projects.

Mr. Torkell Gjerstad from Elf Aquitaine-Norge, discussed the Offshore Reliability Data (OREDA) Study. Statistical data are now being collected from several oil companies on the performance of 150 different components of offshore installations in the North Sea and the Adriatic Sea. The data will be published by the end of 1984 in the form of a reliability handbook. The data will be presented generically and their source will remain anonymous. However, the OREDA Steering Committee will have information on the data source and thus will be able to check the data, if necessary.

RELIABILITY ANALYSIS

OVERVIEW OF CURRENT PRACTICE

by

F. P. Dunn

INTRODUCTION

I appreciate the opportunity to talk with you on this rather important subject -- risk analysis, or, more to my liking, reliability analysis. I have been asked to comment on application of reliability analysis in the offshore oil and gas industry -- how or whether it is being employed, its benefits, limitations, etc.

As some of you already know, the Oil Industry Exploration and Production Forum (E&P Forum) set up a Working Group in 1981 to study and report upon the uses, applicability, and limitations of risk assessment in offshore exploration and production operations. The Working Group made a survey among member companies in order to ascertain the extent to which risk assessment is used offshore, for what purpose, and with what effect. A member of the E&P Forum will discuss the efforts of the group a little later.

I will talk briefly about the various facets of the offshore industry, from exploration to development and production, with emphasis placed upon the methods employed to achieve an acceptable level of reliability and safety. Since my background is mostly offshore structures, I hope you'll pardon me if I spend a little more time on that subject than on the other aspects of our business.

I will not concentrate on the formal mathematical procedures involved in carrying out a classical reliability analysis -- you're not going to see any formulas with summations, probabilities, or double integrals -- rather I will concentrate on the fundamental philosophies, methods, and procedures employed by the industry to establish the desired level of reliability in its activities.

I believe one of the most important considerations in establishing and maintaining a high degree of reliability in the offshore industry is the development and maintenance of codes, standards, and guidelines. The knowledge and the experience gained through the years are documented in such codes, standards, and guidelines for use by all. I quote from an article which appeared in the Marine Board Annual Report, 1981:

> "The engineering profession, which serves both industry and government, has long recognized the need to provide self-regulation and guidance to ensure the maintenance of professional standards of design and construction. The engineering profession in the United States pioneered self-regulation of many activities before their regulation was taken up by government, through such steps as professional licenses, the standardization of materials

and testing procedures, the development of guidance rules and codes, and the promulagation of recommended practices.

Similarly, industry has recognized the need to produce the resources and carry out activities in the demanding environment of the oceans in a safe manner, to ensure the ongoing productivity of its personnel and its facilities, and thus to protect its investment.

The engineering profession and industry have historically joined together in voluntary actions to produce a wide range of consensus standards."[1]

Many organizations participate in creating these documents -- the Coast Guard, the Minerals Management Service, industry organizations such as the American Petroleum Institute (API), the American Bureau of Shipping (ABS), professional societies like the American Society of Mechanical Engineers (ASME), and various domestic and foreign standards writing organizations. All of these organizations have cooperated in creating a fairly comprehensive set of documents, whose purpose is basically to provide for an acceptable level of reliability in conducting various activities.

Formal reliability analyses have been employed frequently in creating rational bases for the contents of these documents, and I will point out later a few examples of the use of such analyses in some of our operations.

EXPLORATION

There are three major categories of equipment used in offshore exploration activities: (1) seismic vessels; (2) mobile offshore drilling units; and (3) support vessels, e.g., crew boats, helicopters, etc.

1. Seismic Vessels

Seismic vessels, as a percentage of the whole, represent a very small part of offshore operations. Therefore, I will not only point out in passing that such vessels and their maritime appurtenances are regulated under USCG regulations, ABS certification requirements, and the International Convention on Safety of Life at Sea, 1974. Also, the maritime personnel on board are subject to government license requirements.

Reliability in these operations is provided as a part of the normal course of business through the use of industry codes and standards, government regulations and certificiation requirements.

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[1] "The Employment of Voluntary Consensus Standards in the Regulation of Offshore Development," Ben C. Gerwick, Jr., Chairman, Marine Board, National Academy of Sciences.

2. Mobile Offshore Drilling Units (MODUs)

Drilling units were designed, built, and operated under guidelines and voluntary standards written primarily by industry-sponsored organizations until 1979. Since that time all U.S. flag MODUs have been certified by the USCG[2]. The units are surveyed by the ABS and carry an ABS classification. The design and construction of industrial equipment on board these units is subject to industry standards, whereas the maritime equipment on the vessels is controlled by USCG certification requirements for Mobil Offshore Drilling Units.

The same is true for personnel. During drilling operations, the industrial personnel on board are not licensed by the Coast Guard. While underway though, varying maritime licensing requirements apply depending on whether the vessel is capable of independent navigation.

The USCG now requires that MODU industrial systems be designed in accordance with the principles of API 14C (Analysis, Design, Installation, and Testing of Basic Surface Safety Systems on Offshore Platforms).

Further, the industrial systems must be analyzed and certified to comply with other applicable industry standards.

Thus, since 1979, there has been a U.S. regulatory requirement for the formal application of the principles of designed-in safety protection from potentially hazardous conditions, with consideration for inclusion of a safe alternative when there is failure of a primary industrial component. Several different types of reliability analyses, such as damage assessment studies, hazards identification analyses, studies on causes of blowouts, etc., have been done and are done as routine evaluations.

In summary, then, there are four categories of design standards for a Mobile Offshore Drilling Unit:

1. Voluntary standards for the industrial equipment;

2. ABS classification standards;

3. USCG requirements (in excess of ABS) in areas such as lifesaving appliances;

4. Requirements to facilitate international travel:

    a. International Convention for the Safety of Life at Sea (SOLAS) 1974 for self-propelled vessels.

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[2] Foreign flag units must have a "Letter of Compliance" issued by the USCG.

b. International Maritime Organization - Code for the Construction and Equipment of Mobile Offshore Drilling Units (MODU code).

With the exception of very special categories such as lifesaving appliances, the primary difference between application of the voluntary standards in the first category and the other three categories is a requirement for third party verification that the vessel in fact complies with a standard. In most cases, the standard used is a standard developed through the voluntary system. For illustration, the ABS has a special committee on Mobile Offshore Drilling Units which is composed of industry, Coast Guard, and ABS personnel. This committee drafts the ABS requirements. The result is an industry voluntary standard which is administered by ABS, accepted by the U.S. Coast Guard for national and international purposes, accepted by insurance companies for insurance purposes and paid for by industry.

3. Offshore Support and Standby Vessels

The third category is offshore support vessels. These vessels are common in all phases of offshore operations. Most of the vessels are now operating as USCG certified vessels. Again, reliability analyses of one form or another have been employed by industry, ABS, and the government to assist in developing applicable codes and standards.

A very important support vessel for offshore operations is the helicopter. Most helicopter operations, including the licensing of the pilot, and the design, construction, and maintenance of the helicopter, are closely controlled by the Federal Aviation Authority (FAA). The offshore landing areas are designed, constructed, and operated in accordance with industry standards such as API RP 2L, Recommended Practice for Planning, Designing and Constructing Heliports for Fixed Offshore Platforms, and the Helicopter Safety Advisory Committee (HSAC) manual. Component reliability analyses have been conducted for helicopter operations, primarily by the manufacturers.

FIELD DEVELOPMENT

A. Structures

There are three distinct phases for development of oil and gas leases offshore. The first is the installation of the structure to be used for drilling the development wells, the second is the drilling of those wells, and the third is the installation of production and pipeline facilities.

First, a suitable structure must be designed and installed taking into consideration water depth, environmental climate, foundation conditions, size of facilities, etc.

The basic philosophy of the offshore industry has been to provide redundancy or alternative solutions where experience or analysis indicates possibility of failure, in order to minimize the consequences of failure. This philosophy is embodied in the industry guideline API RP 2A. This document was written by

knowledgeable representatives of various companies, updated as appropriate, and supported by the cumulative research and development efforts of the industry (upwards of 200 million dollars over the past 10 years). I have been a participant in this effort for almost 20 years, and I know that uppermost in the minds of the participants who wrote this document was the desire to create the best technical document possible, balancing, on the one hand, the cost of over-conservatism, and on the other hand, the consequences of failure. Decisions of this sort were not made arbitrarily. They were made by experienced people who fully understood the consequences of these decisions.

I would now like to discuss a specific example of the use of formal reliability analyses in our business. These methods have been employed to establish design criteria for some areas where we operate, like the Gulf of Mexico. First, we establish what level of reliability we need to acheive. Figure 1 shows one reasonable means of achieving the answer. Basically, an optimization process is involved wherein the analyst proceeds through several iterations of design, making the structure stronger (and more costly), but also reducing the probability of failure. The analyst's goal is to find an equitable balance between costs (first cost plus failure cost) and reliability. Desirable criteria can then be established and incorporated into a design code or recommended practice, such as RP 2A. An absolute necessity in this exercise is calibration with reality -- we must check our descriptions of the environment and our estimates of structural strength with actual experience. If necessary then, we change our analytical model to correspond with that experience. Too often this is not done, and as a consequence, the analysis is of little real value.

I might also mention that the API Task Group on Offshore Structures is now in the process of changing RP 2A, the industry guideline, to a relaibility-based format. This has been going on for the last 4 or 5 years. A draft of the revised Recommended Practice will be published within 2 years. Moreover, the American Institute of Steel Construction has just published a draft of their Load and Resistance Factor Design Code, which will be used for certain designs.

At times there is need to perform reliability analyses in order to assist in arriving at an optimum solution when presented with various courses of action. Such techniques were recently used to determine the relative ranking of several proposed exploration drilling structures for Harrison Bay in the Beaufort Sea offshore Northern Alaska. The primary objective was to determine the feasibility of a particular concept based upon its probability of being driven off location due to ice loads.

Ice forces for Harrison Bay were computed probabilistically, using an ice simulation model to forecast the structure's exposure to multi-year ice floes on a seasonal basis. The ice environment was subdivided into four ice seasons -- break-up, summer, freeze-up, and winter -- that were modeled using site specific environmental data. Annual and seasonal ice force distributions resulting from multi-year ice floe collisions were subsequently computed using both empirical and mechanistic relationships that have been calculated with both small- and large-scale test results.

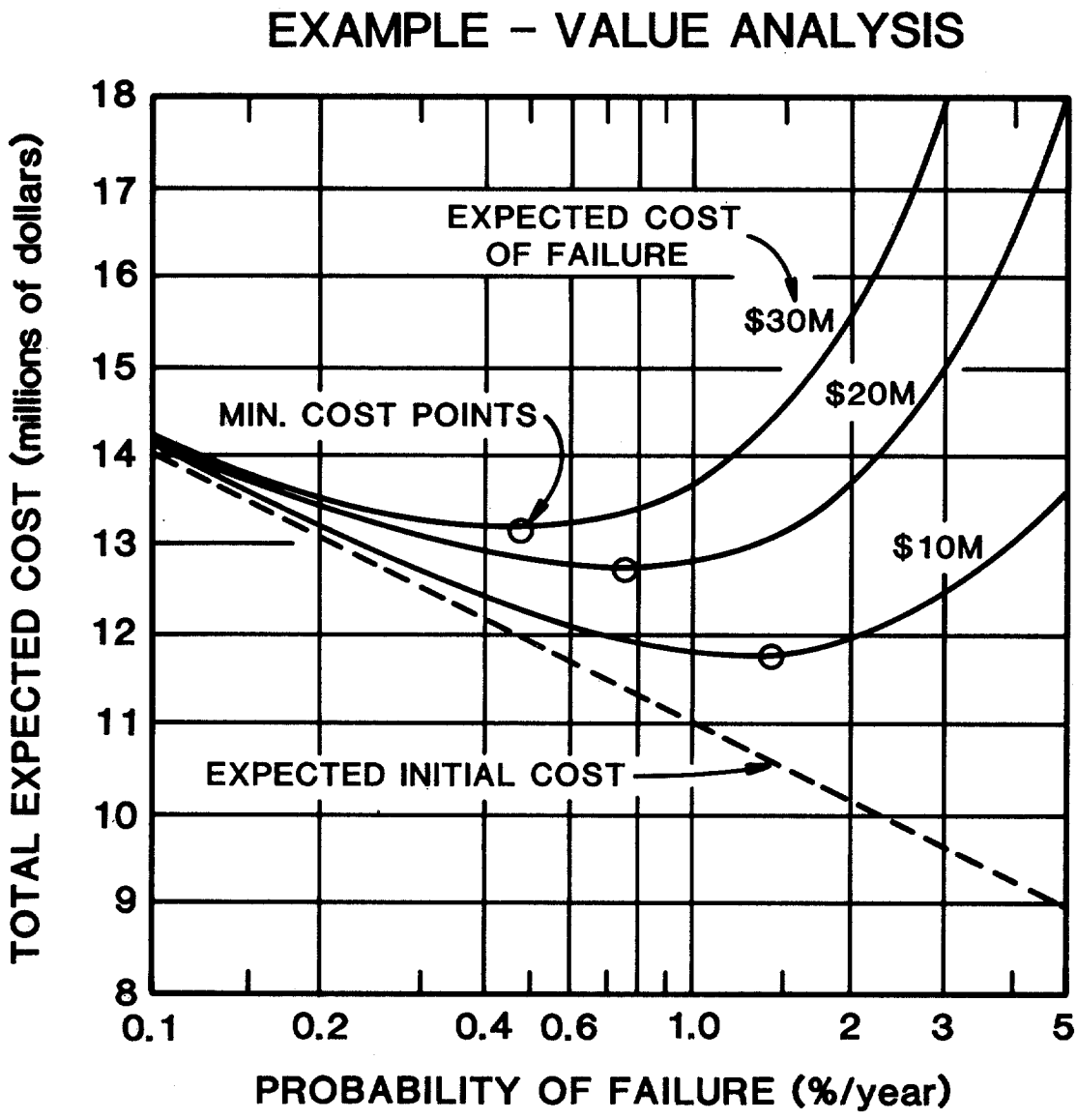

Figure 1. Application of Reliability Analysis in Cost Optimization

The probabilistic loads were combined with structure foundation resistance distributions using a conventional reliability analysis to determine the concept's ability to resist lateral load. The annual probability of being driven off location was computed for soil conditions where the resistance function does not vary with time (sand and stiff clay sites in which consolidation effects are not important). At the weaker clay sites, where the lateral resistance increases in time through consolidation, seasonal reliabilities were determined assuming an average resistance throughout the season. The seasonal reliabilities were combined to determine the annual resistance reliability. The structural concepts were then ranked in order of their calculated resistances. Quite an interesting and valuable evaluation.

Formal reliability analyses have thus been employed as a tool to arrive at optimum choices in determining design criteria, or to choose a particular course of action when confronted with several reasonable choices. It is important, however, to remember that such analyses are only tools -- they do not supplant experienced engineering judgement -- they only assist in making a more rational judgement.

I have seen some reliability analyses which, while done using acceptable methods, reach the wrong conclusions. An example of this is an analysis which indicates that one should not pay a premium in order to reduce the likelihood of an undesirable consequence, because the likelihood is so small. Well, in some cases, one simply cannot afford the consequences under <u>any</u> circumstances (e.g., bankruptcy), so he will pay the premium.

I have also seen some rather sophisticated analyses which really do nothing more than "prove" that the choice of action favored by the analyst (or his boss) is indeed the correct choice.

There are many other considerations which are more important in contributing to system reliability than formal risk analysis. Competent people are on the top of the list. No amount of sophisticated analyses can substitute for intelligent, experienced, hard-working people. Moreover, we must encourage such people to document their experience in codes and standards, so that others can benefit.

In our offshore structures business, I would much prefer having an engineer knowledgeable about materials, welding and welded connections than one knowledgeable about risk analysis. I will go further than that -- I would advise my son, a structural engineering student, to take courses offered in materials, welding, and connection details rather than any courses in reliability analysis per se. I believe that any study of failures of buildings, bridges, offshore structures, etc., will conclude that most of the failures are caused by poor selection of material or lack of attention to detail (especially of connections), either by the design engineer or the builder. It seems that almost every week we read in Engineering News Record of some failure caused by one or the other of these problems.

I therefore believe that we can move much more efficiently toward more reliable structures and systems by concentrating our efforts on more intense review of

design and more attention to inspection of construction, so that we will have a better chance of catching the blunders that cause most of our failures.

B. Drilling and Well Control

The second phase in field development commences after the structure is in place.

The rig illustrated in this slide is portable and has an extended life expentancy of about 20 years. The unit is built to meet industry codes and standards. The list of such codes and standards is extensive, as you can see.

Subsurface well controls are designed and operated in accordance with the API 14 series of specifications and recommended practices. As an aid in creating these documents, a typical risk analysis was conducted for a well completion system in order to compare reliability of key components of the system. The primary source of data was operators' experience; secondary source was United States Geological Survey records on safety valve failure. The objective of the study was to optimize equipment performance and to develop data for studying sensitivity of system reliability with respect to key components. Reliability analyses were performed using logic diagrams. The results demonstrated marked penalties for complicated well completion systems and determined a probability of blowout among competing systems.

C. Production Facilities

The third phase occurs after drilling is completed. The rig is removed and producing facilities are installed on the platform.

These facilities are designed and constructed utilizing a broad spectrum of voluntary industry standards and recommended practices. For the most part, design criteria used are the same as are used in onshore refineries and chemical plants. There are cases where it is necessary to have specific offshore standards. These are usually written as API standards or recommended practices, such as API RP 2A, previously discussed. These documents represent an assembly of proven technology, written by engineers who take advantage of industry R&D efforts to arrive at rational criteria and guidelines. Depending on the purpose, the documents are issued as specifications, standards, recommended practices, guides, bulletins, etc.

In the case of production facilities, there is an MMS regulatory requirement that the facilities be protected with a system designed, analyzed, tested, and maintained in accordance with the provisions of API 14C. The purpose of the API standard is to protect personnel, the environment, and the facility, i.e., identify undesirable events and define measures to prevent or minimize their effect.

D. Pipelines

Pipeline systems are usually built while production facilities are being installed. Gas and oil are normally separated offshore and transported via separate pipelines to onshore facilities. These pipelines are usually common

carrier facilities and are designed, installed, and operated in accordance with 49 Code of Federal Regulations (CFR) 192 and 49 CFR 195. These regulations incorporate the voluntary standards listed below as appropriate.

Interconnecting field pipelines are designed in accordance with American National Standards Institute (ANSI) voluntary standard B 31.4 Liquid Petroleum Transportation Piping Systems and ANSI B 31.8 Gas Transmission and Distribution Piping Systems. The regulatory agency having jurisdiction over common carrier pipelines is the Department of Transportation. The MMS administers governmental requirements on intra-field lines under OCS Order Nos. 5 and 9.

OPERATION AND MAINTENANCE

The industry philosophy on operation and maintenance varies, understandably, with the company and/or type of equipment and operations.

Most companies operating on the Outer Continental Shelf have standard safe practices, operating procedures, and training requirements which are designed to provide for operating efficiently and for the prevention of unplanned incidents. These operating procedures incorporate industry practices and government regulations as appropriate. The same is true for maintenance. I have chosen cranes as a piece of equipment to illustrate further how the system works and how U.S. governmental requirements and industry voluntary standards are meshed to minimize risk.

Cranes are a very necessary piece of equipment offshore. They provide the final link in the supply line to and from onshore. Due to limited offshore storage, an inoperative crane quickly brings operations to a standstill.

The MMS requires that API Specification 2C, Offshore Cranes, be used as a guideline for the selection of cranes. The USCG requires that cranes for MODUs be designed in accordance with API Specification 2C. Similarly, both agencies require that operation and maintenance, including personnel qualifications, be in accordance with API RP 2D for Operation and Maintenance of Offshore Cranes.

Acceptable loading and environmental criteria are set out as appropriate in Specification 2C. Guidelines for training and qualifying personnel as operations and maintenance personnel are included in RP 2D. Also included are recommended practices on operation, inspection, testing, and maintenance. These procedures are designed to keep the crane in a satisfactory condition to operate within its designed capability. Again, the writers of this RP pooled their cumulative knowledge and experience over the last 20 years to create a guide for other less experienced to follow. Formal analyses of several types were conducted, both by manufacturers and by operators, including fault tree analyses, cause/consequence diagrams, etc. The results were used as background for the recommendations.

CONCLUSION

We have just completed an overview of the major aspects of offshore operations. The experience and knowledge of many members of the industry and the extensive R&D budgets of the many companies involved have been employed to arrive at voluntary standards, codes, and recommended practices for safe and reliable conduct of these operations.

In summary, we take risks in whatever we do and their existence should be recognized. The primary advantage of a systematic analysis of these risks is that the analysis assists greatly in understanding the major sources of these risks and how important they may be. It points the way to a decision to proceed or not proceed with a project, or an optimum choice of alternatives, or a more rational choice of safety factors and design criteria. However, it is not a panacea -- it is a tool for the analyst, and like any other tool, it is as valuable as the intelligence and experience of the analyst makes it.

Reliability analysis has its place, but it will not substitute for sound engineering judgement, thorough analyses, and, most important, attention to those million and one details which, together, make up the whole of a structure, a drilling rig, well, production facility, or pipeline. Almost as important, in my opinion, is the documentation, via guidelines and standards, of the knowledge and experience of good engineers, so that less capable and/or less experienced engineers can take advantage of that expertise.

METHODOLOGIES FOR THE ANALYSIS OF SAFETY AND RELIABILITY PROBLEMS IN THE OFFSHORE OIL AND GAS INDUSTRY

by

Dr. D. H. Slater and Dr. R. A. Cox

ABSTRACT

This paper gives a comprehensive review of safety and reliability assessment methodologies as applied to offshore installations, with special reference to North Sea experience. There are several distinct techniques which may be applied.

- "Conceptual Design Safety Evaluation"
- Hazard and Operability Study
- Fault Tree Analysis
- Event Tree Analysis
- Structural Reliability Analysis
- Simulation Techniques
- Risk Analysis

In the paper, these techniques are discussed in terms of their relevance and usefulness in offshore problems. The extent of practical application of these methodologies in the offshore oil and gas industry, and the results from this experience, are reviewed.

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1. INTRODUCTION

Development of offshore oil and gas in the North Sea has necessitated construction of very large platforms, accommodating several hundred people in an unusually inhospitable environment. Major accidents have already occurred - notably the capsize of the semisubmersible Alexander Kielland, the Ekofisk blowout and the collapse of the Sea Gem jack-up. As a result, there is great interest in achieving a better understanding of offshore risks and in improving designs and evaluating the effectiveness of such improvements. Techniques of safety analysis play an important part in this effort.

The last decade has seen a tremendous growth in the application of formal analytical techniques to hazard analysis and loss prevention in the chemical, petroleum, and offshore industries. The array of methods, each with an impressive title or acronym, is bewildering on first acquaintance, the more so, because individual methods have often been presented as if they were the one and only solution to the loss prevention problem. The truth, however, is that the problem themselves are many and varied, and different methods are required in order to deal with them. It is quite rare to find a real choice of method, once the problem has been correctly formulated.

Most of the techniques developed to date are designed for application during the development of a specific project. It is therefore easiest to discuss them by reference to the normal sequence of project development phases: conceptual design and planning; detailed design; construction; commissioning and operation (see Figure 1). The guiding principle is to carry out each analysis at such as stage in the project that it is still possible to make the particular types of changes that the analysis may suggest. Thus, for example, it is appropriate to carry out an initial survey of the principal hazards involved (e.g., drilling, riser pipes, etc.) while the platform layout is still being developed, not as an afterthought. A list of techniques and their applications is given below; the techniques are reviewed in more detail in the next section.

HAZARD SURVEY/HAZARD INVENTORY

Identifies all stocks of hazardous materials or energy, with relevant details of conditions of storage. Identifies platform features of fundamental importance for safety, e.g., riser pipes connected to major product pipelines, drilling equipment, fuel stocks, crane operations and so on. (Conceptual design stage.)

"CONCEPTUAL DESIGN SAFETY EVALUATION"

Used in the Norwegian Sector to help identify "design accidental events" which are used to define the accident survival capacity of the installation. (Conceptual design stage.)

PROCESS SAFETY DESIGN CHECKS

Typified by use of internal controls and checking within the design team, and the application of API RP 14C type analysis. (Detailed design stage.)

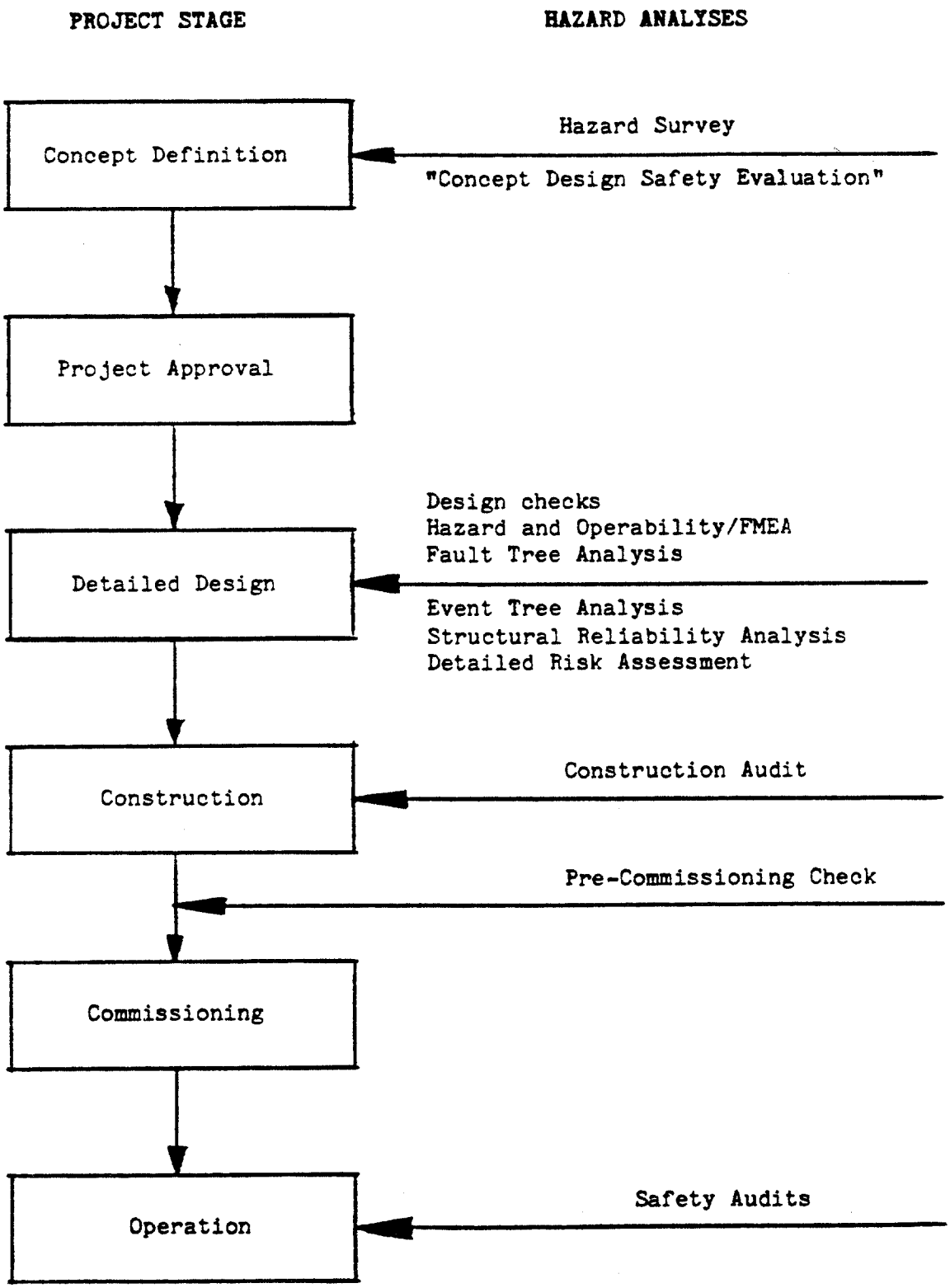


Figure 1. Hazard Analyses During the Development of a Project

HAZARD AND OPERABILITY STUDY/FAILURE MODES AND EFFECTS ANALYSIS

For identifying failure modes that could occur in the process plant and might have undesirable consequences. (Detailed design stage.)

RELIABILITY STUDIES (SINGLE EQUIPMENT)

Usually a statistical analysis of failure rates on a critical component (e.g., turbine) with a view to optimizing redundancy or maintenance provisions. (Detailed design or operational stage.)

SYSTEMS RELIABILITY/FAULT TREE ANALYSIS

These techniques are used for estimating the frequency of failures of a system involving many components (e.g., pressure control of a vessel). Dominant causes of failure are identified. (Detailed design stage.)

EVENT TREE ANALYSIS

Used to find the various possible outcomes of a given initiating event (used in Risk Assessment - see below).

CAUSE-CONSEQUENCE DIAGRAMS

A flexible method for presenting system reliability problems, including features of both fault and event trees, with allowance for time delay factors. (Detailed design stage.)

STRUCTURAL RELIABILITY ANALYSIS

This includes analysis of extreme seismic, wind, and wave loadings and considers collapse states rather than design (elastic) stages, defect-tolerance and impact resistance. (Detailed design stage.)

SIMULATION TECHNIQUES

These are used for many purposes. A good example is simulation of emergency evacuation sequences, using Monte Carlo or event tree methods. (Detailed design stage.)

RISK ASSESSMENT

Quantification of the total risk (to life, capital investment, or production) associated with a hazardous process. This is used to check on the adequacy of the design by identifying the most significant contributors to risk and indicating how improvements may be achieved, if required. It can also show that a specific proposed improvement is ineffective. (Detailed design stage.)

CONSTRUCTION AUDIT/PRE-COMMISSIONING CHECK

A check that the plant as built conforms to required standards and to recommendations made in earlier safety studies. (Construction stage.)

SAFETY AUDIT

This normally refers to a check of the plant hardware and operating procedures after some time in operation. (Operational stage.)

Although some of these techniques have been part of the oil and gas scene for a long time, others are new to the industry and introduce revolutionary ways of thinking. For example, Fault Tree Analysis makes possible a process-specific evaluation of the need for extra redundancy or particular attention to maintenance of critical items; this cannot be so well addressed under the procedures of the established Code of Practice API RP 14C because it does not take account of the reliability characteristics of specific items of equipment, nor of the likelihood of various different process upsets occurring in the first place. Fault Tree Analysis can show the designer where to make economies and where to spend money; it also tells the operational maintenance people what to spend time on, and what to ignore.

A second example is the Norwegian "Concept Safety Evaluation." This tells the designer what accident scenarios are sufficiently likely that he ought to design for them - at least on a "survivability" basis.

These ideas are new and of obvious value to practitioners in the industry. It is therefore not surprising that the oil and gas industry in the North Sea has taken up these techniques with enthusiasm and is actively pursuing their further development. The techniques themselves are discussed in more detail in Section 2 of this paper, while a review of North Sea experience is given in Section 3.

2. TECHNIQUES AND THEIR APPLICATIONS

2.1 INITIAL HAZARD SURVEYS

These are an essential preliminary to many safety studies. The survey consists of inventorizing all stocks of hazardous material or energy and noting relevant details of storage conditions. When carried out at the conceptual stage of a project, such a survey can contribute to layout optimization and may suggest process changes to reduce stored quantities. It generates information that can be used in a preliminary risk assessment, but the hazard survey itself is little more than "screening" exercise designed to identify problem areas.

For offshore installations, particular attention is given to equipment items with either a large hazard potential (e.g.. pipeline risers) or a high probability of occurrence (e.g., pump or compressor leakage) or both (e.g., blowouts). These considerations often have an important influence on platform layout or overall design concept. For example, it is now recognized that riser pipes located inside concrete platform structures are much less likely to fail than the exposed riser typical of steel jacket installations. Also, the distance separating drilling areas from living quarters has been optimized (see the side elevation of the Norwegian "Gullfaks A" platform - Figure 2 - which is an outstanding example of a layout strongly influenced by fundamental safety thinking at the initial design stage).

2.2 "CONCEPT DESIGN SAFETY EVALUATION" (NORWAY)

Concern over offshore safety has led to Norwegian Petroleum Directorate to impose a requirement for the execution of a thorough safety evaluation at the "conceptual design stage" of any development of fixed installations in the Norwegian sector. Approval of the developer's Main Plan (a vital step in the authorization procedure) is now effectively contingent upon submission of a safety evaluation accepted by the NPD.

Guidelines for the approach to be adopted in carrying out these safety evaluations have been published (Norwegian Petroleum Directorate, 1981) and these are firmly based in the concepts of risk analysis, although adapted so as to maximize the direct usefulness of the analysis to the platform designers.

The object of this approach is to divide the complete list of failures (or "accidental events" as they are called in this context) into two groups:

1. A group of "Design Accidental Events" whose consequences must be small enough to allow safe evacuation of all personnel not in the immediate vicinity of the event;

2. A group of "Residual Accidental Events" whose consequences may be such as to exclude them from group 1, but whose total expected frequency must not exceed a stated level (of the order of 10^{-4} to 10^{-3} per platform-year, depending on the interpretation).

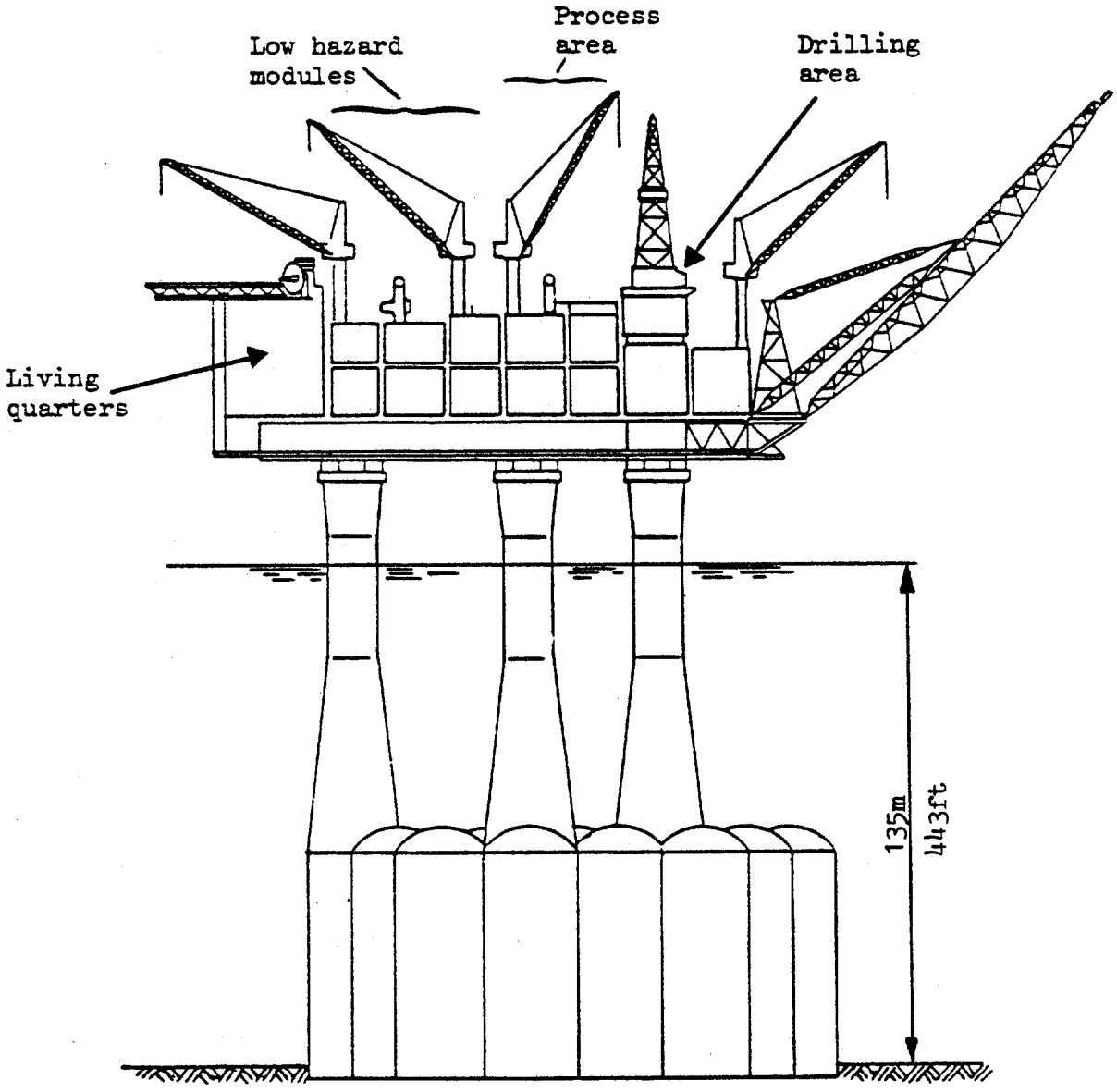


Figure 2. Side Elevation - Gullfaks "A" Platform

This division elegantly achieves two objectives:

first, while acknowledging that a finite risk of a severe disaster must be accepted, it analyzes this risk and seeks to keep it below a target level;

second, it provides "design cases" which can be put in a form that platform designers can use within conventional design procedures.

The accidential events include process failures, wellhead accidents, helicopter and ship collisions, structural failures and extreme environmental loadings (notably waves). The division between Design and Residual accidental events is determined by the total frequency of the latter so that a large and complex platform may have to be designed for more severe failure cases than a small simple one. This, of course, is reasonable in the interests of maintaining acceptably low risk levels for all offshore personnel.

Safety evaluations of the kind just described use consequence models that are adapted for the particular circumstances of offshore platforms. For example, they include models for: gas explosions in confined spaces, damage to structures from heat or impacts; burning liquid on the sea, and so on.

The studies also call for a probability analysis of the accidental events. The best data on failure rates of offshore equipment are those from the Gulf of Mexico, although care is required in applying them to North Sea conditions. Unfortunately, attempts to collect data directly for North Sea operations have not progressed far yet, although the Norwegian "OREDA" project should achieve this objective in due course.

Some 10 to 12 of these safety evaluations have been carried out so far but the full reports are not usually published. A paper by Pyman and Gjerstad (1983) gives a short description of one of these studies and concludes that the NPD's Concept Safety Evaluation procedure is "a modern, practial and constructive method of ensuring an acceptable level of safety in basic engineering design."

2.3 DESIGN CHECKS

A checking procedure is usually built into the design process but there is a trend towards making this more formal and more independent of the original designer. Checklists are often used to make this procedure more systematic and comprehensive, and a good example of such a checklist is given in the booklet "Flowsheeting for Safety" published by the Institution of Chemical Engineers (Wells et al., 1977). This takes the form of a series of questions addressed to different aspects of the plant:

- basic process considerations
- mechanical specifications
- deviations from normal operation
- reliability
- containment integrity
- layout

- personnel protection
- documentation

The questions are simply used as a prompt to the reviewing engineer, and have to be adapted to suit the process under scrutiny.

For the purposes of this discussion, we should consider under this heading the widely-used code of practice, API RP 14C - Recommended Practice for the Analysis, Design, Installation and Testing of Basic Surface Safety Systems for Offshore Production Platform (American Petroleum Institute, 1978). This RP is widely used in the offshore industry as setting the minimum standards for provision of safety devices on potentially hazardous equipment and therefore the document is often referred to in contract specifications and even in government regulations.

The RP sets out both general principles and specific design guidelines. The prime example of the former is the principle that, in addition to normal process control loops, there should be two independent protective systems to guard against each hazardous process condition. The more specific guidelines, however, provide direct illustrations of protective devices that are recommended for particular typical process units.

The strong points of RP 14C are that:

- it is internationally recognized and design engineers are familiar with it;
- it specifies standard documentation for the safety analysis so that the adequacy of the work can be checked;
- it helps in producing the first draft design;
- it ensures that some measure of diversity and redundancy will be included in the design of the main typical process units.

However, as a method of analysis, it has important limitations in that:

- the general principles permit considerable variation in interpretation by individual design contractors;
- the specific guidelines are only given for a limited range of equipment items whereas on large and complex platforms it is known that many other systems may give rise to hazards;
- the design engineering details in 14C are now considerably out-of-date because of advances such as programmable logic controls, automatic ESD systems, depressurization systems, and so on;
- the analysis part of 14C is relatively crude compared with modern techniques now actively applied in the North Sea, such as HAZOP and Reliability (Fault Tree) Analysis. In particular, it does not take account of the reliability of specific protective systems, nor of the likelihood of a demand being placed on such systems. This omission leads to a potential misallocation of resources.

Design checks of these types are concerned with compliance with current good design practice and therefore cover a wide variety of types of hazard, ranging from faults that interrupt production (but have little risk to life) to major disasters. However, they do not provide any quantitative measure of effectiveness of the proposed improvements in reducing risk. This is particularly important when complex systems have to be considered, or when the hazard potential of a plant item is so large that special high integrity engineering has to be employed.

2.4 HAZARD AND OPERABILITY STUDIES (HAZOP) AND FAILURE MODES AND EFFECTS ANALYSIS (FEMA)

These two techniques are considered together here because they have very similar objectives and methods of approach. The purpose is to identify systematically all of the possible ways in which the system could fail, and to evaluate these and formulate recommendations for action.

FEMA is the simpler of the two techniques. The procedure is to take each component in turn, list all the possible failure modes and consider the consequences of each. The results are recorded in a standard format in which recommendations can be included. The weakness of this type of analysis that there is no actual method for finding the failure modes or their effects: the engineer is expected to do this from first principles or past experience, and the only discipline imposed on him or her is that of the reporting format itself.

HAZOP overcomes the main difficulty by introducing a systematic method for identifying failure modes. This involves scrutiny of a large number of possible deviations from normal operation conditions, which are generated by applying guide words such as MORE, LESS, REVERSE etc., to each of the parameters describing conditions in each component or pipeline in the plant.

Often there is no realistic cause, or the effects are unimportant; such cases can be quickly passed over. Sometimes the causes are credible and the effects significant either for the correct functioning of the process or for safety or both. In such cases, there may be a need for design changes to eliminate the identifed cause, or alternatively a more detailed reliability study may be recommended, to determine whether the probability of the event is high enough to justify action. The team may subjectively assess the consequences and probability as "large" or "small" and rank the actions accordingly.

HAZOP as practiced to date is only applicable to process hazards but there is no doubt that it could be developed to apply to structures, management procedures and many other systems that relate to safety. This would, however, probably involve the use of new guide words.

The technique is rather laborious but the efficiency of the study team increases rapidly with experience, as trivial cases can be more quickly identified and disposed of. It is unwise however, to take too many short-cuts because this undermines the main advantage of the method, which is its thoroughness and comprehensiveness in failure case identification.

Both HAZOP and FMEA are limited in that they do not provide a technique for discrimination between alternative options for improvement; this is still left to the team's collective judgment.

For further reading, see the booklet "A Guide to Hazard and Operability Studies" published by the Chemical Industries Association (1977) and Roach and Less (1981).

2.5 RELIABILITY ANALYSIS OF COMPONENTS AND SYSTEMS/FAULT TREE ANALYSIS

There are many techniques available for special purposes under the general heading of reliability. The simplest type of analysis is one done for a single equipment item within the system. This may be required because it is clear from the start that a particular piece of equipment will be critical for the safety or availability of the whole system, or because an estimate of the failure rate of the equipment is required as part of a risk assessment.

2.5.1 Reliability Analysis - Single Equipment Items

Assuming that the equipment item is not a complex one (for which a system reliability analysis of its components is appropriate - see 2.5.2 below), this work has to be done by a statistical analysis of the failure rates of similar equipment from past experience. Frequently, the only statistics available are overall average failures, which are affected by the actual service and maintenance conditions. In order to relate such data to the particular equipment under study, allowance must be made for any changes in these conditions. Another problem, often encountered in the offshore industry, is that adequate statistics for comparable equipment items do not exist. In this case, an inference has to be made based on the nearest equivalent equipment items, with adjustments based on engineering judgement to allow for any different factors that may have an influence on the failure rate.

A more detailed analysis of the failure rate may be required for the design of maintenance schedules. This involves determination of the time-distribution of failures in the equipment in the absence of maintenance actions. Various distribution functions can be defined of which two of the most important are the reliability function R(t) (i.e., probability of survival at time t) and the hazard rate function Z(t) (i.e., the instantaneous failure rate at time t). These functions tend to have characteristics forms, for example the "bathtub curve" form for Z(t) which features high hazard rates at early times, due to defective manufacture or installation, and again at later times due to wear out.

For safety studies and risk assessment, the long-term average failure rate is of more interest, and this can be assumed to be constant with time (although random in occurrence) once the maintenance and repair cycle is established.

2.5.2 Reliability Analyses - Systems

Reliability analyses become particularly important to the designer where complex systems are involved. These systems may arise because of inherent complexity in

the process as a whole, or because particular units require instrumentation for process control or for safety. The basic technique for analyzing these cases is Fault Tree Analysis. In this approach, the failure modes of interest must first be defined, for example by use of Hazard and Operability Study. These defined failure modes are known as "Top Events" and for safety analyses these would often be loss-of-containment cases, such as:

- overpressure of vessel leading to rupture
- release of flammable liquid through flare systems
- failure of firewater deluge when demanded
- failure of emergency power generators when demanded

For each failure mode, the analyst must then identify all those events or combinations of events that could lead directly to the failure. The precise logical relationship between cause and effect is expressed by AND or OR gates and is usually presented in diagrammatic form.

The immediate causes of the top event have their own contributory causes, and these can be presented in a similar way, so that a complete Fault Tree is built up. This process ceases when all of the causative factors at the bottom of the tree are of a simple kind for which frequencies of occurence or probabilities can be estimated. Fault Trees include operator action both as an initiating cause and as corrective actions. Figure 3 shows a complete fault tree, taken from a recent offshore safety analysis. The diagram is reduced in detail and in size so that the whole tree (originally drawn on 14 sheets) can be displayed on one page to illustrate the degree of complexity in which the system has been analyzed.

This process of Fault Tree synthesis is well described by Barlow and Lambert (1975) who also give details of a structured method for assisting the analyst in finding causes throughout the tree.

The quantitative analysis of a fault tree is a separate activity. The procedure involves first a logical decomposition of the tree, which re-expresses it in a standard form in which a single OR gate connects the top event to a number of sets of bottom events grouped under AND gates. These sets are called cut sets and the frequency of occurrence of each cut set can be easily calculated. Each cut set represents one particular failure mode. In this way, the causes that contribute most to the occurrence of the top event can be found. Analytical complications arise when the bottom events are not independent (e.g. mutually exclusive events or events connected by common-mode failure effects) and this is why a specialist will usually be required for the analysis of Fault Trees.

For plant availability studies, repair times are needed as well as failure rates, and the top event (plant outage) is expressed in probability units (e.g., plant out of operation 5 percent of the time). For safety studies, the top event is expressed in frequency form (e.g., loss of containment once per 10^5 years).

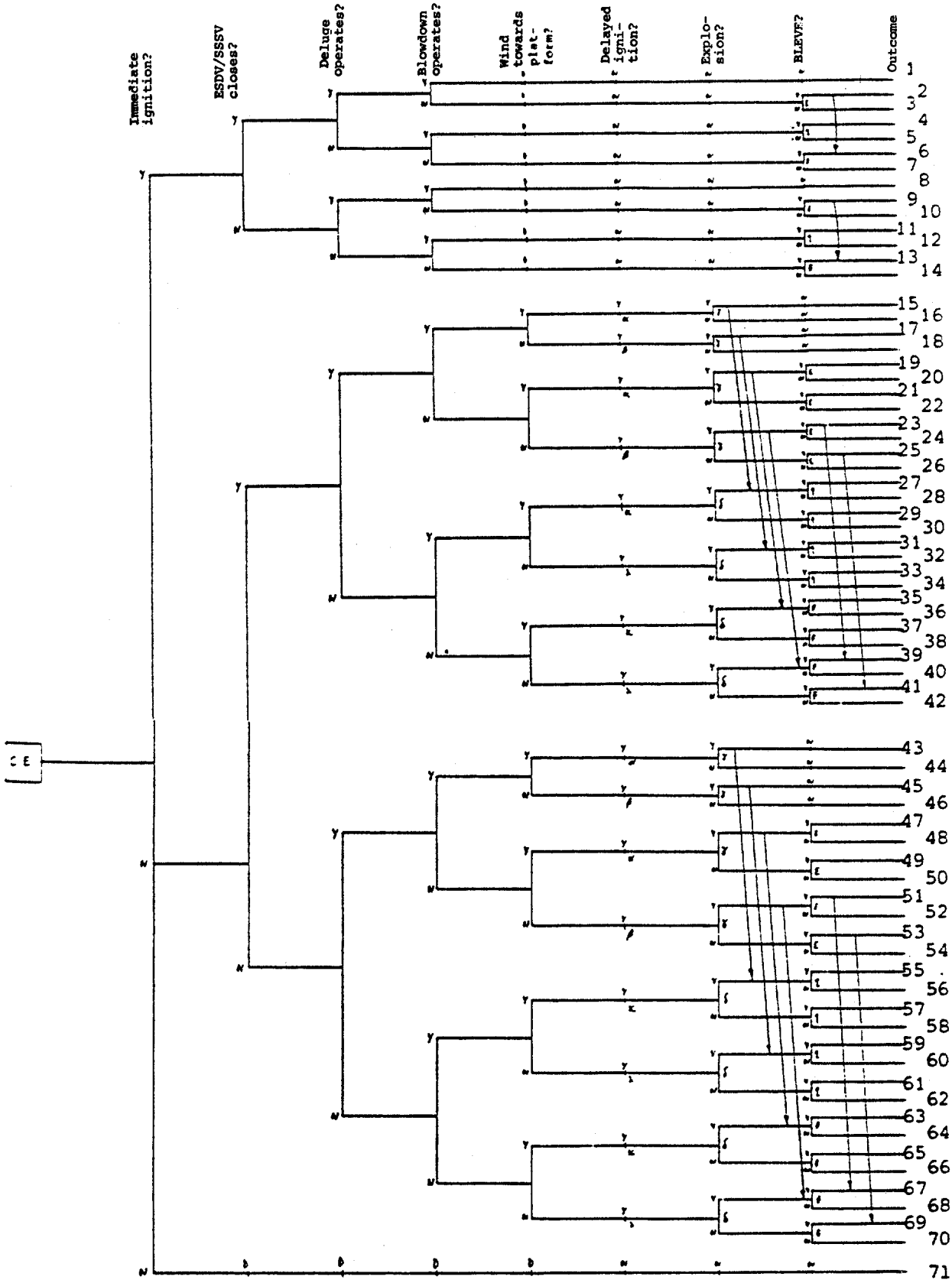


Figure 4. Typical event tree for hydrocarbon leakage, with deluge protector

Cause-Consequence Diagrams are sometimes referred to in the literature. These are the most flexible type of logic diagram, in that they combine the features of both Fault Trees and Event Trees, and they also provide for a much wider choice of logic gates. The analysis starts from a "critical event" whose causes are traced by Fault Tree methods and whose consequences are traced in an Event Tree. A "critical event" could be a process deviation which is potentially hazardous but not necessarily so. The gates available allow for externally-applied conditions, whose probability must be given, and for time delays. The latter are particularly useful for the analysis of start-up and shut-down and for batch processes.

All logic diagram analyses are liable to error through:

- ommission of branches
- uncertainty of probability and frequency numbers
- neglect of interdependencies such as common mode failures.

Those faults are, however, not fundamental to the technique, but more a question of proper application. In particular, it would be desirable for more research to be done on failure rates for equipment items relevant to the offshore industry, with more detailed recording of failure modes and of the number equipment items contributing to the survey. There is also a need, arguably more important still, to evaluate the reliability of the human operator and the factors that affect his or her performance both in normal operation and during emergencies.

2.7 STRUCTURAL RELIABILITY ANALYSIS

In a complete examination of risk on an offshore installation, possible structural failure must be included. These events include:

- failures caused by structural weakness or inadequacy relative to normal loads, and
- failures caused by abnormal loads, or
- combinations of the two.

For convenience, all kinds of external impact events are often included under this heading, so that in a recent offshore risk analysis, the "structural" events considered were as follows:

Structural Failures (under normal loads):

- concrete base structure cell structures
- concrete base structure drilling shafts
- concrete base structure utility shaft
- concrete base structure seawater service shaft
- module support frame
- module structures
- helideck
- foundation

Falling objects, etc.

- dropped crane loads
- collapse of crane boom
- collapse of crane pedestal/main bearing
- dropped derrick load
- collapse of derrick
- collapse of flare boom

External impacts

- passing vessel collision
- tanker collision
- supply vessel collision
- fishing vessel collision
- helicopter crash
- flotel impact
- crane barges and other construction vessels impact

Extreme loads

- excessive weight
- extreme wind and wave
- extreme seismic loading

From this list of events, it can be seen that a wide range of different analytical techniques have to be brought to bear on the question, in order to produce results which are expressed in the same final form, i.e., probabilities and consequences.

For many of these cases, historical data on event frequencies exist. This is particularly true of crane and derrick failures and external impacts. These data may have to be normalized on a suitable basis, such as:

"per helicopter movement"
"per supply vessel visit"
"per crane load"
etc.

This is much more realistic than "per platform year." The use of data in this form requires a detailed analysis of the frequency of transport operations as the field development proceeds through one phase to the next. (For example, dropped objects are much more likely while drilling is still in progress.)

The rigorous analysis of the consequences of impact events requires sophisticated nonlinear dynamic structural models but the use of these can only be justified in very critical cases. Usually, a more crude analysis based on simple energy concepts or "punching shear" will suffice for risk analysis purposes.

For several of the structural events, notably those involving environmental loads, an analysis of the ultimate load-bearing capacity is required in order to arrive at an estimate of failure frequency. For example, in seismic design, North Sea platforms are designed on the basis of 100-year earthquake return periods using linear elastic methods, with substantial safety factors. Increasingly, however, the 1000-year earthquakes are being used for design, with reduced safety factors but still on a linear elastic basis. It is no easy matter to estimate from this information the expected failure frequency, because the loading is transient and the structural behavior nonlinear in the region of interest. This has, however, been done approximately, using a static nonlinear analysis to identify likely structural failure modes and, from extrapolation of the ground acceleration/return period curve, the expected frequency of various degrees of collapse.

This type of analysis is of fundamental importance because it gives a measure of the actual level of safety implicit in the codes of practice for structural design. This makes it possible to compare, say, structural risks with blowout risks, and thereby establish an order of priorities.

2.8 OVERALL RISK ANALYSIS

In the offshore industry, risk analysis is used quite frequently for evaluating specific design options. A good example of this is its use in determining the effectiveness of subsea remote operable block valves in major pipelines, to protect manned platforms against risk of fire-induced structural collapse if a pipeline riser were to fail. Risk analysis if being used to consider the need for such valves depending on the riser configuration and risk of dropped object or anchor impact on the pipe.

The reason why this type of problem is well suited to risk analysis is that a great number of possible remedial measures may be proposed for improvement of the risk, some of which reduce the consequences of failure while others reduce the probability. Thus, the relative effectiveness of such measures cannot be directly compared: only their effect on risk (which combines probability and consequences) can be used for comparison.

A second application of risk analysis is in the development of a comprehensive picture of all the risk to which an installation may be subjected. This type of study naturally involves a considerable volume of effort - 4500 man-hours have been expended on one very large platform in this type of work. The purpose

is to develop a picture of the priority areas for future safety developments as well as to contribute to the detailed design of an individual platform.

In this type of application, fundamental principles for the application of risk analysis were soon established in a form that has not greatly changed since. These principle are:

1. that the residual risk should represent the total risk caused by all possible accidents on the installation,

2. that the spectrum of all possible accidents should be represented by a finite set whose consequences and expected frequencies should be estimated,

3. that the results should be so presented as to assist the designer to improve the safety of the installation, and

4. that criteria should be established whereby the results may be judged.

Although individual studies vary in content and style, they nearly all conform to a general logical structure illustrated in figure 5. The first step is to define a set of failure cases based on an engineering appraisal of the platform. Since the final objective is to evaluate the total risk impact of the installation, this failure case list must be checked to ensure that it is truly representative of the spectrum of events that could actually occur - that is, there should be no gaps and no overlaps between cases. For a large platform, some 200 to 400 failure cases may be defined.

FREQUENCY ESTIMATION

The frequency estimation step in figure 5 is closely allied to failure case identification since in practice each case stands for a range of actual cases on the real plant, whose total probability must be retained in the analysis.

The failure probabilities are estimated from historical failure rate data, statistics on extreme events such as earthquake and ship collisions and , where appropriate, from detailed examination of the failure case by Fault Tree Analysis.

Failure rate data in the offshore oil and gas industry are sparse and approximations are necessary to complete most analyses. Probabilities also have to be estimated for the case of the release igniting immediately, rather than forming a dispersed cloud, and for the likelihood that each potential ignition source would actually cause ignition. At present, accident case histories are the main source of data on ignition probabilities, but much more work is required on this aspect since it can have a critical effect on the final risk estimates.

CONSEQUENCE ANALYSIS

The consequence models have great variety, because of the different conditions under which materials may be handled in this industry. Enormous research and development effort is being expended on certain aspects of these models, such as:

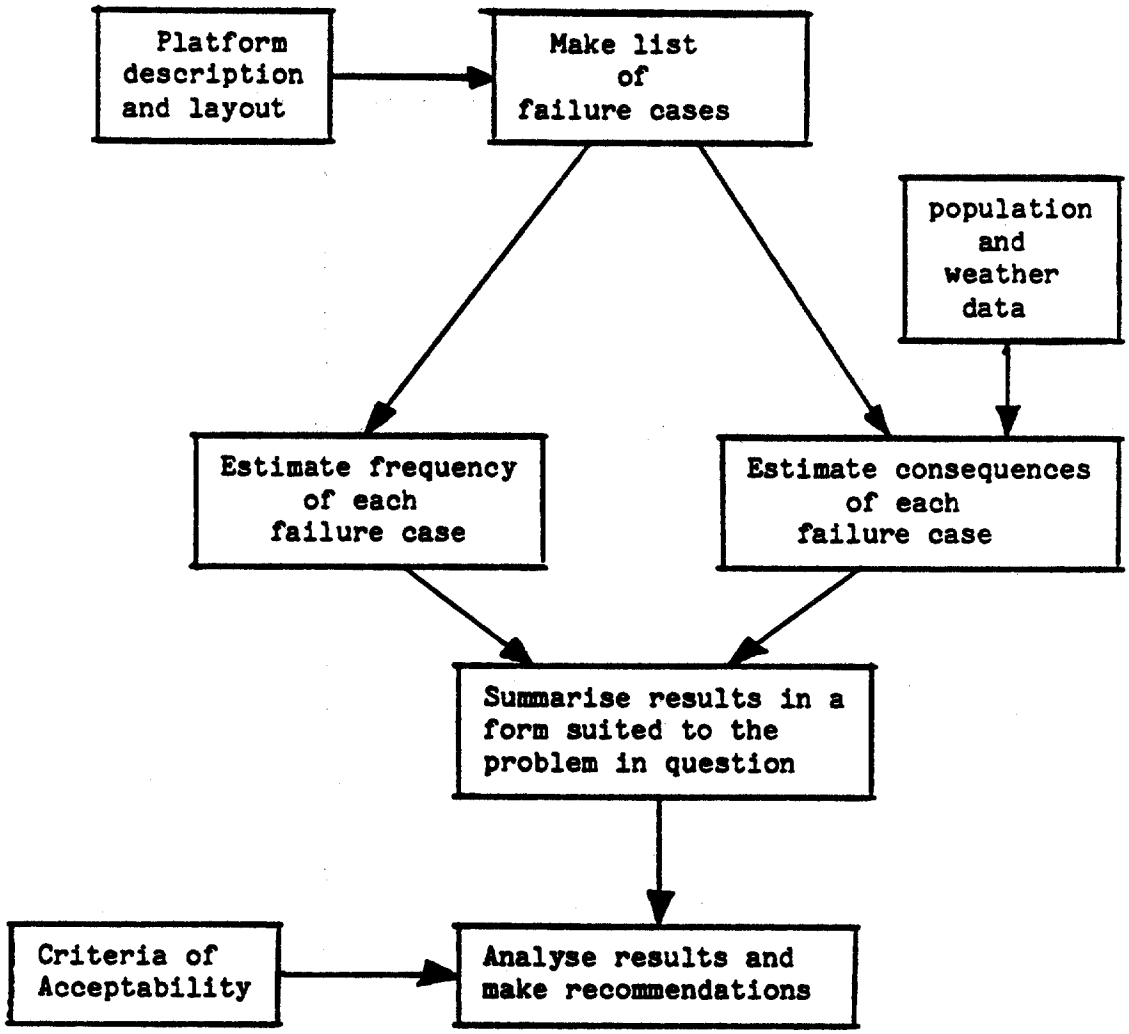


Figure 5. Overall flow diagram of risk analysis

- dispersion of dense gas/aerosol clouds
- two-phase discharge behavior in hydrocarbons
- initial mixing of high-pressure release
- combustion of hydrocarbons in realistic circumstances of confinement and high turbulence.

For risk analysis purposes, the consequence models most commonly needed are as follows:

1. Calculation of discharge rate using the relevant formulae for liquid, gaseous or two-phase discharge.
2. Dispersion of the vapor cloud in the atmosphere using models which take account of density and momentum effects as appropriate. Note that offshore oil and gas hazard analysis puts special demands on the models that are used for this purpose, because of the massive scale of the releases (Cox, 1980).
3. Modeling of the combustion of the dispersed cloud, including both confined and unconfined vapor cloud explosions (of which the former are much the most important offshore). Jet flames, pool fires and BLEVEs must also be considered.

Collections of such mathematical models are given in the COVO report (Rijnmond public authority, 1982) and by TNO (1980). There is still a considerable degree of controversy about the best methods of prediction of some of these phenomena, but advances in theoretical understanding and in the experimental data available for checking models have led to the emergence of a fairly consistent consensus view on at least the principal phenomena.

Presentation of Results

The frequency and consequence analyses generate a large number of intermediate results, each characterizing one particular scenario or Event Tree outcome. For an offshore platform, these intermediate results typically comprise:

f_i - the estimated frequency of the event

A_i - an area of the platform experiencing more than some stated degree of damage (e.g., 50 percent chance of fatality).

N_i - number of fatalities

P_i - amount of oil spilled

V_i - loss of platform capital value.

For direct comparison with risk targets, the f_i values can be summed for N_i, P_i, or V_i values within defined ranges. Some oil companies have developed risk targets or criteria in this form.

These results can also be presented in graphical form as an "F-N curve" (i.e. frequency versus consequence). An example, taken from an actual North Sea platform analysis, is given in figure 6.

Both of the above forms give information about the size and likelihood of accidents of different magnitudes. They contain no information, however, about the distribution of risk as a function of location on the platform. For fatalities, this can be achieved by summing, for each location, the f_i values for all scenarios for which the zone A_i includes that point. This is then repeated for all locations of interest.

These results are difficult to present in a pictorial form, because of the three-dimensional nature of the platform, so a tabular form is normally used instead.

Critical events which contribute the most to such indices of risk are then identified. For each of the most significant events, an indication can be given of whether it is the probability or the consequence (or both) that causes it to be significant; this information is useful in suggesting possible improvements.

Naturally, the question or risk acceptability criteria arises. This is not a matter on which there will ever be total agreement, but it has been found that it is useful to have some quantitative criteria or targets so that risk (actual or predicted) can be put in some kind of context. With experience, ones quickly acquires a feeling for the magnitudes of "high" and "low" risks. However, these criteria should not be interpreted rigidly - neither the criteria nor the methods of risk analysis are accurate enough for that.

Criteria or targets for risk have been developed by oil companies, by the nuclear industry and by government and a comparison of some of these for multiple-fatality accidents (drawn in the F-N plane) is shown in figure 7. In addition, risks to individuals may be compared against the general observable background of risk:

Type of Risk	Frequency Per Million Years	Source
Overall mortality	11000	USA, UK, France Belgium, Netherlands
All accidents	460	ditto
Occupational:		
Chemical industry	25	Lees (1980)
General manufacturing	20	ditto
Fishing	175	ditto
Coal mining	200	ditto
Construction	335	ditto
UK offshore	1000	Burgoyne (1980)

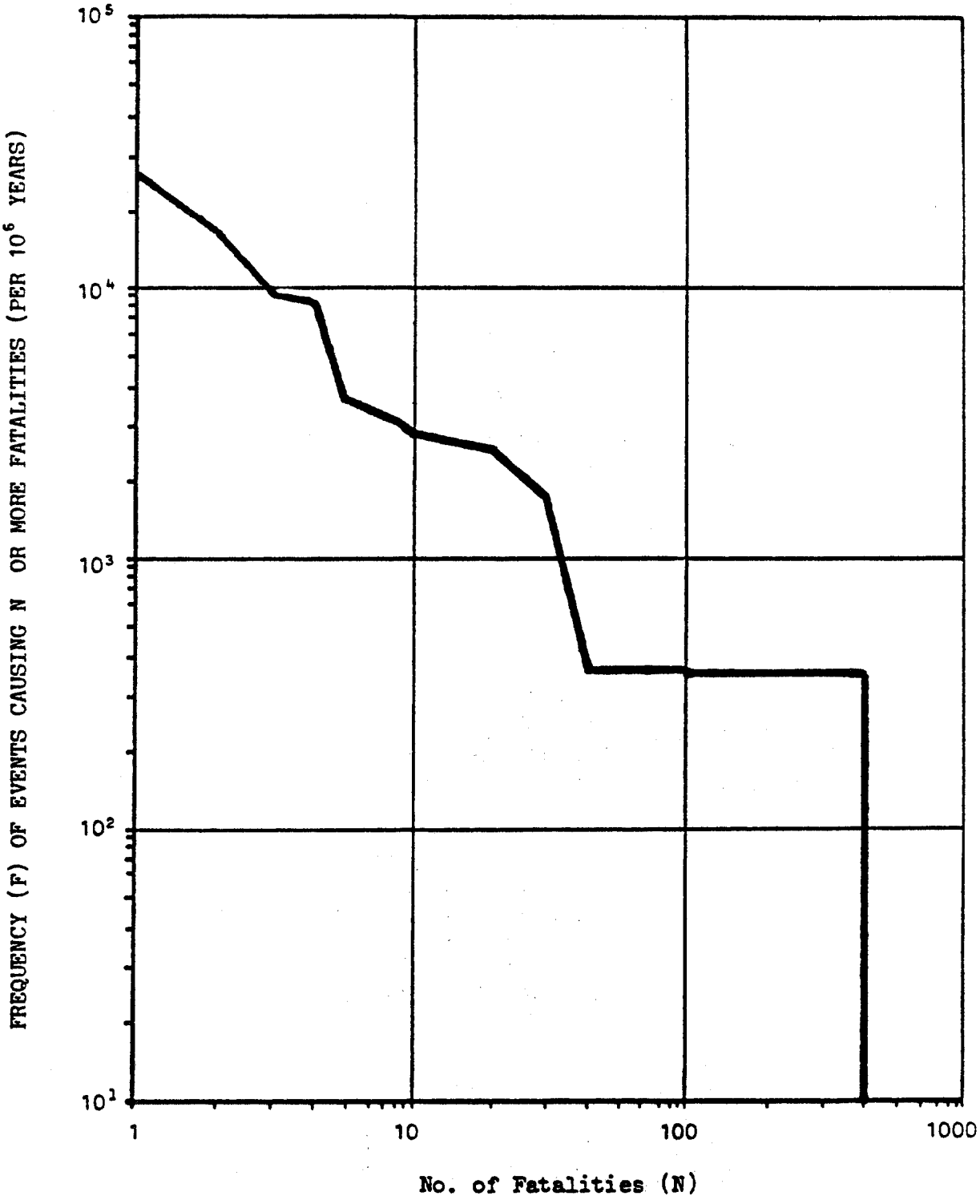
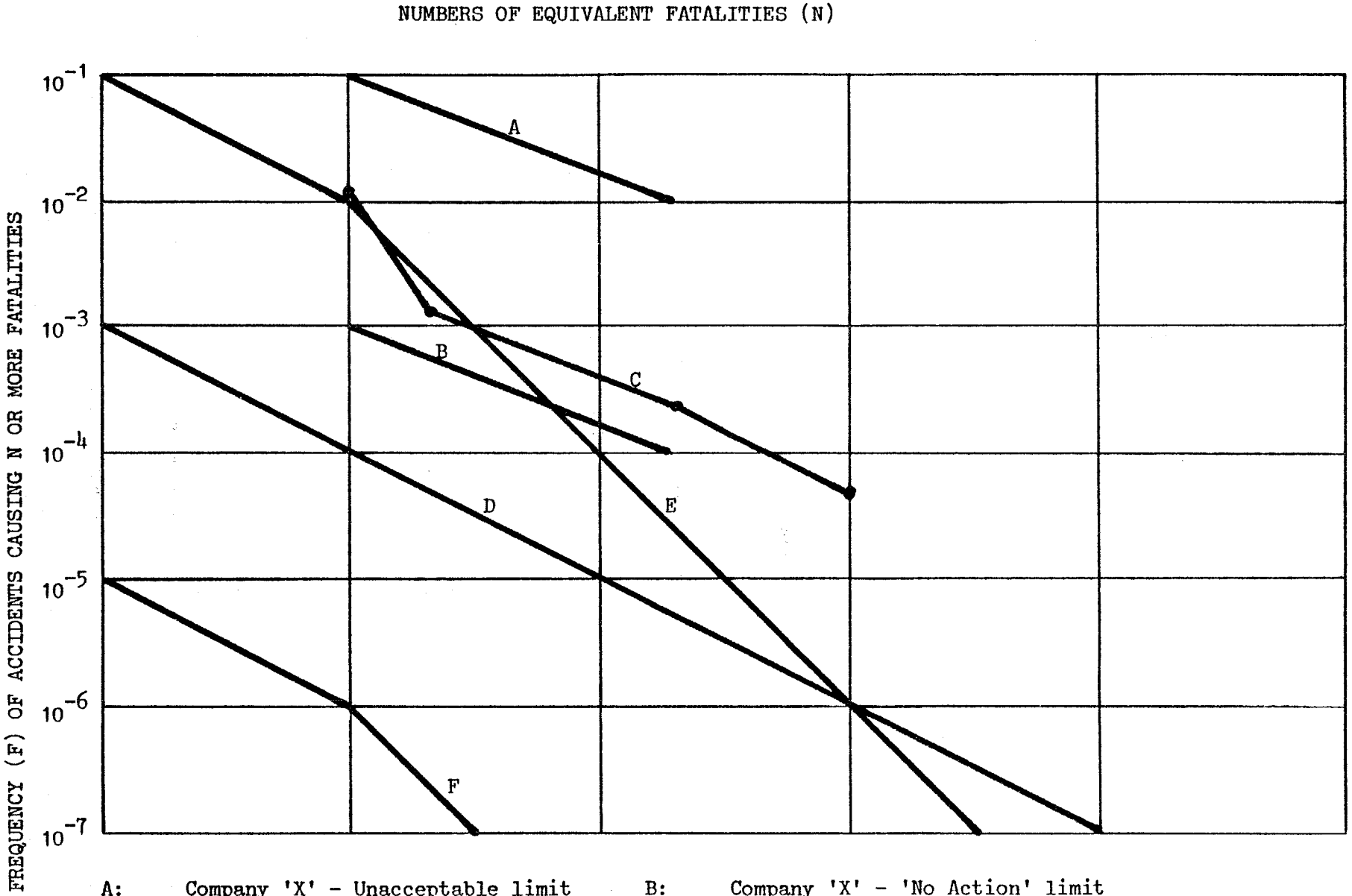


Figure 6. F-N curve for fatalities - offshore platform



A: Company 'X' - Unacceptable limit
B: Company 'X' - 'No Action' limit
C: Company 'Y' - Risk Targets
D: UK Nuclear Industry - Risk Criteria (Kinchin, 1978)
E: Groningen - Unacceptable limit
F: Groningen - Acceptable limit
(Provinciale Waterstaat Groningen, 1979)

Figure 7. Comparison of risk criteria and targets from various sources

2.9 AUDITS

Various types of engineering audits may be used during the construction, commissioning and operational phases of the development.

CONSTRUCTION AUDIT

Whereas certain inspections have to be made during construction to comply with legal or insurance requirements, some companies carry out an audit of construction procedures and activities for internal use. This is done to ensure that the installation, as built, conforms to the original specifications and codes of practice and with recommendations arising from eariler safety studies.

The audit is usually done with the aid of a checklist or questionnaire. This will cover such matters as:

- procedures for quality control
- qualifications of personnel (welders, inspectors, etc.)
- procedures for implementing late changes and rectification
- material control
- non-destructive testing
- equipment and material vendor's quality control.

The scope of the audit will include civil works, plant, and instrumentation. It will not only involve spot checks on site but can also look at the dependability (or reliability) of the procedures or systems in use.

PRE-COMMISSIONING CHECK

Most companies carry out a brief but comprehensive check just prior to initial start-up. Often, this is not very formal; it is concerned mainly with ensuring that all previously ordered jobs have actually been completed on site. A checklist procedure may, again, be used, but the main element is a detailed tour of the plant itself.

OPERATIONAL PHASE - SAFETY AUDITS

Once a plant enters operation, hardware and procedures will start to change from those originally established by the commissioning team. Usually, there are good reasons for this: the operators may find simpler or more economic procedures and the operational requirements themselves may change. However, it is also quite possible that safety standards fall off with time because the designer's original intentions and concerns have been forgotten and experience of satisfactory operation leads to overconfidence and a false sense of security.

For these reasons, occasional safety audits are much used in operating companies. These, however, may take many forms, as is well illustrated in the booklet "Safety Audits" (Chemical Industry Safety and Health Council, 1973). Audits may vary from a half-day tour by the manager to a review lasting several weeks, carried out by a team of engineers of different disciplines and independent

of every day plant mangement. For the most penetrating audit, the study should not be announced in advance.

Questionnaires and checklists are often employed and several are given in the booklet mentioned above. These, however, vary considerably in quality and care must be taken with the wording of questions. Factual questions whose answers can be checked are much preferred over vague ones that may permit a complacent answer.

Safety audits are useful mainly for keeping up the standard of occupational safety (i.e., preventing relatively minor accidents) and are only relevant to major disasters insofar as they reduce their probability. It may well be that the time has come for extending the safety audit concept so that its questioning is also focussed on the equipment items that give rise to major hazards. The structure of this part of the audit could then be cast in probability/consequence terms in the manner of a risk assessment (but without quantification). This would impose a consistent and logical thought process on the audit team, in which failure modes are considered with regard to possible causes on the one hand and to the containment of their consequences on the other.

3.0 EXPERIENCE OF PRACTICAL APPLICATIONS IN THE NORTH SEA

A summary is given below of the extent of practical applications of the techniques discussed above in the offshore North Sea area, so far as the authors are aware.

FULL RISK ANALYSES

At least four such studies have been completed, to the authors' knowledge, all commissioned by industry and all for internal use (i.e., not prepared for submission to government). The purposes of these studies were all the same - to obtain an overview of the risk picture and to use it both to enhance safety on the project itself and to learn something useful for the next project. Subjects of study included major and medium-sized production platforms and a platform/pipeline system.

CONCEPT SAFETY EVALUATIONS

About a dozen of these rather specific studies have been completed to date, all commissioned by industry but in many cases primarily for submission to the Norwegian Petroleum Directorate. Subjects have included major integrated drilling/production/quarters platforms with steel and concrete structures, small riser platforms, a major water injection, drilling and quarters platform, advanced deep water concepts and semisubmersibles.

It is generally agreed that the CSE methodology is effective in injecting a strong safety influence at the formative stage of a project, and both industry and government agree that it provides a suitable basis for design which is neither too strict nor too lax. There is no doubt that it has caused designers to take account of both the probabilities and consequences of events in a systematic way and there is every reason to expect that the resulting designs will, indeed, have great reserves of "survival capability," as was the main original intention.

HAZOP

Although at first resisted, on the (spurious) grounds that it added nothing to the existing practice of API RP 14C, HAZOP has recently become very widely used in the North Sea Offshore industry, in all national sectors. Process departments appreciate HAZOP for its ability to stimulate creative thought and for its broad range of applicability, relative to RP 14C - although the latter is easier to use.

Experience with HAZOP is that potential troubles are, indeed, often identified by this means. HAZOP teams usually feel satisfied, after conclusion of the study, that the plant will be safe. However, care must be taken not to allow too much "adding on" of protective devices without proper consideration of their need and effectiveness, particularly when several such extras are considered together.

RELIABILITY ANALYSIS

In the main, reliability analysis has been used offshore for three purposes:

1. To verify, or contribute to, achievement of target levels of reliability of production. This has been done, for example, for certain key gas fields in the UK sector where peak supply is the main objective and reliability is therefore important.

2. To evaluate frequencies of failure in complex plant as part of a risk analysis.

3. To evaluate the effectiveness (reliability) of active protective systems such as firewater, gas detection and so on, as an aid to detailed design.

In general, the Fault Tree method has been used as the basic approach and, while the usual problems of failure rate data adequacy have inevitably been encountered, the results have generally been considered worthwhile. This is mainly because the intellectual exercise of comprehending the system and analyzing its logic rigorously is valuable in its own right and tends to suggest improvements before the tree has been quantified. Even the process of quantification is not so difficult as appears at first sight, since data can usually be found for broadly comparable plant without excessive research effort. The main obstacle to getting the data is usually just the psychological one of making a start on the problem - the data often exist, but it is not always immediately obvious where to look for it; also, work may have to be done to adapt data to a special application.

4. CONCLUSIONS

1. Techniques for analysis of safety and reliability problems are established in many applications within the offshore oil and gas industry in Europe.

2. Different analytical methods are available for the many and various safety problems that arise in the offshore industry. It is rare that there is a choice of method, provided that the problem has been correctly identified and formulated.

3. While some of the techniques are very thorough and comprehensive, others are lacking in any structure save for a predetermined checklist. In general, the more sophisticated techniques are gaining steadily broader acceptance in the North Sea area.

4. The techniques of risk and reliability analysis for process plant and structures for offshore developments have improved rapidly in the past few years. In particular, the consequence models are much improved and there is less variation between different models than was the case five year ago. The main areas requiring further effort are in adapting consequence models to typical platform situations (i.e., high pressure hydrocarbon releases, closely-packed equipment and structures and confinement) and in obtaining good failure data.

5. The results of risk analyses are actively used in the North Sea area in all national sectors both in strategic decisions such as permission to build new platforms, and in providing detailed information for improving the safety of a specific platform design.

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MANAGEMENT OF OFFSHORE RISK

A presentation of some of the safety control elements of the petroleum activities as practiced by the Norwegian Continental Shelf.

by

Dr. Øystein Berg, Deputy Director
The Norwegian Petroleum Directorate (NPD)

In order to explain how offshore risks are managed in Norway, it is first necessary to briefly describe the development of the official formwork concerning safety regulation and control. Thereafter, I shall describe more in detail how the various elements of risk management are taken care of in relation to major offshore development projects. I shall, in particular, describe these activities in relation to two NPD guidelines for offshore petroleum activities which are quite unique in the world of the offshore industry, namely, "Guidelines for the licensees internal control" (Appendix 1) and "Guidelines for safety evaluation of platform conceptual design" (Appendix 2).

INTRODUCTION

The "petroleum adventure" in Norway really started in 1959 with the enormous gas find in Gronigen in the Netherlands. It was well known that hydrocarbons were found and produced on the other side of the Channel, and the oil industry deducted that there might be reservoirs under the North Sea. They were correct, as evidenced by, for instance, the important offshore gas fields on the British Continental Shelf.

Encouraged by this, some companies got the idea that it might be worthwhile looking for hydrocarbons further north, and towards the end of 1962, an American company, Phillips Petroleum Company, approached the Norwegian Government and asked for the sole right to explore for and exploit hydrocarbons on the Norwegian Continental Shelf.

The Government had to take its time. There was no legislation covering such activities, no administrative apparatus, and apart from the shipping companies expertise in transporting oil in tankers, our industry had hardly any knowledge of the various aspects of oil and gas exploration and production.

Some basic questions had to be dealt with before operations could be allowed to start, the first one being "what is the entension of our Continental Shelf?"

In accordance with the 1958 Geneva Convention, a Royal Decree was issued in May 1963, declaring tht "the seabed and the subsoil in the submarine areas outside the coast of the Kingdom of Norway are subject to Norwegian sovereignty in respect of the exploitation and the exploration of natural deposits, to such extent as the depth of the sea permits the utilization of natural deposits, irrespective of any other territorial limits at sea, but not beyond the median line in relation to other states."

The median lines were drawn up in agreement with the UK and Denmark in 1965, with Sweden in 1968, and this clarified the situation south of 62°. North of this parallel there are still some important question marks.

Just a month after the 1963 proclamation stating that the shelf outside the coast of Norway belonged to the Kingdom of Norway, the Storting (the Norwegian Parliament) issued a law relating to Exploration and Exploitation of Submarine Natural Resources. This is a very short law with only six sections. The law, which is a typical framework law, contains the following three main principles:

1. The right to submarine natural resources is vested in the State.

2. The Government may give Norwegian or foreign persons, including institutions, companies, and other associations, the right to explore for or exploit natural resources.

3. The Government may issue regulations concerning the exploration for and exploitation of submarine natural resources.

Obviously, when this started, there was a pressing need for the regulation of drilling activities while similar rules for the production could wait. Thus we got a Royal Decree of 25 August 1967, relating to Safe Practice, etc., in Exploration and Drilling for Submarine Petroleum Resources. The Decree has later been revised and now bears the date of 3 October 1975. The 1975 version was not substantially different from the 1967 version, but had some important additions, particularly a Chapter IV on Contingencies, which sets out rather detailed requirements for contingency plans for use in the event of accidents or dangerous situations.

The 1975 Decree has in all 121 sections. In addition, it authorizes the Ministry of Industry (today transferred to the Ministry of Labor and Municipal Affairs) and the various controlling agencies "to issue further regulations and orders as deemed necessary for the implementation of these regulations." This authorization has been used extensively, a subject to which I shall revert in a moment, and we are therefore faced with very comprehensive regulations.

The Decree of 3 October 1975, can in many ways be regarded as a framework. It specifies, for example, in many cases, that equipment shall be of a kind involving the smallest possible risk of accident, fire, explosion and the like, and that wells shall be properly secured in accordance with good and careful oil industry practice. In the course of time a need has arisen for a further specification of requirements, and detailed supplementary regulations have been drawn up or are in preparation.

The supervision of compliance with the 1975 Decree has been delegated to the following governmental institutions:

- The Norwegian Maritime Directorate

- The Norwegian Petroleum Directorate

- The Norwegian Water Resources and Electricity Board
- The Directorate of Public Health
- The Norwegian Telecommunications Administration
- The Directorate of Civil Aviation
- The National Inspectorate of Explosives and Flammables
- The Norwegian Directorate of Seaman

It is the Norwegian Maritime Directorate that is responsible for the coordination of the control activities from the different agencies in relation to the 1975 Decree. These agencies have on their side issued regulations covering their specific area of control.

Fixed installations, pipelines, were, etc., for a long time dealt with in a manner which seemed rather unsatisfactory with little or no written rules. However, on 9 July 1976, we got a Royal Decree, Safety Rules for Production, etc., of Petroleum Resources under the Seabed, which is broadly speaking, technical in nature.

In the Committee Report upon which the Decree to a large extent is based, it is emphasized that the installations and equipment used vary greatly both in design and function and that the operations to be performed are of many different kinds. So are the accidents that may occur. Consequently the Committee says: "It is not realistic to foresee a set of regulations that can apply to every detail." The regulations therefore concentrate upon "material and operations that experience shows involve special risks and where failure may lead to the gravest consequences."

Most of the 123 sections of the 1976 Decree are of a rather general nature and great emphasis is put upon a regular flow of information between the licensee and the authorities so that at the earliest possible stage it can be made sure whether technical or safety-related issues are acceptable or not. The Norwegian Petroleum Directorate has the same role as coordinator for the control on fixed installations as the Maritime Directorate has on mobile installations. A number of other governmental agencies are also involved such as:

- The Norwegian Maritime Directorate
- The Norwegian Telecommunications Administration
- The Coastal Directorate
- The Directorate of Civil Aviation
- The State Pollution Control Authority
- The Directorate of Public Health

Even though the regulatory system indirectly foresees a certain amount of flexibility on behalf of the authorities, it is intended that more detailed regulations should be drawn up. The Norwegian Petroleum Directorate has issued such documents in most safety areas.

Earlier, I mentioned the Continental of 1963 on which the 1975 and 1976 Decrees are based. We also have another important law which is partly applicable offshore. That is, the Act of 4 February 1977 relating to Worker Protection and Working Environment.

The legislation for the protection of labor has traditions in Norway back to 1892, when we got the Act of Supervision of Factory Work. A more extensive and radical Act was introduced in 1936. Since the 1956 Act, Norway, has experienced an extensive industrial development. We constantly introduced new chemical substances and materials, new production methods, and new ways of organizing the work. This development in many ways changed the risk exposure of the working places, and also increased our knowledge about the negative effects and long-term consequences of this new high risk working environment. Besides, stress developing conditions in connection with the organization of the work, wage payment systems and management handling became dominating subjects.

This industrial development has gradually been followed by a series of important amendments in the working environment legislation. However, finally there was a need for a complete revision and extension of the foundation of the law in order to bring it up to date with the technological, economical, and social development which had taken place. This resulted in the Working Environment Act of 1977.

The main priciples of the law of 1977 may be listed in the nine points as follows:

1. The Act shall secure a working environment which gives the employees full safety against harmful physical and psychological influences.

2. The Act is intended to apply for as many working situations as possible, no matter what line of business, and it includes both public and private enterprise.

3. The working environment is supposed to be "fully satisfactory."

4. The working environment has the main responsibility for the implementation of the law.

5. The employees have first of all a duty to show care and attention and to carry out the prescribed measures from the employer of the Labor Inspection/ The Norwegian Petroleum Directorate.

6. The working place should be designed in such a manner that the employer in general could employ handicapped persons.

7. The Act has certain provisions concerning minimum age of employees.

8. The employees shall have influence in working environment questions.

9. The common sanctions have been strengthened.

As mentioned earlier, the Worker Protection and Worker Environment Act is only applicable partly on the Continental Shelf. The reason for this is that that the activity offshore is somewhat special compared with the onshore industry. The Ministry of Labor and Municipal Affairs issued a Royal Decree of 1 June 1979 stating which sections in the law should apply offshore. In addition, the Decree also has some provisions that only apply to the Continental Shelf. It is the Norwegian Petroleum Directorate that ensures that these regulations ar complied with.

The status today, is therefore, that we have two laws followed by three Royal Decrees governing the safety aspects in the petroleum industry on the Norwegian Continental Shelf. (In addition, the Norwegian Seaworthiness Act is applicable to mobile units.) This framework has resulted in a situation where there is a marked difference in the control system for mobile and fixed installations. The consequence is, for example, that an existing drilling rig cannot readily be used for drilling production wells because it will not comply with regulations applicable to production installations.

Another practical problem is that the regulations governing the activities of the control agencies and also the industry, are on a very detailed level, thus restricting technological development and flexible solutions to problems.

FUTURE REGULATORY FRAMEWORK

In 1972, it was decided that the petroleum activity needed to be regulated in a dedicated law, and that there was sufficient experience available to be able to develop such a law. Work started, and is now, 10 years later, in the final stage of preparation. The new "Petroleum Law" is expected to be passed by the Storting (the Norwegian Parliament) in the spring of 1985.

Two Royal Decrees will be added to the Law. One will concentrate on resource management aspects and the other will concentrate on safety aspects. The latter will replace the Royal Decrees of 1975 and 1976.

The report to the Storting concerning the "Alexander L. Kielland" accident contained an evaluation of the existing control system and discussed necessary changes with particular emphasis on main policy matters. I will describe the most important ones as these will be reflected in the new Royal Decree regarding safety in the petroleum activity. These are:

1. The objective of the new Royal Decree is to establish a unified safety standard for mobile and fixed installations and a more coordinated control system based on the principle of "internal control."

2. Development of more functional requirements must be carried further.

3. The development of the "internal control" system must be continued in order to provide a regulatory system which can secure effective control within the limitations of the resources available to public authorities.

4. The future control system shall consist of the smallest number of regulatory agencies possible and be well coordinated.

5. Conceptual safety evaluations must be performed for all types of installations used in the petroleum activity.

Regarding 1: ("The objective of the new Royal Decree is to establish a unified safety standard for mobile and fixed installations and a more coordinated control system based on the principle of "internal control".)

This will result in one regulatory framework applicable to the total offshore activity and hopefully eliminate the problems we are experiencing today as a result of the differences between the regulations for mobile and fixed installations.

In order to fulfill these intentions, it is necessary to harmonize the detailed regulations issued by the various control agencies and wherever possible have identical regulations with respect to mobile and fixed installations. It is also essential that the involved authorities implement the regulations in the same manner. This requires very good coordination which cannot easily be achieved with the number of institutions involved today and the present delegation of authority and tasks.

Statement 1 also specifies that the principle of the internal control duty shall be the main principle for the total petroleum activity. So far, this principle has only applied to activities related to production installations, but it is now in the process of being implemented by the Maritime Directorate and some other authorities, not only for offshore activities but also for land based industries.

In the future, other participants in the petroleum activiity will have to establish systems for internal control. That means that all participants are expected to be responsible for compliance with rules and regulations and must implement a control system that ensures that rules and regulations are adhered to.

This principle will also have an important impact on some contractors and some operators that, up to now, have only been engaged in the exploration activity. Regarding, for example, mobile drilling units, the role of the Classification Authorities will be regarded as a part of the operator/owners internal control system. The owner will therefore need a minimum staff to carry out the necessary control work because it will be expected that the internal control function is delegated to a specified unit within the organization. This unit must have sufficient organizational freedom to be able to examine all subordinate control functions and to perform system revisions on these.

The control performed by the authorities will in the future be concentrated upon controlling the internal control system. This will mean a change from "equipment control" to a "system control." This system control will be performed as audits going through documentation, procedures, and also spot checks on physical parts of installations.

A control environment as described, will hopefully improve the safety level as more conscious efforts will have to be made among those performing the activities on the Continental Shelf regarding safety aspects in the planning, design, construction , and operation phases. This environment will hopefully also result in a better utilization of the resources in the industry, support organizations, and the public control apparatus.

Operating Internal Control System

The fundamental principle in the legal framework for the offshore activity is therefore that the licensees are responsible for ensuring that the activity is performed according to the safety regulations in force.

The control being performed by the public control agencies will be a supplement to the internal control which the involved operators, contractors, etc., must carry out and must in no way be considered a replacement or a part of this control.

The licensee, therefore, has a clear duty to perform necessary control himself and to do this through an organized internal control system. This system shall not only cover his own activities, but also include all contractors/subcontractors who perform work for him.

The NPD first issued, "Guidelines for the Licensees Internal Control," on 7 June 1979. These were revised 15 May 1981. (The main principles of these guidelines are presently being upgraded to become "Regulations for Internal Control." This is done in order to satisfy the new Petroleum Law and will therefore cover all activities on the Norwegian Continental Shelf, not only those connected to fixed installations.)

The aim of the guidelines is to clarify one of the main principles of safety control of the petroleum activity on our Continental Shelf.

The guidelines have the following definition of "internal control":

"All systematic actions that are necessary to ensure that the activity is planned, organized, executed and maintained to requirements in and pursuant to laws and regulations."

It is important to notice that this definition includes the quality term. (Conformance with specified requirement.) This means that the internal control normally will be taken care of by a total Quality Assurance system that shall ensure conformance with the company's own requirements. The requirements from the authorities concerning the scope of an internal control system, might thus

be regarded as minimum requirements to a total Quality Assurance system in the company.

The guidelines are applicable to all activities, such as design, construction, installation, and operation facilities.

It is required that the internal control system is described in a general form with reference to more detailed descriptions of the different parts of the organization and/or different phases of the project.

The description of the system, once accepted by the authorities, is binding with regard to the operator internally and the authorities externally.

The internal control system shall cover all parts of the operators organization and all phases of an activity.

This shall ensure:

- That competent persons are used during planning, construction, building, installation, and operation.
- That worker protection and health personnel shall be able to perform their work according to the intentions of the Law.
- That all employees and contractor personnel are given necessary training.
- That a total safety evaluation is performed at final concept choice.
- That an analysis of the construction is performed.
- That systems are established for the administration of documents in all phases of a project.
- That purchasing documents, specifications, etc., contain sufficient Quality Assurance requirements.
- That control of responsibility and communication lines (interface control) are ensured.
- That the suppliers' Quality Assurance is assessed, accepted, audited, and verified.
- That it can be documented (by test reports, certificates, etc.) that goods or services supplied have an acceptable quality.
- That satisfactory operating programs (for example, program for drilling, start-up, production, and programs for simultaneous activities, inspection and testing, maintenance, etc., are made and followed).
- That temporary equipment may be installed and operated in a secure way and pursuant to established requirements.

- That Quality Control during the operation functions effectively.
- That corrective actions take place when the Quality Control indicates deviation from established quality requirements.
- That specifications for repair are established and that the specifications give sufficient support for - and sets sufficient requirements for the execution of the repair.
- That modifications or repair do not reduce the originally specified safety level.
- That procedures are performed in such a way that the safety is taken care of, even if the production installation must be operated in a not predetermined way.
- That the safety of the installations also is ensured throughout work conflict and irregular shutdown of production.
- That necessary actions take place and involved authorities are informed if abnormal incidents or accidents should occur.
- That information and documentation are presented on time for the authorities in accordance with laws, regulations, and guidelines.

These examples are not a comprehensive list of what the licensee's internal control shall contain, but highlight some areas that should be given special attention.

It is of importance that the licensee does evaluate those areas that are covered through normal internal routines and also areas where special efforts are required. It must also be possible to continuously update the internal control system.

To ensure the intended function of the internal control, the organization plans shall include and/or describe the function and the position of personnel that shall supervise internal control and their duties and responsibilities in that connection.

General responsibilities and supervision for the internal control is expected to be delegated to a special unit in the licensee's organization. This unit must have the necessary organizational freedom to execute supervision of all relevant control systems and to perform a system audit.

Necessary organizational freedom will normally mean that this function should be excluded from operational responsibility and should have the possibility to report to a higher organizational level than the ones this unit supervises.

It is emphasized that this responsibility shall not be in conflict with the free and independent position that worker protection and health personnel shall

have according to the law. The internal control shall ensure the integrity of these functions also with respect to organizational freedom.

The development of the internal control philosophy has in a very satisfactory way reduced the NPDs heavy control-work on a detailed level and made it possible to concentrate on the main important aspects. Control on a detailed level is still performed, but now as a part of a planned audit on a specific subject.

The NPD's impression is also that by checking the operators internal control system, instead of only checking individual technical components, we have achieved a better safety understanding and acceptance within all parts of the operators organization. This again has resulted, we feel, in a higher safety level on the fixed installations in general.

Regarding 2: ("Development of more functional requirements must be carried further.")

A consequence of the above described control approach is that the requirements in the new Royal Decree will only be presented as safety goals and it will be up to the control agencies to issue more detailed regulations. These regulations will have to be functional in form and as far as possible, avoid specifying how safety aspects shall be resolved. The intention is to avoid frequent revisions of the regulations due to rapid development of new technologies, etc. The objective is therefore to achieve a more flexible regulatory system.

Regarding 3: ("The development of the internal control system must be continued in order to provide a regulatory system which can secure effective control within the limitations of the resources available to public authorities.")

This item has been commented under 1, but I will add that in order to further develop the control system based on the philosophy of the internal control duty vested with the industry, it is important that all parts of the industry really put an effort into developing a good, trustworthy internal control system. If this effort is not made, it can result in reverting back to a control system that is less flexible, more time consuming, complicated, and more resource demanding.

Regarding 4: ("The future control system shall consist of the smallest number of regulatory agencies possible and be well coordinated.")

This statement means that a conscious effort will be made to reduce the number of public control agencies and develop a system where coordination is easy. If this is achieved, one of the main problems of getting the same safety framework for the total offshore activity is eliminated. It will therefore also be easier to establish a flexible regulatory environment for the industry and control agencies.

Regarding 5: ("Conceptual safety evaluations must be performed for all types of installations used in the petroleum activity.")

This item is identified because it is expected that the safety of an installation should normally be checked on three levels.

1. Serviceability control where the main aim is to reduce downtime.

2. Component failure control where one verifies safety against structural and equipment failures. Failure control is checked for events of larger effect but less frequent than serviceability control.

3. Major accident control where one verifies the installation safety against major accidents jeopardizing a large number of lives, causing severe pollution or major economical losses.

The serviceability and component failure control are normally covered by existing codes and regulations. Procedures and criteria for major accident control are not. It is therefore necessary to introduce a requirement stating that a conceptual safety study shall be performed as this is considered being a vital part of the major accident control.

The NPD has therefore developed a, "Guideline for Safety Evaluation of Platform Conceptual Design," with the purpose of giving guidance for the execution of safety evaluations of installations. The intention of the guidelines is to express the general attitude of the Norwegian Petroleum Directoratge to the problem area, and to indicate how the safety aspects can be handled at an early stage of design.

It is important to note that the guidelines are intended to be used for safety evaluations and analysis of installations as completed in the operational phase.

The main chapters of the guidelines are as follows:

- Principles of the evaluation
- Design accidental events
- Acceptance criteria

Principles of Evaluation

It is presupposed that the operator has chosen a concept that complies with general safety criteria. The intention of the evaluation is to verify at an early stage that the concept chosen will result in an acceptable installation, and that no major changes during design and construction phases will be necessary because of safety requirements. The aim of the evaluation is therefore to establish acceptable safety in compliance with given criteria.

Design Accidental Events

For the installation, or parts of it, that are relevant to the acceptance criteria, the licensee should specify a set of design accidental events. In principle, the design accidental events shall be the most unfavorable situations relative to the acceptance criteria.

In practical terms, it may be considered necessary to exclude the most improbable accidental events from the analysis. However, the total probability of occurrence of each type of excluded situation should not, by best available estimate, exceed 10^{-4} per year for any of the main functions specified in the guidelines.

This number is meant to indicate the magnitude to aim for, as detailed calculations of probabilities in many cases will be impossible due to lack of relevant data.

Acceptance Criteria

The platform design must be such that a design accidental event does not impose a danger to personnel outside the immediate vicinity of the accident.

This statement can be considered satisfied by complying with the following three criteria:

1. At least one escape way from central positions, which may be subjected to an accident, shall normally be intact for at least 1 hour during a design accidental event.

2. Shelter areas shall be intact during a calculated accidental event until safe evacuation is possible.

3. Depending on platform type, function, and location, when exposed to the design accidental event, the main support structure must maintain its load carrying capacity for a specified time.

In summary the basic concepts of the NPD Guidelines for Concept Evaluation are as follows:

1. The adequacy of the platform design is measured by the ability of escape ways, shelter areas and main support structure to remain functional or partly functional during any of the several Design Accidental Events (DAEs) to permit personnel outside the immediate vicinity of the accident to reach a safe location.

2. The DAEs are particular scenarios in each of which an initiating failure (e.g., pipe rupture) is considered in combination with particular conditioning circumstances (e.g., wind directions, protective system operation, etc.).

3. Accidental events which do not fall in the DAE class because they would make all escape ways impossible should not have a total probability exceeding 10^{-4} per year; the same applies for shelter areas and main support structures.

As it is expected that such evaluations are carried out on all types of installations, it is natural to assume that guidelines such as the one just mentioned are developed for use in the industry as a total. This development will result in a more overall and thorough evaluation of safety aspects, and assure in a more systematic way that major safety problems are defined and

handled at an early stage in a project and thereby improving the overall safety of the installation.

GENERAL DESCRIPTION OF PROCEDURES FOR APPROVAL OF THE DEVELOPMENT OF PETROLEUM RESOURCES ON THE NORWEGIAN CONTINENTAL SHELF

The Norwegian Authorities approvals of the various phases of offshore development projects are a major part of the safety management structure. The Norwegian Authorities put great emphasis on the safety and risk-related activities in a project and that they are performed in a systematic and controlled manner. The phase-related approvals given by the authorities are therefore considered as control stations in this safety management process.

If an offshore operator wants to develop a petroleum field, he first has to present to the Ministry of Petroleum and Energy a "Field Development Plan" (figure 1). The formal approval of the Field Development Plan will subsequently be given by the Storting (the Norwegian Parliament) on the recommendation of the Ministry of Petroleum and Energy concerning resource-related matters and the Ministry of Labor and Municipal Affairs/The Norwegian Petroleum Directorate concerning technical and safety-related matters.

The Field Development Plan shall in addition to topics concerning geology, reservoir characteristics, economy, and technical installations, etc., also contain a section concerning the safety management of the project. This section should contain a description of the operator's safety policy, his management system for internal control and Quality Assurance and the initial safety evaluations undertaken which form the basis for the choice of development concept.

The next approval given by the authorities will be at approximately the end of the preengineering phase when the operator has to submit to the Norwegian Petroleum Directorate what is known as the "Extended Field Development Plan" (the "Main Plan").

This is a continuation of the Field Development Plan, but is more detailed than the former. The "Main Plan" is mostly of technical and safety-related nature and forms the basis for the Governmental acceptance for the project to proceed into Detail Engineering.

In addition to a technical description of the various parts of the installation, including platform protection and monitoring, the main emphasis of the "Main Plan" will be a detailed description of the Internal Control and Quality Assurance systems for the Development Project (Appendix 3) and a major Safety and Risk Analysis of the installations (Appendix 4).

Following these two major approvals, there will be a number of part approvals given by the authorities, such as:

- Approval to start fabrication
- Approval to tow out and install platforms

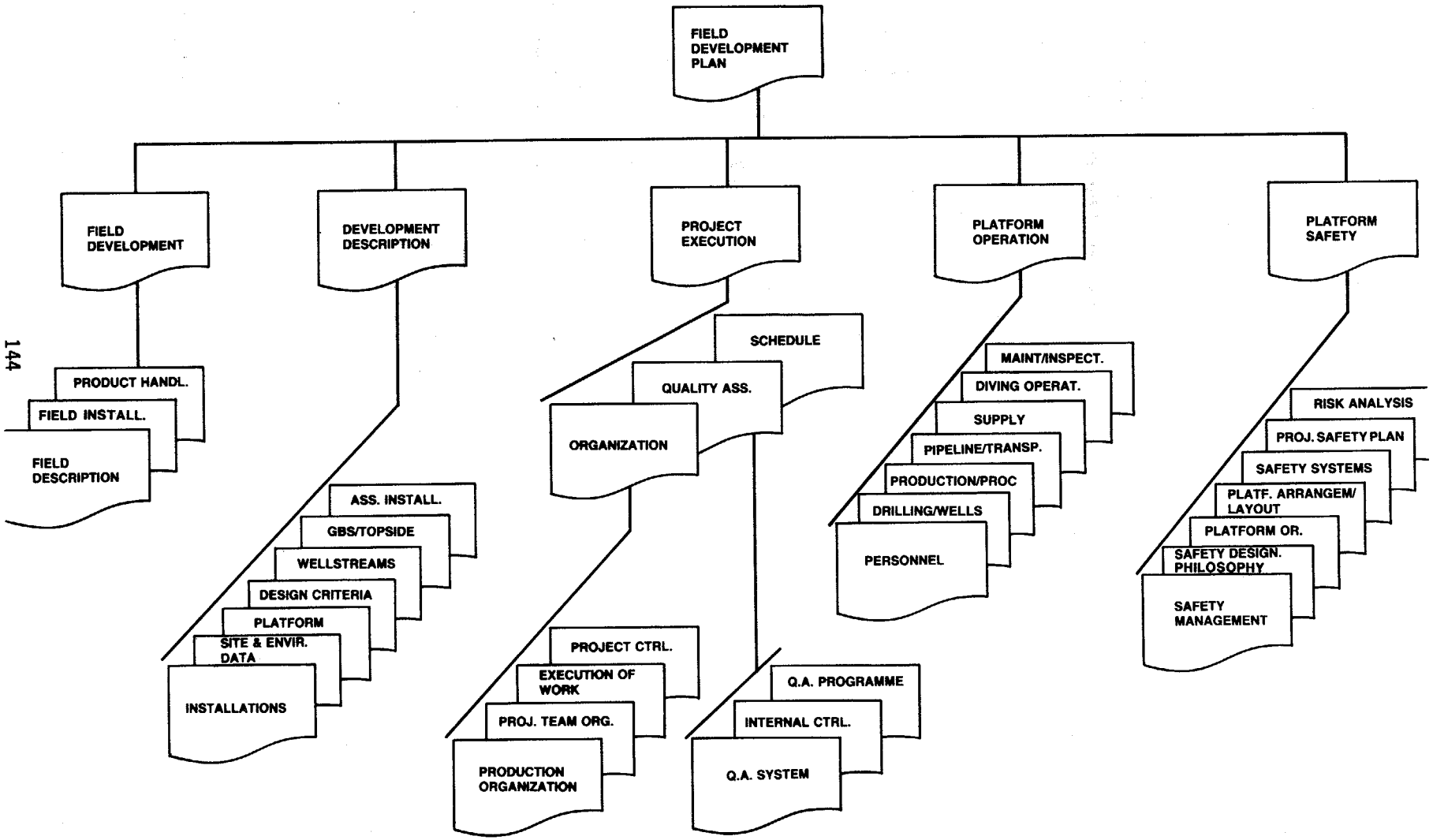
FIELD DEVELOPMENT PLAN
FIELD DEVELOPMENT
DEVELOPMENT DESCRIPTION
PROJECT EXECUTION
PLATFORM OPERATION
PLATFORM SAFETY
PRODUCT HANDL.
FIELD INSTALL.
FIELD DESCRIPTION
ASS. INSTALL.
GBS/TOPSIDE
WELLSTREAMS
DESIGN CRITERIA
PLATFORM
SITE & ENVIR. DATA
INSTALLATIONS
SCHEDULE
QUALITY ASS.
ORGANIZATION
PROJECT CTRL.
EXECUTION OF WORK
PROJ. TEAM ORG.
PRODUCTION ORGANIZATION
Q.A. PROGRAMME
INTERNAL CTRL.
Q.A. SYSTEM
MAINT/INSPECT.
DIVING OPERAT.
SUPPLY
PIPELINE/TRANSP.
PRODUCTION/PROC
DRILLING/WELLS
PERSONNEL
RISK ANALYSIS
PROJ. SAFETY PLAN
SAFETY SYSTEMS
PLATF. ARRANGEM/ LAYOUT
PLATFORM OR.
SAFETY DESIGN. PHILOSOPHY
SAFETY MANAGEMENT

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FIG. 1

- Approval to lay pipelines
- Approval to dry and test pipelines, etc.

In addition to these part approvals, the operator also has to apply for various operating permits. These are:

- Permit for use for dwelling purposes
- Permit for use for production drilling
- Permit for use for petroleum production
- Permit for use for pipeline systems
- Permit for use for shipment facilities

Common to all these approvals, the operator has to confirm to the authorities, that all aspects related to safety and Quality Assurance for the following activity are taken care of and in accordance with Norwegian Laws and Regulations. For some of the approvals, the Norwegian Petroleum Directorate specifically asks for documentation (as indicated by the regulations) to follow the applications.

In other instances, the Norwegian Petroleum Directorate, may only spot check certain documents or activities to make sure the project is executed in accordance with the required safety standards.

The Norwegian Petroleum Directorate only does a 100% control of the project up to and included the "Main Plan." For subsequent activities the project control is undertaken through the system for internal control. There is therefore no formal system for certification as in many other countries, although certificates or certifying authorities may be used by the operator as part of his internal control system.

The control undertaken by the Norwegian Petroleum Directorate is therefore a control of the operators internal control system and is usually undertaken on a spot check basis. This form for auditing may be carried out on all levels and on all activities, both technical and managerial and during all phases of the project. Particular emphasis is put on auditing the safety management system of the operator and the development project.

SAFETY MANAGEMENT IN OFFSHORE DEVELOPMENT PROJECTS

As a consequence of the blowout on the Bravo platform on Ekofisk in 1977, the Norwegian Authorities decided that too little had been done on research and development related to the safety and contingency planning of offshore petroleum activities in Norway.

A major 4 year R&D program, "Safety Offshore," was therefore initiated in 1978. The program was terminated in 1983, cost a total of 153 mill. kr., and included

282 projects. (A summary of the various projects can be ordered from the NPD.) The program was split into three parts. Two of these were managed by the Norwegian Petroleum Directorate and the third by the Royal Norwegian Council for Scientific and Industrial Research.

A substantial part of the program dealt with aspects of safety management and risk and reliability analysis. Two projects in particular looked at the overall safety management aspects of offshore development projects in Norway. These were:

1. "Project Model for Safety Management in Offshore Development Projects."

2. "Risk Analysis in Offshore Development Projects."

A Norwegian consultant company, Bedriftsrådgivning A/S, and the Safety and Reliability Section of SINTEF (The Foundation of Scientific and Industrial Research at the Norwegian Institute of Technology) undertook these projects in cooperation with two project groups consisting of representatives of the Norwegian Authorities, offshore operators, and engineering and certifying companies.

Even if these two projects present the ideal safety management model and risk analysis activities of offshore development projects, they do to a large extent reflect the intentions of the Norwegian Petroleum Directorate's guidelines for "internal control" and "concept evaluation." The projects also give an excellent overview of the main structure of a field development project where special emphasis is put on safety-related activites. (The two project reports are available from Bedriftsrådgivning A/S and SINTEF in Norway. See appendices 5 and 6.)

PROJECT MODEL FOR SAFETY MANAGEMENT IN OFFSHORE DEVELOPMENT PROJECTS

(Extracts from the project report with the kind permission of Bedriftsrådgivning A/S.)

FRAMEWORK FOR SAFETY MANAGEMENT

The main result of this project is a framework for safety management (figure 2). It shows, roughly and in principle:

- What the safety activities in a project may consist of.
- How they may be planned, carried out, and followed-up through safety management.

1. INTRODUCTION

2. MAIN STRUCTURE OF A DEVELOPMENT PROJECT

3. SAFETY MANAGEMENT

4. SAFETY OBJECTIVES AND REQUIREMENTS

5 SAFETY PROGRAMME

6. PHASE MODELS

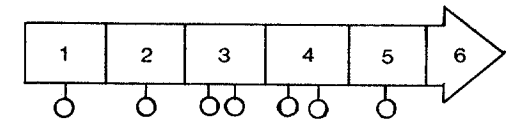
7. SAFETY ANALYSIS

8. STEERING OBJECTS

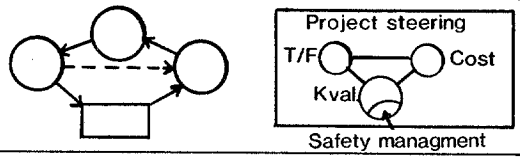
9. ORGANIZATION OF THE SAFETY WORK

10. USE OF THE MODEL

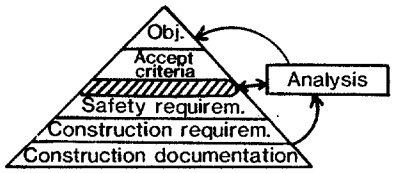
OVERVIEW OF THE PROJECT
- PHASE
- DECISIONS
- PARTIES
- TASKS
- DOCUMENTS
- SAFETY ASPECTS



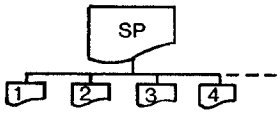
OVERVIEW OF SAFETY MANAGEMENT
- SAFETY
- SAFETY MANAGEMENT PROCESS
- PART OF PROJECT MANAGEMENT



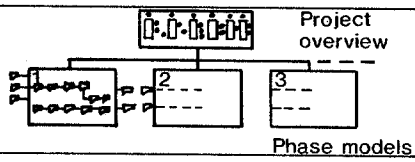
BREAKDOWN OF SAFETY-OBJECTIVES AND REQUIREMENTS
- PARTIES IN THE PROJECT
- STEPS IN BREAKDOWN
- CONNECTION TO SAFETY MANAGEMENT



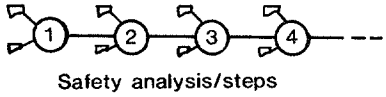
SAFETY PROGRAMME
- OBJECTIVE
- CONTENT
- USE IN PRACTICE PROJECT MANAGEMENT



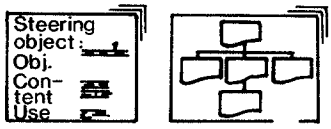
MAIN DESCRIPTION OF MODEL
- TOTAL PROJECT MODEL
- PHASE MODELS INCLUDED STEERING PROCESS



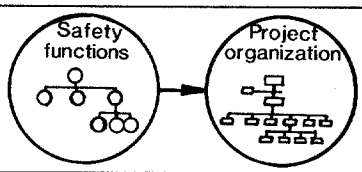
DESCRIPTION OF ANALYSIS



MAIN DOCUMENTS IN SAFETY MANAGEMENT
- STEERING OBJECT ARE DESCRIBED



PRINCIPALS FOR THE POSITIONING OF THE SAFETY FUNCTIONS IN THE PROJECT ORGANIZATION



WHAT THE MODEL/FRAMEWORK CAN BE USED FOR AND HOW

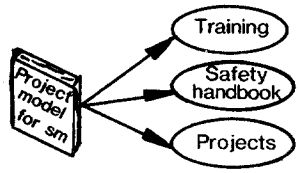


Figure 2

The framework clarifies and interconnects important aspects concerning safety:

- Safety objectives and safety requirements and how they are established.
- Safety analysis; which, when, and on what basis.
- Safety oriented decisions.
- Design tasks involving safety.
- Documents concerning the safety of an installation; both safety reports and design documents.
- Safety control by reviewing design and construction of installations.

The project model for safety management aims at influencing the practice concerning safety management in Norwegian field development projects in the future. It is therefore realistically future oriented, mainly for the following reasons.

- It is assumed that safety management in the future will be given considerable emphasis in field development projects (corresponding to the level of ambition reflected in the model).
- Intentions, principles, and concepts in the new Petroleum Act which is forthcoming, have been taken into the model as far as practically possible.
- Increasing requirements for thorough risk analysis, both from the authorities and the oil companies.
- The competence to carry out such analysis is now being built up in the petroleum industry.
- The safety management process is now becoming regarded a total process, starting with goals and ending with verification.
- Safety is not the responsibility of the project safety discipline alone, but involves all those who can influence the design and construction of the installation.

ASPECTS OF SAFETY MANAGEMENT IN A PROJECT

Safety management (objectives, plans, analysis, decisions, documents) and the organization of safety activities in the project will vary from one phase to the other in the course of the project.

Project Phases

The project may be divided into six separate phases.

1. Feasibility study;
2. Concept study;
3. Preengineering;
4. Detail engineering;
5. Construction; and
6. Commissioning and startup.

In the first three of these phases, the premises for a safe installation are established. The possibility to influence the final result is considerable in these phases, whilst it falls rapidly in the later phases.

Analysis

Two main principles should be followed when planning safety analysis in the project:

1. The number of analyses should be limited as far as possible.

2. Analysis should be performed where central decisions are made.

This leads to five types of safety analysis:

1. Rough risk analysis;
2. Concept safety analysis;
3. Hazard analysis;
4. Total risk analysis; and
5. Risk analysis and construction work.

Control Entities

By control entities is meant project documents to which special attention should be paid (especially concerning safety) and which are the subject of management. In the project model these documents are marked and specially described.

In each project phase certain control entities are particularly important:

- Safety Program (figure 3).

  This is a plan for safety activities for the project phase in question and subsequent phases. The safety program is an essential document in practical safety management.

- Risk Analysis Reports.

  Analysis and evaluation reports which form the bases for decisionmaking.

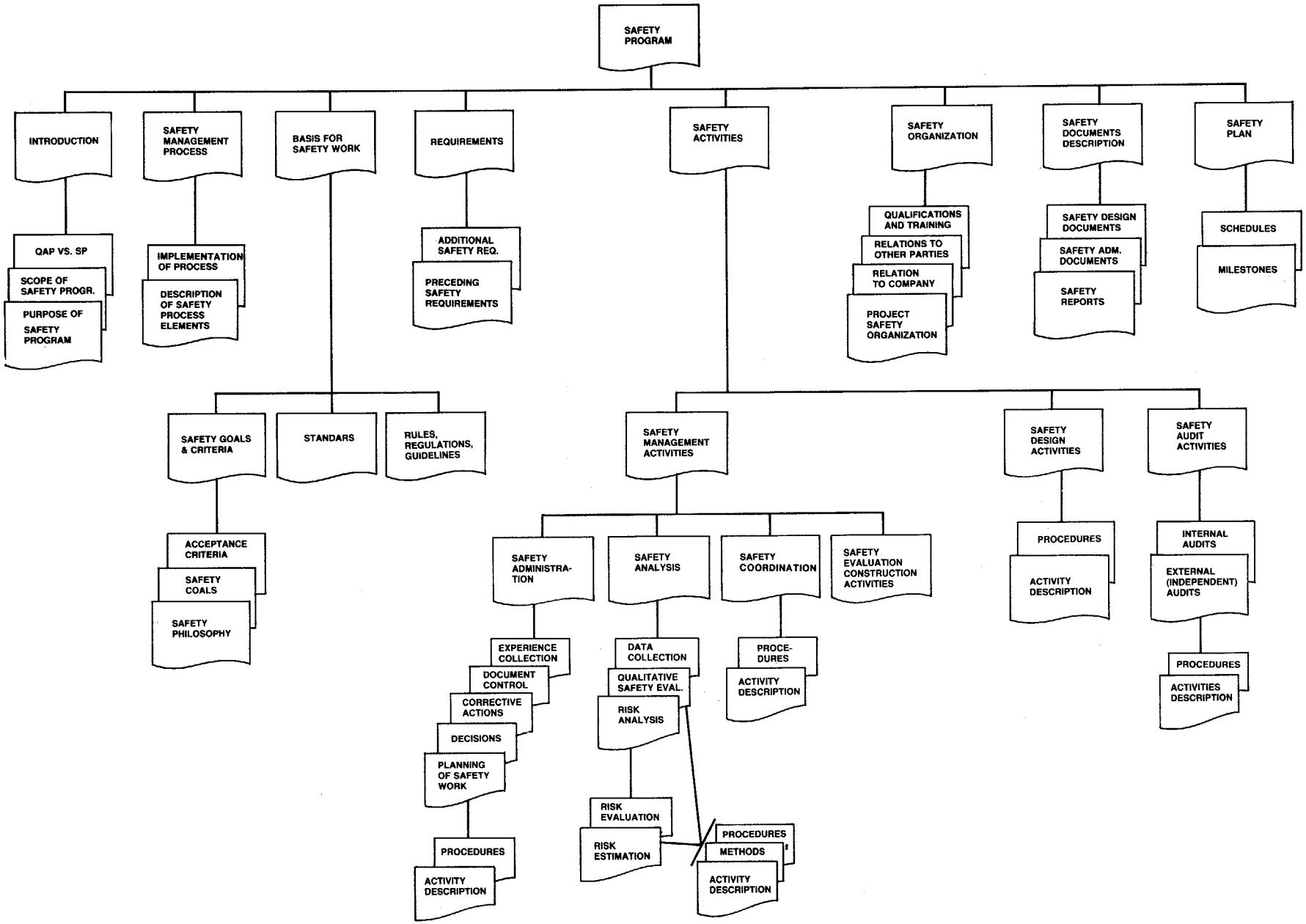

SAFETY PROGRAM
INTRODUCTION
SAFETY MANAGEMENT PROCESS
BASIS FOR SAFETY WORK
REQUIREMENTS
SAFETY ACTIVITIES
SAFETY ORGANIZATION
SAFETY DOCUMENTS DESCRIPTION
SAFETY PLAN
QAP VS. SP
SCOPE OF SAFETY PROGR.
PURPOSE OF SAFETY PROGRAM
IMPLEMENTATION OF PROCESS
DESCRIPTION OF SAFETY PROCESS ELEMENTS
ADDITIONAL SAFETY REQ.
PRECEDING SAFETY REQUIREMENTS
QUALIFICATIONS AND TRAINING
RELATIONS TO OTHER PARTIES
RELATION TO COMPANY
PROJECT SAFETY ORGANIZATION
SAFETY DESIGN DOCUMENTS
SAFETY ADM. DOCUMENTS
SAFETY REPORTS
SCHEDULES
MILESTONES
SAFETY GOALS & CRITERIA
STANDARDS
RULES, REGULATIONS, GUIDELINES
SAFETY MANAGEMENT ACTIVITIES
SAFETY DESIGN ACTIVITIES
SAFETY AUDIT ACTIVITIES
ACCEPTANCE CRITERIA
SAFETY COALS
SAFETY PHILOSOPHY
SAFETY ADMINISTRA-TION
SAFETY ANALYSIS
SAFETY COORDINATION
SAFETY EVALUATION CONSTRUCTION ACTIVITIES
PROCEDURES
ACTIVITY DESCRIPTION
INTERNAL AUDITS
EXTERNAL (INDEPENDENT) AUDITS
PROCEDURES
ACTIVITIES DESCRIPTION
EXPERIENCE COLLECTION
DOCUMENT CONTROL
CORRECTIVE ACTIONS
DECISIONS
PLANNING OF SAFETY WORK
PROCEDURES
ACTIVITY DESCRIPTION
DATA COLLECTION
QUALITATIVE SAFETY EVAL.
RISK ANALYSIS
RISK EVALUATION
RISK ESTIMATION
PROCEDURES
METHODS
ACTIVITY DESCRIPTION
PROCE-DURES
ACTIVITY DESCRIPTION

FIG. 3

150

- Safety Report From A Given Phase.

  Summary of the safety analysis and decisions made in that phase.

- Safety Audit Report.

  Results from the design reviews, including recommendations.

- Documents sent to the authorities concerning safety-related matters such as the Field Development Plan (Main Plan at present).

- Other documents produced in the given phase of significance to safety:

  - Engineering/design documents
  - Bid documents
  - Handbooks/manuals
  - Etc.

Organizing The Safety Functions

In this report, we have not proposed an organization chart for the "ideal" safety organization in a development project.

What we have done is:

- to define safety functions in a project,
- to establish principles for organizing the safety activities in the project.

These are to be regarded as guidelines, not as solutions.

The safety functions are:

- SAFETY MANAGEMENT

  - Safety administration
  - Safety analysis
  - Safety design coordination

- DESIGN OF SAFETY SYSTEMS

- SAFETY AUDITS

  - Internal audits
  - External audits

The principles of organization should ensure positive influence on safety, that is:

- Safety activities are given the necessary place and priority.
- Safety considerations influence all stages of the design.

THE SAFETY MANAGEMENT PROCESS

Safety management is a continuous process running through the whole project. By means of a Safety Program (figure 3), a plan for all safety oriented activities in the projects, we ensure in practice that the safety management process will be carried through.

A safety program is a document showing how the individual elements in safety management should be carried out, when and by whom.

The individual elements in the safety management process consist of:

- Safety Objectives.

  Establishment of the main safety objectives of the project (verbally described). Based on the safety objectives of the operating company the objectives will be adapted to the project's own basic premises.

- Acceptance Criteria.

  On the basis of safety objectives specific acceptance criteria (risk targets, reference norms) will be established. These will be used for evaluation and acceptance of risks.

- Risk Analysis.

  This includes identification, description, calculation/estimation and evaluation risk. We here distinguish between:

  - Risk assessment (risk calculations): that is to determine risk for a given design by suitable methods.
  - Risk evaluation: to compare the calculated risk with the acceptance criteria.

- Safety Requirements.

  The establishment of safety requirements (safety oriented design basis), based on risk evaluations, or from guidelines established by the operating company.

- Implementation.

  To make objectives and requirements operatively available for those who shall fulfill them in design and construction. Organization and contract formulation are essential factors to make this possible.

- Realization and Objectives and Requirements.

  Objectives and requirements are realized in the process of project tasks, i.e., they are incorporated in the selected design and final product. This implies:

  - Establishing design specifications.

  - Establishing complete design solutions.

  - Documentation of safety and emergency measures in accordance with requirements, regulations, and standards.

- Design Review.

  Review and improvement of design with respect to safety, as well as other aspects, carried out by project personnel. Continuous coordination of safety in design will to a large extent satisfy this requirement.

- Safety Audits.

  Independent review of the design with regard to safety, carried out by an independent group. Proposals for improvement.

- Rules, Regulations, and Standards.

  The Government seeks to regulate the level of safety through:

  - definition of responsibility (the principle of internal control),

  - guidelines for concept safety analysis, and

  - a series of detailed regulations.

  - The operating company's standards and specifications will also influence the execution of the project.

  - On the engineering side, more or less formal standards and "good design practice" are established.

  - To make objectives and requirements operatively available for those who shall fulfill them in design and construction. Organization and contract formulation are essential factors to make this possible.

- Experience.
  Relevant experience and information for the tasks to be carried out must be acquired and utilized in the project.

The model for safety management which has been developed is based on:

- A safety management process as described, shall take place through the whole life of the project.

- A safety program is the principal means of bringing safety management into the project. This shall state:

  - Which safety activities are to be carried out
  - How (basis, method result)
  - When
  - By whom (participants, responsibility)

MAJOR TASKS IN EACH PHASE (figure 4)

A brief description of the major tasks within each phase in the project, is given in the following with special emphasis on the safety-related activities.

Feasibility Study

The work in this phase is mainly directed towards the definition, evaluation, and description of a number of development concepts for an offshore oil/gas field, i.e., concepts which are technically, economically, and safetywise feasible on the basis of the characteristics (geographical position, the extension of the reservoir's characteristics of water depth, seabed condtions, etc.) of the field in question.

On the basis of these descriptions a decision is made on whether to proceed with a more detailed concept study.

Safety-related activities consist here principally of formulating the primary safety goals and objectives to be applied in the further development of the project, establishing a safety program for this phase and for the rest of the project, and performing a first, rough risk analysis of alternative field development concepts with respect to the main types of accidents and their possible consequences.

The work is mainly performed by the operator's own project team, but special consultants may be engaged for special studies and reports.

Concept Study

The work from phase one is here continued with more detailed studies for selected concepts, to be able to choose the best concept for development of the entire field and for the first platform. The platform should here be described in sufficient detail to form the basis for an "official" cost estimate, and for the invitation to tender for preengineering.

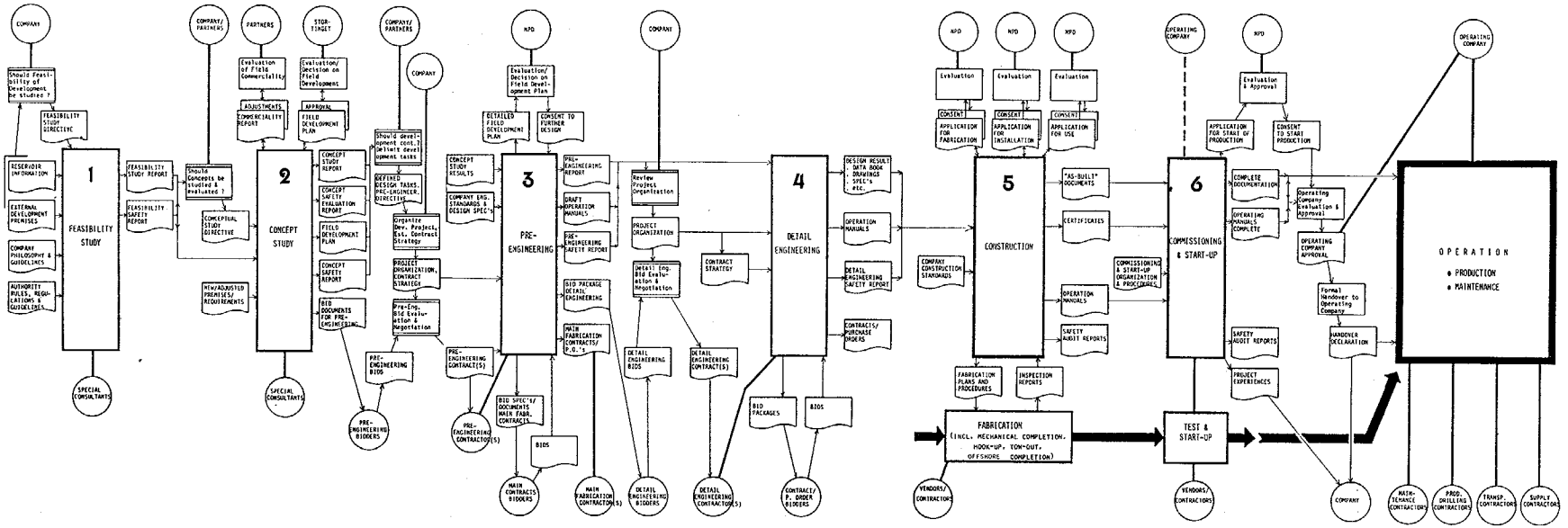

COMPANY
Should Feasibility of Development be studied ?
FEASIBILITY STUDY DIRECTIVE
RESERVOIR INFORMATION
EXTERNAL DEVELOPMENT PREMISES
COMPANY PHILOSOPHY & GUIDELINES
AUTHORITY RULES, REGULATIONS & GUIDELINES
1
FEASIBILITY STUDY
SPECIAL CONSULTANTS
FEASIBILITY STUDY REPORT
FEASIBILITY SAFETY REPORT
COMPANY/ PARTNERS
Should Concepts be studied & evaluated ?
CONCEPTUAL STUDY DIRECTIVE
NEW/ADJUSTED PREMISES/ REQUIREMENTS
PARTNERS
Evaluation of Field Commerciality
ADJUSTMENTS
COMMERCIALITY REPORT
2
CONCEPT STUDY
SPECIAL CONSULTANTS
STOR-TINGET
Evaluation/ Decision on Field Development
APPROVAL
FIELD DEVELOPMENT PLAN
CONCEPT STUDY REPORT
CONCEPT SAFETY EVALUATION REPORT
FIELD DEVELOPMENT PLAN
CONCEPT SAFETY REPORT
BID DOCUMENTS FOR PRE-ENGINEERING
PRE-ENGINEERING BIDDERS
COMPANY/ PARTNERS
COMPANY
Should Development cost, Delimit development tasks
DEFINED DESIGN TASKS, PRE-ENGINEER. DIRECTIVE
Organize Dev. Project, Est. Contract Strategy
PROJECT ORGANIZATION, CONTRACT STRATEGY
Pre-Eng. Bid Evaluation & Negotiation
PRE-ENGINEERING BIDS
PRE-ENGINEERING CONTRACTOR(S)
NPD
Evaluation/ Decision on Field Development Plan
DETAILED FIELD DEVELOPMENT PLAN
CONSENT TO FURTHER DESIGN
CONCEPT STUDY RESULTS
COMPANY ENG. STANDARDS & DESIGN SPEC'S
3
PRE-ENGINEERING
PRE-ENGINEERING REPORT
DRAFT OPERATION MANUALS
PRE-ENGINEERING SAFETY REPORT
BID PACKAGE DETAIL ENGINEERING
MAIN FABRICATION CONTRACTS/ P.O.'S
BID SPEC'S/ DOCUMENTS MAIN FABR. CONTRACTS
BIDS
MAIN CONTRACTS BIDDERS
MAIN FABRICATION CONTRACTOR(S)
COMPANY
Review Project Organization
PROJECT ORGANIZATION
Detail Eng. Bid Evaluation & Negotiation
DETAIL ENGINEERING BIDS
DETAIL ENGINEERING BIDDERS
CONTRACT STRATEGY
DETAIL ENGINEERING CONTRACT(S)
4
DETAIL ENGINEERING
BID PACKAGES
BIDS
CONTRACT/ P. ORDER BIDDERS
DESIGN RESULT : DATA BOOK : DRAWINGS : SPEC'S : etc.
OPERATION MANUALS
DETAIL ENGINEERING SAFETY REPORT
CONTRACTS/ PURCHASE ORDERS
NPD
Evaluation
CONSENT
APPLICATION FOR FABRICATION
APPLICATION FOR INSTALLATION
APPLICATION FOR USE
COMPANY CONSTRUCTION STANDARDS
5
CONSTRUCTION
"AS-BUILT" DOCUMENTS
CERTIFICATES
OPERATION MANUALS
SAFETY AUDIT REPORTS
FABRICATION PLANS AND PROCEDURES
INSPECTION REPORTS
FABRICATION (INCL. MECHANICAL COMPLETION. HOOK-UP. TOW-OUT. OFFSHORE COMPLETION)
VENDORS/ CONTRACTORS
OPERATING COMPANY
COMMISSIONING & START-UP ORGANIZATION & PROCEDURES
6
COMMISSIONING & START-UP
NPD
Evaluation & Approval
APPLICATION FOR START OF PRODUCTION
CONSENT TO START PRODUCTION
COMPLETE DOCUMENTATION
OPERATING MANUALS COMPLETE
Operating Company Evaluation & Approval
OPERATING COMPANY APPROVAL
Formal Handover to Operating Company
SAFETY AUDIT REPORTS
PROJECT EXPERIENCES
HANDOVER DECLARATION
TEST & START-UP
VENDORS/ CONTRACTORS
OPERATING COMPANY
OPERATION
• PRODUCTION
• MAINTENANCE
COMPANY
MAINTENANCE CONTRACTORS
PROD. DRILLING CONTRACTORS
TRANSP. CONTRACTORS
SUPPLY CONTRACTORS

FIG. 4

Should the rest of the studies be satisfactory, a declaration of commerciality will be prepared for the partners (the other licensees). Also, an application for landing permit is submitted to the Ministry of Oil and Energy, including the licensee's plan for development of the field (Field Development Plan).

Safety activities include primarily specifications of safety requirements for the installation and performing of certain safety analyses:

- Rough risks analysis of the installation concept.
- Preliminary safety analysis of the selected process and layout.
- Total risk analysis of the selected concept according to the guidelines of the Norwegian Petroleum Directorate.

The operator's own organization undertakes most of this work.

Preengineering

In this phase, the engineering of the process system and other main areas and modules of the platform is carried out to a degree sufficient to invite tenders for complete detail engineering. This work should result in a complete design philosophy for the installation, a description of the scope of work for the detail engineering and bid documents for relevant engineering contracts. In addition, purchase for long lead items and critical equipment should be awarded.

In this phase, an extended detailed Field Development Plan shall also be prepared. This shall be sent to the Norwegian Petroleum Directorate as a basis for consent for futher engineering.

Safety activities continue with:

- Hazard analysis of process and utility systems.
- Overall risk analysis of the platform.

The greater part of the engineering will now usually be performed by an engineering contractor. To assist in procurement and project management, the operator may engage a Project Services Contractor (PSC), who will also take part in the project from this phase on.

Detail Engineering

Put simply, the main activities are to prepare the necessary technical and economical basis for all contracts and purchase orders, to award these to qualified suppliers, and ensure that delivery takes place according to plan. This phase is usually the longest and most resource demanding of the engineering phases.

With regard to safety, the work will to a large extent consist of ensuring that previously specified requirements and premises are taken into account in detail engineering. The following analysis may be performed:

- An extended detailed hazard analysis of process and utility systems.
- Availability analysis of safety systems.
- Updating of the overall risk analysis.
- Risk analysis of construction and hookup work.

The detail engineering is also normally performed by an engineering contractor (DEC). The operator's own project team, possibly assisted by a PSC, performs technical and progress control of engineering and carries out procurement and contract adminstration.

Special parts of the platform, e.g., the living quarters and the drilling modules, may be awarded as combined engineering and construction contracts, which means that the construction company will perform the necessary detail engineering.

Construction

In this phase, the greater part of the work will be performed by selected suppliers and construction contractors. A considerable number of people will now participate in the construction and erection of the final product, according to the engineering basis which has been developed in the preceding phases.

The operator's own project organization, assisted by various consultants, will have as their main responsibility, control of the many fabrication and construction activities with respect to:

- time/progress,
- economy, and
- quality/safety.

The basis for project control will be according to contractual agreements for fabrication and construction regarding:

- scope of work,
- technical performance of the work,
- time and cost limits, and
- payment conditions, etc.

In addition, special guidelines for the operator's quality assurance and safety management in the phase will be prepared in the form of:

- QA-program and procedures,
- safety program and procedures,
- requirements for safety education and training, and
- requirements for protection of the equipment during the construction period.

Project control itself may take place at three levels, which are briefly described in the following:

- Overall project control which consists of following up progress and costs for the whole project to be able to keep the entire activity within stipulated time and cost limits. It will normally be performed by the operator's own project team.
- Contracts administration is detailed follow-up of each contract or delivery to ensure completion according to plan. This is also performed by operator's representatives, usually in permanent organizations at major construction sites, and by routine visits to minor fabricators/suppliers.
- Inspections may vary from simple verification of quantity, weight, and dimensional control to investigation and certification of welds, etc. This may be performed by the operator's own project team and/or an independent third party with special competence in this field.

Commissioning and Start-up

The purpose of the last of the project phases is to ensure that all parts of the completed installation function as required and are ready for normal operation.

This is done by activating all equipment and systems singly or together according to established procedures, test their function, and if necessary, make adjustments or corrections.

For practical reasons it may be convenient to perform some of these tests while the installation is still near a land-based site. The final commissioning and start-up will of course be performed after the installation is towed out and placed in its correct position in the field. The operator's acceptance and takeover of the installation takes place when the above is completed with a satisfactory result.

As a part of the total safety work of the project, an evaluation of the commissioning work itself is performed early in this phase with the aim of revealing possible risk factors for personnel and equipment, and taking the necessary precautions.

Potential Influence on Safety in the Various Phases

From the above, it is clear that the design of the platform will develop gradually, assuming increasingly fixed forms as the work with studies and engineering proceeds. It is thereby clear that the possibility of building safety into the product is greatest in the early stages of the project, especially in feasibility and concept study phases. Here, the freedom of choice of technical solutions is great regarding the type and position of equipment, fire and explosion barriers, safety systems, etc.

Several decisions and choices with safety-related consequences are, as stated above, made in the early project phases. The major premises for later design and safety analysis and evaluations are thereby to a large extent frozen. It is therefore important, in the early phases, to have access to tools and aids which enable as good an assessment as possible to be made of the safety-related consequences of the decisions to be made, thus avoiding major design changes at a later stage and resulting delay and possible cost escalation.

RISK ANALYSIS IN OFFSHORE DEVELOPMENT PROJECTS

(Extracts from the project report with kind permission of SINTEF.)

The use of risk analysis to support safety management should be consistent and continuous. The consistency that should be achieved, is the iterative process illustrated in figure 5.

From the description of the various phases of an offshore development project, it can be seen that there are ten important safety studies to be performed. These studies are all to be found in the first four phases. Ten studies may seem a large number, but one must notice that one study is often only a more detailed version of a study performed in the previous phase. Figure 6 gives an overview of the various safety studies, the phase where it should be performed and the interrelation between the various studies.

A short discussion of each study is given in the following.

Phase 1. Feasibility Study

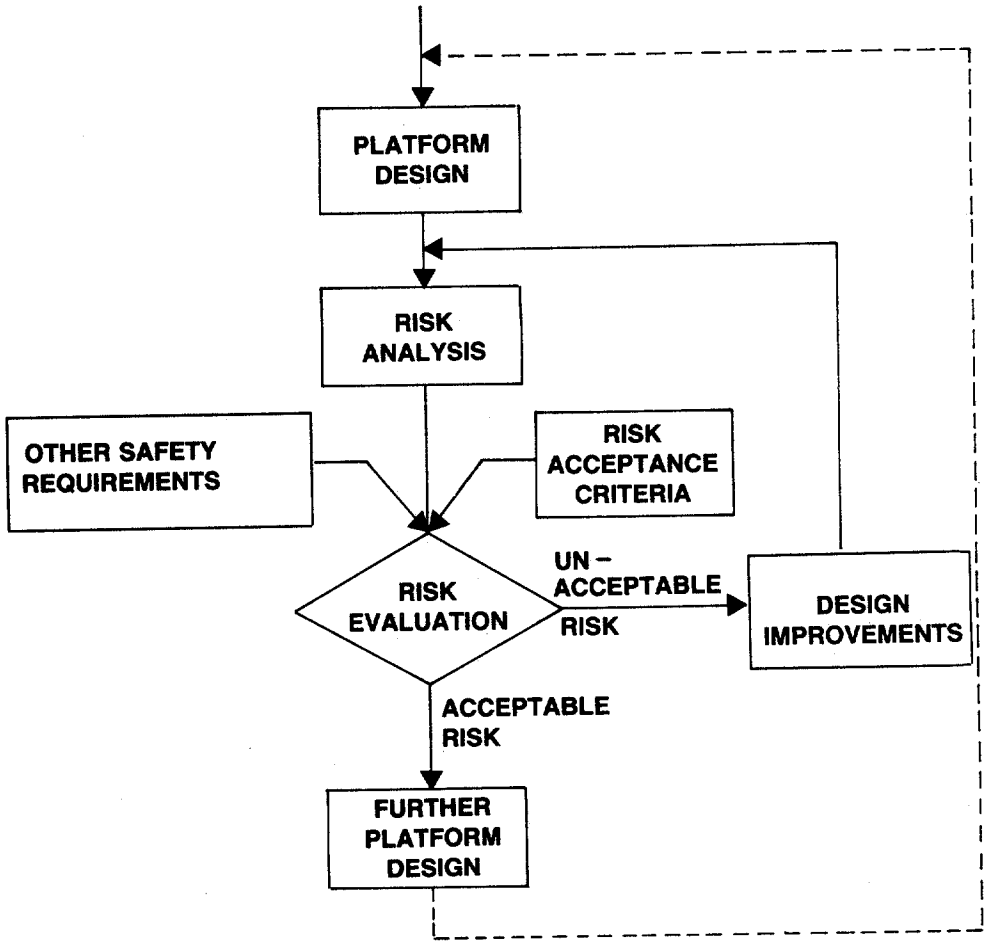
1. Risk estimation of various field concepts.

   Used as one of the criteria for selecting field development concept. The study is of a comparative nature, and mainly based on experience from previous installations or studies made of similar concepts.

Phase 2. Concept Study

1. Risk estimation of various installation concepts.

   The study is of a similar nature as the previous one. It should give recommendations regarding selection of platform type and combinations,



THE ITERATIVE PROCESS

Figure 5

PHASE	ANALYSIS NR.	TITLE	TYPE OF ANALYSIS				
			COURS RISK ESTIMATION	CONCEPT EVALUATION	HAZARD ANALYSIS	OVERALL RISK ANALYSIS	RISK ANALYSIS OF PLATFORM CONST.
FEASIBILITY STUDY	1	RISK EVALUATION... OF FIELD CONCEPT	X				
CONCEPT PHASE	2	RISK EVALUATION OF INSTALLATION CONCEPT	X				
	3	PRELIMINARY PROCESS AND LAYOUT STUDY		X			
	4	CONCEPT SAFETY EVALUATION		X			
PRE-ENGINEERING	5	HAZARD ANALYSIS OF PROCESS AND UTILITY SYSTEMS			X		
	6	OVERALL RISK ANALYSIS				X	
DETAIL ENGINEERING	7	DETAILED HAZARD ANALYSIS' OF PROCESS AND UTILITY SYSTEMS			X		
	8	AVAILABILITY ANALYSIS OF SAFETY SYSTEMS				X	
	9	UPDATE OVERALL RISK ANALYSIS				X	
	10	RISK ANALYSIS OF PLATFORM CONSTRUCTION WORK					X

Figure 6

e.g., PDQ, PQ + D, P + D + Q, ... The study is based on more detailed information than the field concept risk estimation. In addition to giving recommendations with respect to installation selection, the study should evaluate the acceptability of the installation relative to authority and company internal criteria given.

3. Preliminary process and layout study.

   The study should be performed during the concept design of each platform, evaluating various designs and recommending layout modifications.

4. Concept safety evaluation.

   A study of the "finalized" platform concept, verifying that the concept will comply with authority safety criteria given. A principle of analysis is recommended by the NPD, but methods to use are for the operator to decide.

Phase 3. Preengineering

5. Hazard analysis of process and utility systems.

   The study shall give input to the design of process and utility systems. Typical type of analysis is the HAZOP (Hazard and Operability Analysis). The study is based on preliminary P&IDs and should be performed before the design is finalized.

6. Overall risk analysis.

   As a basis for final design of the platform, a total safety evaluation should be performed. The analysis will differ from the concept safety evaluation in several ways, e.g., residual risk included, the installation phase is included, the study is based on more detailed information and will therefore be more extensive in nature.

Phase 4. Detail Engineering

7. Detailed hazard analysis of process and utility systems.

   This hazard analysis is a more detailed version of the previous hazard analysis. It differs from the previous by being more detailed and acting more as a safety audit of nearly finalized P&IDs.

8. Availability studies of safety systems.

   As a basis for deciding whether the specified reliability features of safety systems have been achieved, detailed studies of safety systems are performed.

9. Updated overall risk analysis.

   This updated version of the overall risk analysis will incorporate all design changes made during later preengineering and early detail engineering. The results will, however, not be easily incorporated in the platform design due to that most of the design is finished.

10. Risk analysis of construction work.

    The object to be analyzed in this study is not the platform during operation, but during its construction. The study will focus on accidents during construction work of the various platform elements, hook-up, tow-out, and offshore construction work.

REFERENCES

1. Regulations relating to safe practice, etc., in exploration and drilling submarine petroleum resources. Issued by Royal Decree on 3 October 1975.

2. Regulations relating to safe practice for production, etc., of submarine petroleum resources. Issued by Royal Decree of 9 July 1976.

3. Regulations relating to worker protection and working environment, etc., in connection with exploration for and exploitation of submarine petroleum resources. Issued by Royal Decree of 1 June 1979.

4. Guidelines for safety evaluation of platform conceptual design. Issued by the Norwegian Petroleum Directorate, 1 September 1981.

5. M. Ognedal, The Norwegian Petroleum Directorate, "The Norwegian Safety Plan." (Lecture notes.)

6. M. Ognedal, The Norwegian Petroleum Directorate, "Future Trends in Influence and Control - A Government View." (EPC Conference 1982.)

7. SINTEF Report STF 18 A83503, "Risk Analysis in Offshore Development Projects."

8. Bjarne Hope and Per A. Johannesen, "Safety Management in Offshore Development Projects." (Tanum-Norli 1983.)

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Retningslinjer for rettighetshavers internkontroll

Guidelines for the licensees internal control

(Unofficial translation)

OLJEDIREKTORATET

NORWEGIAN PETROLEUM DIRECTORATE

1981

018

ISBN 82 – 7257 – 065 – 3

These guidelines for the licensees internal control are issued by the Norwegian Petroleum Directorate 15 May 1981. They replace the previous guidelines for the licensees internal control issued 7 June 1979.

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1. PREFACE

The purpose of these guidelines is to clarify one of the main principles of safety control of petroleum activities on the Continental Shelf. The guidelines deal with important aspects of the internal control task and with the structure of the licensees organization to handle this task.

The below mentioned act states that the licensee shall establish and maintain an internal control system which ensures that work is planned, organized and performed in accordance with the provisions stipulated in or by virtue of the act.

THE FOLLOWING REFERENCE IS GIVEN TO LAWS AND REGULATIONS:

- Act relating to worker protection and working environment § 14 part 1. (ref § 4 in Royal Decree 1 June 1979 relating to regulations for worker protection and working environment in connection with exploration for and exploitation of submarine petroleum resources).
- Regulations relating to safe practice for the production etc. the Royal Decree of 9 July 1976 § 4.
- Regulations relating to safe practice etc in Exploration and drilling for submarine Petroleum Resources. the Roayl Decree of October 3. 1975. § 3.

The internal control duty determines among other things that the licensee establishes a control. and documentation system which shall ensure that the requirements are met.
The authorities supervision does not reduce this responsibility.

Practical interpretation to the text in these guidelines are given in italics.

2. DEFINITIONS

For the purpose of these guidelines. the following means:

Operations:
Start-up. commencement of production drilling. production or exploitation. including the transportation of petroleum on such installations where these guidelines are applicable. and also repair and maintenance of such installations.

Internal control:
All systematic actions that are necessary to ensure that the activity is planned. organized. executed and maintained according to requirements in and pursuent to laws and regulations.

It is important to notice that this definition includes the quality term. (Conformance with specified requirement). This means that the internal control normally will be taken care of by a total quality assurance system that shall ensure conformance with the company's own requirements. The requirements from the authoroties to the scope of an internal control system might thus be regarded as minimum requirements to a toal quality assurance system in the company.

Safety includes here:
- *Securing of human life and health*
- *Protection of environment*
- *Securing of material values*

Quality:
A product or a service's ability to fulfil specified requirements.

Quality control:
That part of the quality assurance which through measurements. tests or inspection ascertain if the product or service is in accordance with established quality requirements.

Quality assurance:
All systematic actions that are necessary to ensure that quality is planned. obtained and maintained.

Licensee:
A company. foundation or group that holds a petroleum exploration and production licence. A licensee is also any company. foundation or group that holds a permit from the Ministry to locate and operate installations associated with the production and/or exploitation of petroleum pursuant to the legislation in force at any time.

Verification:
Confirmation that an activity. a product or a service is in accordance with specified requirement

System audit:
Planned and systematic review of the company's internal control systems to ensure that these are followed and maintained as specified.

3. APPLICATION

These guidelines apply to the planning design. building. installation and operation of production installations. pipeline systems and shipment installations that are located in a fixed position on or above the seabed or its substrata. in inner coastal Norwegian waters. Norwegian territorial waters. and the part of the Continental Shelf which is subject to Norwegian sovereignty.
These guidelines also apply in areas outside the Norwegian part of the Continental Shelf if such application follows from specific agreement with a foreign state or from international law. The guidelines apply also to the exploration phase of the activities.

4. THE SCOPE OF THE INTERNAL CONTROL RESPONSIBILITY

Internal control includes control and systematic actions. to ensure that exploration drilling. planning. design building. installation and operation take place in a secure way persuant to legislation in force.
The internal control activity is expected to be summarized in a general description which gives referance to more detailed descriptions for the different parts of the organization and different phases of the activities.

If one company is operating more than one field project. the description is expected to cover the company in general with referance to separate descriptions for each project.

The description of the internal control activities shall be binding for the company internally and the authorities externally. The document should highlight the licensees own safety aims.
The document must ensure distribution of possible new revisions.

The internal control shall cover all parts of the organization and all phases of an activity.

This shall inter alia ensure:

- that comptetent persons are used during planning, construction, building, installation and operation
- that worker protection and health personnel shall be able to perform their work according to the intentions of the law
- that all employees and contractor personnel are given necessary training
- that a total safety evaluation is performed at final concept choice
- that an analysis of the construction is performed
- that systems are established for the administration of documents in all phases of a project
- that purchasing documents, specifications etc. contain sufficient quality assurance requirements
- that control of responsibility and communicationlines (interface control) are ensured
- that the suppliers quality assurance is assessed, accepted, audited and verified
- that it can be documentet (by test reports, certificates etc) that the supply has an acceptable quality
- that satisfactory operating programmes (for example programme for drilling, start-up, production and programmes for simultaneously activities, inspection and testing, maintenance etc) are made and followed
- that temporary equipment may be installed and operated in a secure way and persuant to established requirements
- that quality control during the operation functions effectively
- that corrective actions take place when the quality control indicates deviation from established quality requirements
- that specifications for repair are established and that the specificaions give sufficient support for — and sufficient requirements to — the execution
- that modification for repair the orginally specified safety level
- that procedures are performed in such a way that the safety is taken care of, even if the production installation must be operated in a not predetermined way
- that the safety of the installation also is ensured throughout work conflicts and irregular shut down of production
- that necessary actions take place and involved authorities are informed if abnormal incidents or accidents should occure
- that information and documentation are presented on time for the authorities in accordance with laws, regulations and guidelines

These examples are not a comprehensive list of what the licensee's internal controll shall contain, but highlights some areas that should be given specal attention.

It is of importance that the licensee does evaluate which areas that are covered through normal internal routines and also areas where special efforts are required. It must also be possible to continously update the internal control system

5. ADMINISTRATION OF THE INTERNAL CONTROL

The licensees organization shall be structured in such a way that it is possible to observe the provisions stipulated in or by viture of the legislation in force.

To ensure the intended function of the internal control, the organization plans shall include and/or describe the function and the position of personnel that shall supervise internal control and their duties and responsibilities in that connection.

General responsibility and supervision of the internal control is expected to be delegated to a special unit in the licensees organization. This unit must have the necessary organizational freedom to execute supervision with all relevant control systems and to perform system audit.

Necessary organizational freedom will normally mean that this function should be excluded from operational responsibility and should have the possibility to report to a higher organizational level than the ones this unit supervises.

It is emphasized that this responsibility not shall be in conflict with the free and independent position that worker protection and health personnel shall have according to the law. The internal control system shall ensure the integrity of these functions also with respect to organizational freedom.

It must, however, be clearly understood that it is the personnel performing the work that shall ensure the execution of their duties in accordance wit existing requirements.

The licensee must specify the requirements to independency in the verification on different sublevels in the internal control system.
This will depend on the complexity and kind of the different activities and availability of internal resources in the licensee's organization.

The general description of the internal control shall be presented to the Norwegian Petroleum Directorate. Detailed descriptions shall be submitted at an agreed time.

6. REFERENCE DOCUMENTS

As quality assurance is regarded as a key element in internal control the following documents could be used as a general guidance and also guidance within different areas in a control system.

ANSI Z-1 15.1979 Generic guidelines for quality systems.

ANSI N18.7.1976 Administrative controls and quality assurance for the operational phase of nuclear power plants.

NS 5801. 5802. 5803 Requirements for the contractors quality assurance with included reference documents

BS-5750. 1979 Quality systems Part 1 Specification for design manufacture and installation

Retningslinjer for sikkerhetsmessig vurdering av plattformkonsepter

Guidelines for Safety Evaluation of Platform Conseptual Design

(Unofficial translation)

OLJEDIREKTORATET

NORWEGIAN PETROLEUM DIRECTORATE

1981

022

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These guidelines for safety evaluation of platform conceptual design are issued by the Norwegian Petroleum Directorate 1 September 1981. The purpose of the guidelines appears from section 2.

(Unofficial translation).

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1. DEFINITIONS

- Platform conceptual design — a general description of the platform, such as:
  - function and operation
  - relative location of the various primary and service facilities
  - escape routes, shelter areas and evacuation systems
  - primary load-bearing structures
  - the most important active and passive measures to reduce the probability of occurence and the consequences of accidents
- Accident — an unwanted incident or condition which is not assumed to occur during normal operation, and which can cause significant damage unless it is taken into consideration during design.
- Accidental event — an accident in combination with other conditions (e.g.: weather conditions) which may affect the accidental effect.
- Design accidental event — accidental event which is the basis for the design evaluation to satisfy the acceptance criteria outlined in chapter 5.
- Design accidental effect — effect of the design accidental event expressed in terms of heat flux, impact force and energy, acceleration, etc which is the basis for the safety evaluations.
- Shelter area — area on or outside the platform where the crew will remain safe during an accidental event.
- Active protection — operational actions and mechanical equipment which are brought into operation when an accident is threatening or after the accident has occured, in order to limit the probability of the accident or the effects thereof. Some examples of this are safety valves, shut down systems, water drenching systems, working procedures, drills for coping with accidents, etc.
- Passive protection — protection against damage, by means of distance, location, strength and durability of structural elements.

2. PURPOSE AND APPLICATION

2.1 Purpose

2.1.1 The purpose of this document is to give guidance for execution of safety evaluations of installations or groups of installations, as required by the Norwegian Petroleum Directorate to be included in the Main Plan (see section 2.2.1).

2.1.2 The document gives guidance with respect to:

- extent of documentation
- method for performing the analysis
- criteria for acceptable safety.

2.1.3 The intention of the guidelines is to express the Norwegian Petroleum Directorate's general attitude to the problem area and to indicate how the safety aspects can be handled at an early stage of design.
The guidelines should not preclude the use of alternative methods for the safety evaluations.

2.2 Approval procedure

2.2.1 Approval procedures given by the Norwegian Petroleum Directorate are summarized in «Procedures for official approval of production facilities, pipeline systems and shipment facilities on the Norwegian Continental Shelf».

2.2.2 The approval procedures assumes that the licensee, after receiving the necessary permits of Field Development from the Department of Oil and Energy, will present a general development plan, (Main Plan) to the Norwegian Petroleum Directorate.

2.2.3 A safety evaluation of the platform concept should be contained in the general development plan. As soon as possible after receiving approval of the Field Development Plan, the licensee should ascertain to what extent the guidelines are applicable.

2.3 Application

2.3.1 These guidelines should only be used for safety evaluations and analysis of the platform as completed in the operation phase. The operation phase is here defined as the stage where the Norwegian Petroleum Directorate have approved the platform for drilling, production or use of the living quarter. Installations which are normally unmanned and with minor pollution potential will not normally be evaluated according to these guidelines.

2.3.2 It is assumed that the design, construction, operation and maintenance of the platform will meet all prevailing regulations.

3. DOCUMENTATION

As a basis for the safety evaluation the licensee should submit the following information:

- description of the platform environment
- description of the platform function and operation
- Layout drawings showing the arrangement and location of the most important functions. Special attention should be paid to the location of activities and equipment with significant damage potential, in addition to living quarters, escape ways, shelter areas and evacuation systems.
- main load-carrying structural systems

- description of the important measures incorporated to reduce the probability of accidents
- description of measures incorporated to reduce the consequences of accidents
- description of evacuation systems
- description of safety related new technology and innovations planned to be used
- specified accidental events will corresponding design accidental effects on parts of the platform described later in these guidelines
- an analysis showing that the concequences of a design accidental effect comply with the acceptance criteria outlined in this document.

4. SAFETY EVALUATION METHODS

4.1 Principles of the evaluation

4.1.1 Safety evaluations of the type described in this document, should be carried out at a superior system level. It is presupposed that the licensee has chosen a concept solution favourable to himself, which satisfies general safety criteria. The intention is only to verify at an early stage that the concept chosen by the licensee will result in an acceptable installation and that no major changes during the design and construction phases will be necessary because of safety requirements.
The aim of the safety evaluation is to establish acceptable safety in compliance with given criteria. The intention is not to include calculation of residual risk (i.e. probability and consequences of accidents which still may occur).

4.1.2 Safety evaluations as outlined in this document should verify a sufficiently low probability of loss of human life, high material damage and unacceptable environmental pollution as a consequense of the accident. An installation, when evaluated in the concept phase, may be deemed adequately safe if it meets the acceptance criteria given in these guidelines.

4.1.3 The following types of accidents should be evaluated where relevant:
- blow-out
- fire
- explosion and similar incidents
- falling objects
- ship and helicopter collisions
- eartquakes
- other possible relevant types of accidents
- extreme weather conditions
- relevant combinations of these accidents

4.1.4 The accidents mentioned in section 4.1.3 may follow from primary failures, for example blow-outs, fracture in riser pipes etc. These primary failures do not require individual consideration as long as the resulting effect is accounted for as an accident under section 4.1.3.

4.1.5 The analysis presupposes that a platform concept has been decided by the licensee. On this basis, a set of design accidental events with corresponding effects should be specified, based on the content of section 4.2. Any reduction in accidental effect, or in the probability thereof, due to active protective measures, may be considered.

4.1.6 The licensee shall ensure that the platform will satisfy acceptance criteria given in chapter 5 when exposed to the design accidental effect. Any passive protective measures should be considered. Strength calculations may comply with the Norwegian Petroleum Directorate's «Regulations for the structural design of fixed structures on the Norwegian Continental Shelf».

4.2 Design accidental events

4.2.1 For the sections of the platform that are relevant to the acceptance criteria outlined in chapter 5, the licensee should specify a set of design accidental events. In principle, the design accidental events shall be the most unfavourable situations relative to the acceptance criteria.

4.2.2 In practial terms, it may be considered necessary to exclude the most improbable accidental events from the analysis. However, the total probability of occurence of each type of excluded situation (see 4.1.3) should not by best available estimate, exceed 10^{-4} per year for any of the main functions specified in 5.2, 5.5 and 5.6.
This number is meant to indicate the magnitude of aim for, as detailed calculations of probabilities in many cases will be impossible due to lack of relevant data.

4.2.3 Based on the design accidental events the licensee should specify a set of design accidental effects for sections of the platform relevant to acceptance criteria outlined on chapter 5. Design accidental effects will normally be expressed in the following terms:
- heat flux and duration
- impact pressure, impulse or energy
- acceleration

4.2.4 When assessing the potential damage, particular attention should be paid to the reliability of equipment, any active protection measures and monitoring systems.

4.2.5 The Norwegian Petroleum Directorate do not require a detailed analysis documentation for specified design accidental events and effects. An engineering approach based on evaluation of actual damage potential, experience, possible historical data, and reliability data for the systems will normally be sufficient. However, if the Norwegian Petroleum Directorate consider the specified accidental effects to be unreasonable, further clarification and justification of the values may be required in the detailed design phase.

5. ACCEPTANCE CRITERIA

5.1 The platform design must be such that a design accidental event does not impose a danger to personell outside the immediate vicinity of the accident.

5.2 Section 5.1 can be considered satisfied by complying with the following three criteria:

a) at least one escape way from central positions which may be subjected to an accident, shall normally be intact for at least one hour during a design accidental event
b) shelter areas shall be intact during a calculated accidental event until safe evacuation is possible
c) depending on the platform type, function and location, when exposed to the design accidental event, the main support structure must maintain its load carrying capacity for a specified time

5.3 If external protection measures (e.g. fire fighting ships etc.) are necessary to satisfy section 5.2, then these shall be assumed to be ineffective if not documented otherwise, until 4 hours after the start of the design accidental event.

5.4 Any important safety-related control functions are assumed to be located in a shelter area.

5.5 Areas where the accidental event could continue for a considerable period of time, (for example, wellhead area), should be located to ensure that continuous effective measures can be carried out during the calculated event.

5.6 In case of a «blow-out» of wellhead(s) the platform shall be designed so that identification of which wellhead(s) are out of control is possible. This should be possible before as well as after evacuation of the platform.

PHILLIPS PETROLEUM 66

Quality Assurance Manual

Rev. no.: 2

Rev. date: May 1983

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EKOFISK FIELD WATERFLOOD PROJECT

CONCEPT SAFETY EVALUATION REPORT

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II PROCESS ACCIDENTS

III STRUCTURAL FAILURES

IV IMPAIRMENT OF PLATFORM MAIN FUNCTIONS

V CONSEQUENCES MODELLING METHODS

BJARNE HOPE
PER A. JOHANNESSEN
SAFETY MANAGEMENT IN OFFSHORE DEVELOPMENT PROJECTS
TANUM · NORLI

SAFETY MANAGEMENT IN OFFSHORE DEVELOPMENT PROJECTS

DESCRIPTION OF A PROJECT
MODEL FOR SAFETY MANAGEMENT
BY
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PER A. JOHANNESSEN

TANUM · NORLI

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3. Survey of the project results

The main chapters in the final report are:

1. Introduction.
   Showing how the project was carried out and what the results are.
2. Main structure of a field development project.
   The phases of the project, specifying milestones, participants, tasks and documents for each phase are described. Special emphasis is put on safety activities and safety documents.
3. Safety management in projects.
   Survey of safety management. What and how, describing purpose, content, role in the total project management, relation to quality assurance, etc.
4. Safety objectives and safety requirements.
   The establishment of safety objectives, acceptance criteria, design requirements and design documents is described. The connection between them and the influence on them of regulations and internal company requirements is discussed together with the role of the safety analyses in this process.
5. Safety program.
   Description of purpose, content and use of the safety program in practical safety management. It is a tool in systematic planning and the evalutation of safety of an installation.
6. Phase models
   These are the main descriptions of the project model, showing activities, documents, decisions and which participants are active in each phase. The safety activities and control entities are indicated in these descriptions.
   The descriptions encompass:
   — a survey of all project phases and the relations between them
   — description of each phase
7. Safety analyses
   A collective survey of 10 important analyses which may be made in a project.
8. Control entities
   The documents on which it is important to concentrate management are here described.
9. Organization of safety activities
   This includes
10. Using the model
    A discussion is presented with proposals as to how the project model for safety management can be used
    — in companies
    — in projects
    — in education

SINTEF REPORT

THE FOUNDATION OF SCIENTIFIC AND INDUSTRIAL RESEARCH AT THE NORWEGIAN INSTITUTE OF TECHNOLOGY

REPORT NO. STF18 A83503

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TITLE OF REPORT	DATE
RISK ANALYSIS IN OFFSHORE DEVELOPMENT PROJECTS	1983-06-15
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DIVISION/SECTION Safety and Reliability Section	PROJECT NO. 185107

PROJECT CLIENT/SPONSOR	CLIENT'S REF.
Safety Offshore and Statoil	E. Wulff

EXTRACT

The report describes when and how different Risk and Safety Analyses should be performed in order to fill the needs that a Development project has regarding safety information. The report is one of two reports from the project "Safety Management in Offshore Development Projects". The report is the result of a cooperation between several SINTEF divisions and oil and engineering companies in Norway.

3 INDEXING TERMS

NORWEGIAN	ENGLISH
Risikoanalyse	Risk Analysis
Offshore	Offshore
Prosjekter	Development

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Trondheim 1983

AUTHORIZED SIGN.

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SUMMARY COMMENTS ON APPLICATION AND LIMITATIONS OF RISK ANALYSIS IN OFFSHORE EXPLORATION AND PRODUCTION

by

Struan Simpson, E&P Forum

Early in 1981 the Oil Industry International Exploration and Production Forum (E&P Forum) initiated a program to study the relevance of risk analysis in offshore operations. Risk analysis, as defined in the program, refers to the use of formalized techniques such as failure modes and effects analysis, Fault and Event Tree analyses, etc., and may include quantitative estimates of risk probabilities.

The program to date has included a survey of current methodology and typical applications in offshore engineering projects. Data were obtained from 16 major companies and 168 projects were identified. The results of the survey indicated that risk analysis techniques have been used in a wide range of projects and at various levels of manpower commitment. Projects include, for example, structures, drilling, production, and product transportation. Studies were carried out at a variety of stages of project development (feasibility, design, construction, commissioning and operations). The survey also indicated that the purposes for conducting these analyses covered a wide range and extended from assisting the engineering design function to providing safety evaluations for project management and statutory agencies.

The number of projects reported and the published literature clearly indicate that the offshore industry assigns a positive value to risk analysis techniques. It is evident, however, that they are used as supplementary aids to the primary engineering and management processes as distinct from primary design or decision-making tools. It is also evident that risk analysis offers no inherent advantage in hazard identification over conventional practices and reviews, i.e., if the basic engineering design model and considerations do not include identification of a given hazard, then the risk analysis cannot identify it. Risk analyses reported in the survey were supplements to and not replacements for conventional engineering and management practices.

The major supplement provided by risk analysis to conventional practices lies in formalized procedures for hazard and risk identification and in a statistical measure of the risk. Used skillfully, risk analyses can assist in clarifying perceptions of risks and their relative importance. However, the statistical measure, in most cases, must be treated as a subjective one because of the uncertainties in modeling the operation and the difficulty in developing applicable data. A high degree of caution, judgement, and experience should be used in interpreting and applying the statistical results.

The present phase of the E&P Forum program has not substantially addressed the overall impact of risk analysis on exploration and production projects. This measure of the relevance of risk analysis to offshore operations is an important one for future consideration.

OREDA - OFFSHORE RELIABILITY DATA

A EUROPEAN APPROACH TO RELIABILITY DATA COLLECTION OFFSHORE

by

Torkell Gjerstad, Elf Aquitaine Norge A/S
OREDA Steering Committee Chairman

Summary:

Seven oil companies operating out of Norway have joined a project with the objective of publishing a reliability data reference for offshore safety, drilling, and production systems. Experience data are being collected within the participating companies, and the total experience will be presented in a handbook as generic reliability data. The plan is to publish the handbook within 1984.

1. PRE-PROJECT

The idea to the OREDA Project was presented in 1980. At that time The Norwegian Petroleum Directorate was carrying out a study called "collection, storing and processing of data." A number of reliability data bank concepts would be to work out a reliability data handbook. This handbook should be based on the experience and information which already were existing within the operating companies. The concept of putting up a centralized data bank which initially had to be fed with inventory information, and to which the operating companies were to report malfunctions and failures, was thus rejected.

The idea of putting together a handbook was further developed to a pre-project sponsored by the Norwegian Petroleum Directorate and later on by the Safety Offshore Program. A number of case studies were undertaken within operating companies, and it was demonstrated that the quality of maintenance, test and inspection records was satisfactory as a basis for reliability parameter calculations.

2. CONFIDENTIALITY

Extensive efforts were put into designing the project organization in a way which would ensure an acceptable level of confidentiality for the companies which would join the project. A number of operators had by now expressed an interest in OREDA, and did actively contribute to find a satisfactory solution to this problem. The main contract for OREDA was placed with Det norske Veritas, with the responsibility for administration, method development and production of the handbook. Each participating company was given the choice to select themselves the subcontractor responsible for the data collection and processing within the company. Only generic data will be handed over to the main contractor for merging of data from the different participants and eventually input to the handbook. Such a project organization requires a link between the main contractor

and the various participants, in order to be able to trace data inputs back to the source when the need for checking and additional information arises. In the OREDA Project, this link is provided by the Project Steering Committee.

3. COLLABORATION

During 1983 seven operating companies joined OREDA:

- Norsk AGIP A/S
- BP Petroleum Development Ltd., Norway
- Elf Aquitaine Norge A/S
- Norsk Hydro A/S
- A/S Norske Shell
- Statoil, Den norske Stats Oljeselskap A/S
- Total Oil Marine

The OREDA budget is US$ 54.000, paid through equal shares by the participants. The OREDA Project today is an exclusive industry project, with no involvement from the Norwegian Authorities. It is a 2-year project planned to be finished by the end of 1984.

Data are collected from the Norwegian and British sector of the North Sea and from the Adriatic Sea. The OREDA participants benefit from the project in many ways. An extensive amount of experience data are being collected and processed internally within the company. This site specific information, including failure histories of the various systems, will remain within the company. Only anonymous information is being put forward to the main contractor for inclusion in the handbook. Being involved in the project, each participant will have the opportunity to compare their own past experience with that of other operating companies. Finally, the whole offshore industry will gain from the publication of this handbook, which we believe will become a standard reference for risk and reliability studies of offshore installations.

4. THE HANDBOOK

The OREDA Project covers a wide range of components and systems. The handbook is expected to present reliability data on approximately 150 different items. The following main areas will be included:

1. Safety Systems

1.1 Gas and Fire Protection
1.2 Process Sensors
1.3 Firefighting Systems
1.4 Emergency Shut-down Systems
1.5 Pressure Relieving Systems
1.6 General Alarm and PA Systems
1.7 Evacuation Systems

2. Process Systems

2.1 Vessels
2.2 Valves
2.3 Pumps
2.4 Heat Exchangers
2.5 Compressors
2.6 Pig Launching/Receiving Systems

3. Electrical Systems

3.1 Power Generation
3.2 Power Conditioning
3.3 Power Protection
3.4 Control Instrumentation

4. Utility Systems

4.1 Slop and Drain Systems
4.2 Ventilation and Heating Systems
4.3 Hydraulic PA Supply Systems
4.4 Pneumatic Power Supply Systems

5. Drain Systems

6. Drilling Equipment

6.1 Drawworks
6.2 Hoisting Equipment
6.3 Diverter Systems
6.4 Drilling Riser
6.5 BOP Systems
6.6 Mud Systems

The data will be presented in the handbook in terms of failure rates and on demand failure probabilities, with an associated failure mode distribution. Additional information concerning the operating environment, test interval, etc., will be given with each data sheet. An indication of the variations in the data inputs will also be included. The plan is to publish the OREDA handbook and get as wide circulation of it as possible.

Risk and reliability studies of offshore installations have in the past to a great extent been based on reliability data input from other industries, primarily from the process and nuclear power industry. There is today a growing application of such studies offshore, and the OREDA handbook will give a significant contribution to improving the quality of this work.

Further details on the publishing of the OREDA handbook may be obtained from:

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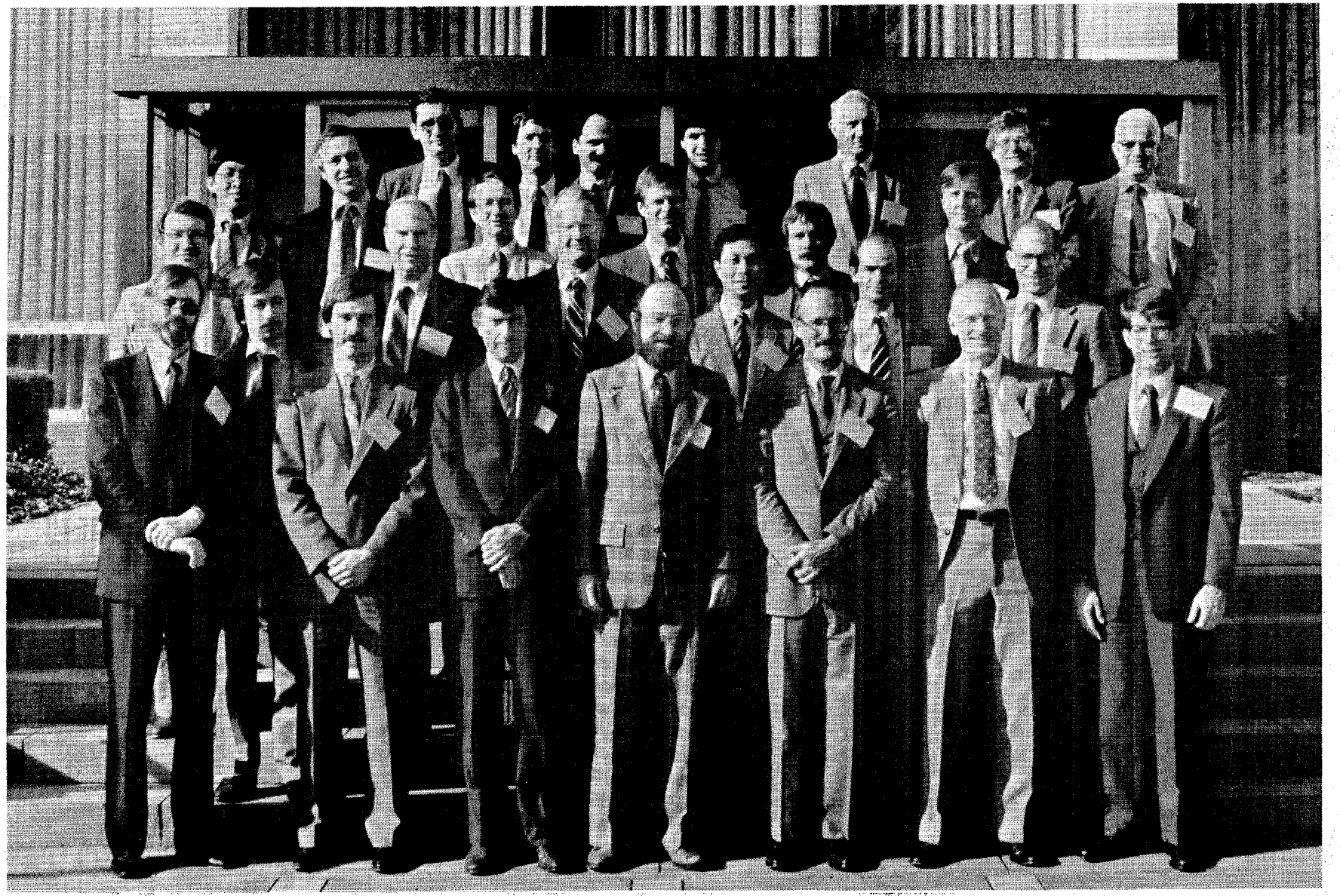
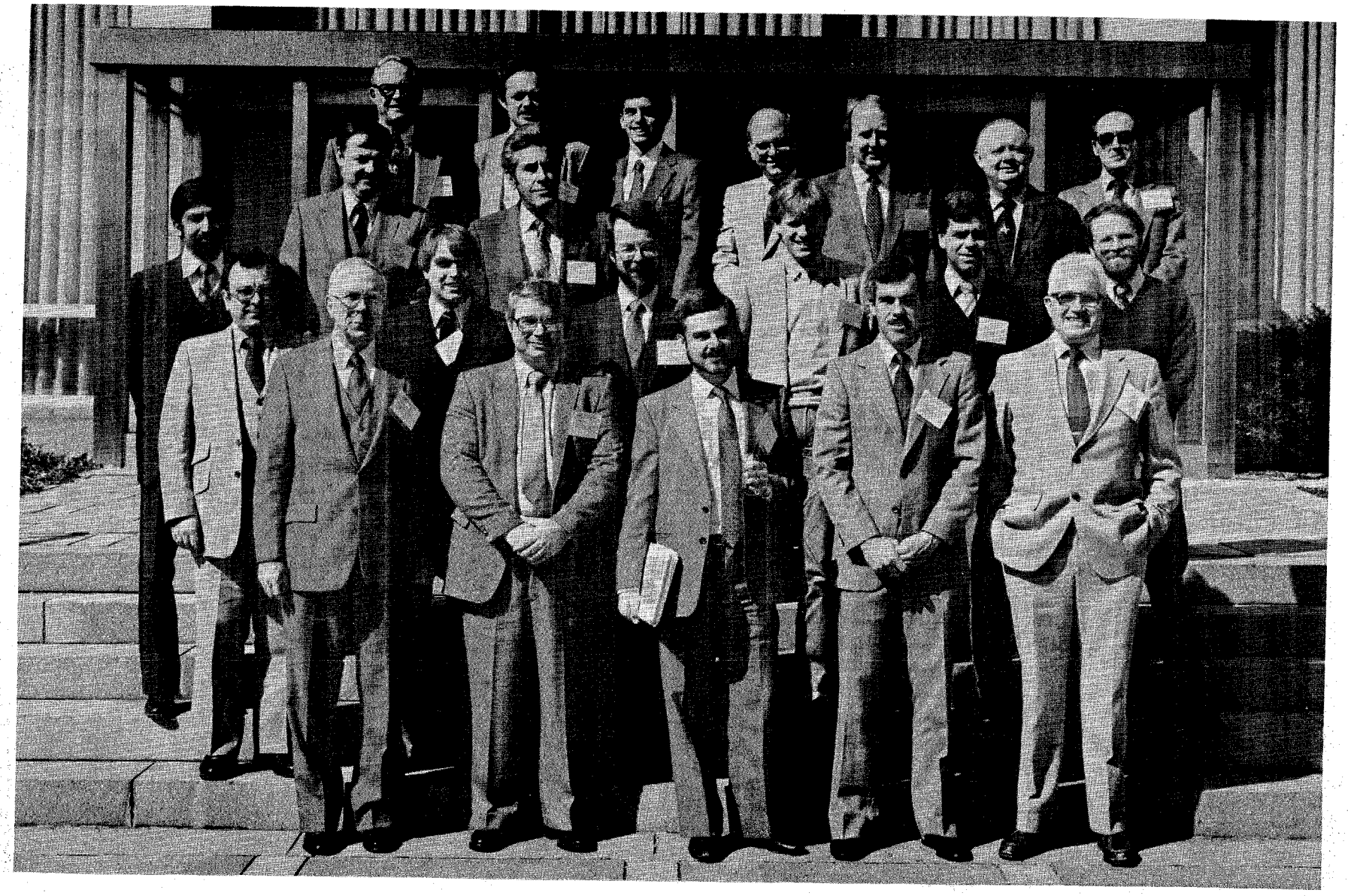


Working Group II



Working Group III

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The proceedings of an International Workshop held at the National Bureau of Standards on March 27 and 28, 1984, are presented. The purpose of the workshop was to examine the application of risk analysis in offshore oil and gas operations. The proceedings include: an executive summary, an introduction, and summary reports and recommendations of four Working Groups: Standards, Codes, and Certification; Concept Evaluation and Design; Operation and Maintenance; and Logistics and Support. Also included are theme presentations on current practice in the United States, Great Britain, and Norway, and on current risk assessment methodologies.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

codes; drilling platforms; gas production; marine engineering; ocean engineering; offshore platforms; oil production; petroleum engineering; probability risk analysis; regulations; shipping; standards.

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