POSITION PAPERS

INTERNATIONAL WORKSHOP
ON THE
APPLICATION OF RISK ANALYSIS
TO
OFFSHORE OIL AND GAS OPERATIONS

NATIONAL BUREAU OF STANDARDS
GAITHERSBURG, MARYLAND
MARCH 26-27, 1984

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UNITED STATES DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

March 5, 1984

MEMORANDUM FOR Participants in the Workshop on the Application of Risk Analysis to Offshore Oil and Gas Operations, March 26-27, 1984

From: Felix Y. Yokel
Emil Simiu

Subject: Position Papers

Attached are the position papers that were submitted by theme speakers and session chairmen.

We would like to urge you to study this material and prepare your comments and questions in advance, since the allotted time for the workshop is short.

We also strongly encourage you to submit written comments which we can incorporate in the workshop proceedings.

Attachment

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Shell Oil Company

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P.O. Box 2099
Houston, Texas 77001

February 27, 1984

Dr. Felix Y. Yokel
B-162 Building Research
National Bureau of Standards
Washington, DC 20234

Dear Dr. Yokel:

Attached is an almost-final draft of my presentation. I will have a few more slides, but the paper will not change appreciably, if at all. Sorry to be late.

Very truly yours,

F. P. Dunn

F. P. Dunn, Manager
Civil Engineering

FPD/ye

Attachment

IAA845806

RELIABILITY ANALYSIS

OVERVIEW OF CURRENT PRACTICE

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 may 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 purposes 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.

IAA844001

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 promulgation 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]

---

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

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; 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 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 certification requirements.

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 equip-ment on the vessels is controlled by USCG certification requirements for Mobile 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).

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

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 blow-outs, 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 life saving appliances;

(4) Requirements to facilitate international travel:

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

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 life saving 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 (slide) 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. <u>Offshore Support and Standby Vessels</u>

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 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 ten 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 achieve. This slide 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. This next slide is a schematic of the procedure. 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 reliability-based format. This has been going on for the last four or five years. A draft of the revised Recommended Practice will be published within two 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 design tasks.

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 modelled 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 calibrated with both small and large scale test results.

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 that consequence under any 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 effectively 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 expectancy 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 blow-out 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 Register (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 No. 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 twenty years to create a guide for others 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 make it.

Reliability analysis has its place, but it will never 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.

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Dr. Felix Y. Yokel
Leader, Geotechnical Engineering Group
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WASHINGTON DC 20234
USA

Stavanger 11.1.84

Dear Dr. Yokel,

./. Enclosed is the written material for my lecture at the workshop on March 26 and 27, 1984.

I am sorry it took so long to produce, but as you can see it is quite bulky. I have decided to enclose a full presentation to the background of the Norwegian legislation which influence Offshore Risk Management over here since I feel it is important that this is known by the participants at the Workshop.

When it comes to my actual oral presentation, I shall leave out most of the detail and discuss the important aspects of our

- Internal Control System
- Requirements for Concept Evaluation og Offshore Development Projects
- Safety Management Model for Offshore Development Projects.

Since Dr. Slater shall talk about Risk Assessment Methodologies, you may consider whether I shall give my presentation before him. I expect Dr. Slater to give examples from his work on development projects in Norway under the framework of Norwegian Offshore legislation. The presentations may fit better together if I start with the overview and Dr. Slater takes care of the details. However, I leave this for you to decide.

./.

I have spoken to some of the Norwegian candidates on your list of participants. These have not had an invitation to the Workshop and we wonder if these have been lost in the post?

As mentioned in my telex last week, I would like to bring my Principal Engineer, Mr. Olaf Thuestad to the Workshop and the following meeting at MMS. His topic in the group discussions will be "Concept evaluation and Design". All his expenses will of course be covered by ourselves.

I look forward to seeing you at the Workshop.

Yours sincerely,

Øystein Berg
Deputy Director

Enclosure

MANAGEMENT OF OFFSHORE RISK

A presentation of some of the safety control elements of the petroleum activities as practized on 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 framework concerning safety regulation and control. Thereafter I shall describe more in detail how the various elements of risk management is 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 Groningen 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 worth while 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 extension of our Continental Shelf?"

In accordance with the 1958 Geneva Convention, a Royal Decree was issued in May 1963 declaring that "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 Rescources. This is a very short law with only 6 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 instituions, 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 bear the date of 3 October 1975. The 75 version was not substantially different from the 67 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 75 Decree has in all 121 Sections. In addition it authorizes the Ministry of Industry (today transferred to the Ministry of Labour 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 -75 Decree has been delagated 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 Flamables

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 -75 Decree. These agencies have on their side issued regulations covering their specific area of control.

Fixed installations, pipelines, etc, were 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 consequenses".

Most of the 123 sections of the -76 Decree are of a rather general nature and great emphasis is put upon a regular flow of information between the licencee 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 Act of 1963 on which the two -75 and -76 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 labour 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 experienced an extensive industrial development. We constantly introduced new chemical substances and materials, new production methods and new ways of organizing the work. This develoment 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 prinsiples of the law of 1977 may be listed in 9 points as follows:

1. The Act shall secure a working environment which give the employees full safety against harmful physical and psycological 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 employer 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 or the Labour 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 the activity offshore is somewhat special compared with the onshore industry. The Ministry of Labour 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 have some provisons that only apply to the Continental Shelf. It is the Norwegian Petroleum Directorate that supervise that these regulations are 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 stages 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 ressources 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 fulfil these intentions, it is necessary to harmonize the detailed regultations issued by the various control agencies and where ever 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 activity 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 operators/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 consentrated 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 concious 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.

Operators 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 according to requirements in and persuant 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 of 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, are 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 programmes (for example programme for drilling, start-up, production and programmes for simultanious 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 specifications gives 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 shut down 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 evalutate 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.

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 for 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 of 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 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 system 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 NPD´s 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 timeconsuming, 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 consious 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 focused because it is expected that the safety of an installation should normally be checked on three levels.

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

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

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

The serviceability and component failure control is normally covered by existing codes and regulations. Procedures and criteria for major accident control is 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 Directorate 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 guideline is 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 licencee 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.

In practical 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 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 of aim for, as detailed calculations of probabilities in many cases will be impossible due to lack of relevant data.

Acceptance critiera.

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:

- 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

- shelter areas shall be intact during a calculated accidental event until safe evacuation is possible

- depending on platform type, function and location, when exposed to the design accidental event, the main support structure must maintain its load carrying capasity 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 structure.

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 firstly has to present to the Ministry of Petroleum and Energy a "Field Development Plan" (Fig. 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 Labour 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 operators safety policy, his management system for internal control and Quality Assurance and the initial safety evaluations undertaken which form the basic for the choice of development concept.

The next approval given by the Authorites will be at approximately the end of the pre-engineering 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, included 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
- 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 the Norwegian Laws and Regulations. For some of the approvals, the Norwegian

Petroleum Directorate specifically ask 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 that 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 thechnical 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.

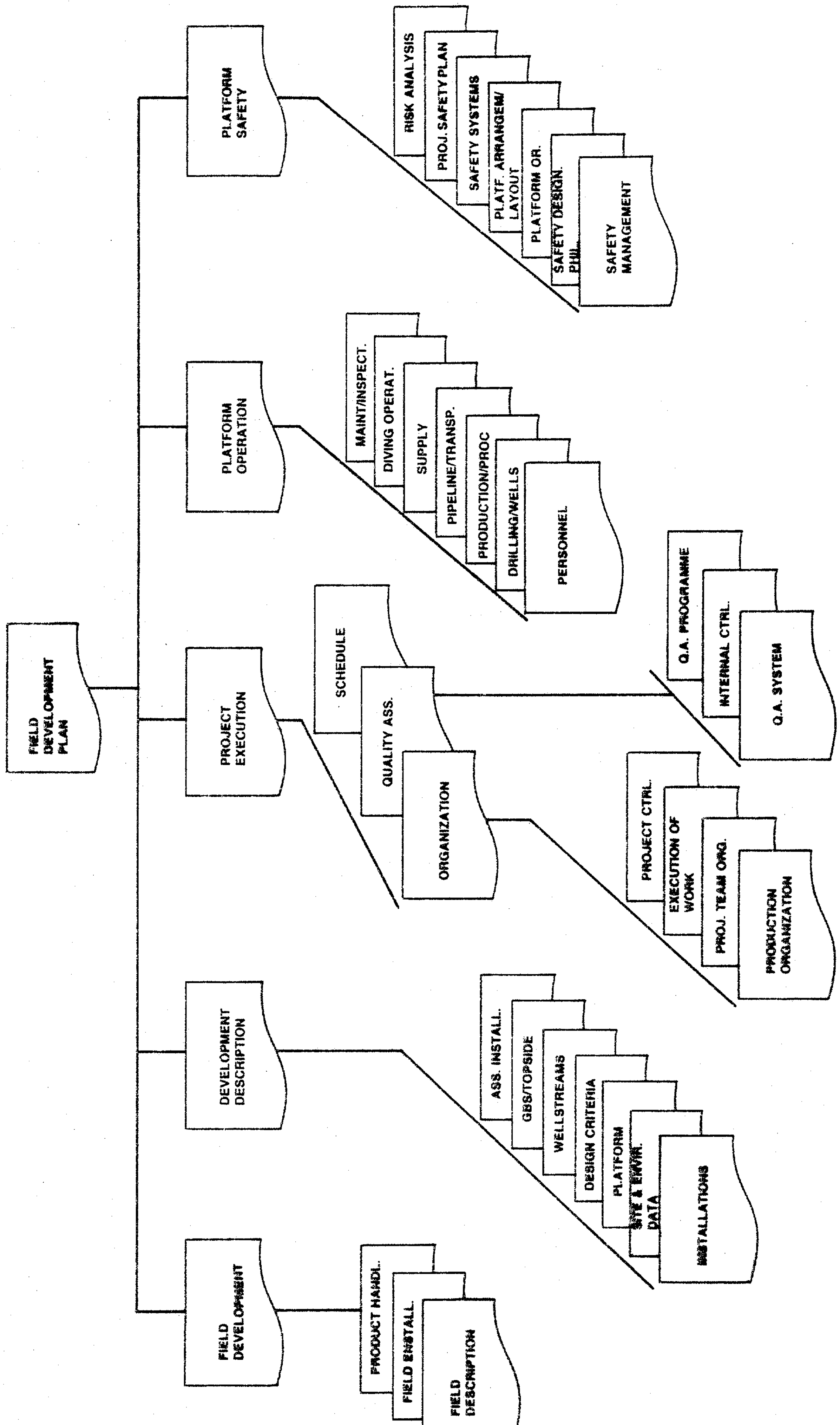
FIELD DEVELOPMENT PLAN
FIELD DEVELOPMENT
PRODUCT HANDL.
FIELD INSTALL.
FIELD DESCRIPTION
DEVELOPMENT DESCRIPTION
ASS. INSTALL.
GBS/TOPSIDE
WELLSTREAMS
DESIGN CRITERIA
PLATFORM
SITE & ENVIR. DATA
INSTALLATIONS
PROJECT EXECUTION
SCHEDULE
QUALITY ASS.
ORGANIZATION
Q.A. PROGRAMME
INTERNAL CTRL.
Q.A. SYSTEM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

FIG. 1

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 programme "Safety Offshore" was therefore initiated in 1978. The programme which 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 programme 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 substantional part of the programme 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:

- "Project Model for Safety Management in Offshore Development Projects"

- "Risk Analysis in Offshore Development Projects"

A Norwegian consultancy company, Bedriftsrådgivning A/S, and the Safetey and Reliablity 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 activities. (The two project reports are available from Bedriftsrådgivning A/S and SINTEF in Norway. See appendix 5 and 6).

PROJECT MODEL FOR SAFETY MANAGEMENT IN OFFSHORE DEVELOPMENT PROJECTS

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

FRAMEWORK FOR SAFETY MANAGEMENT

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

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

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.

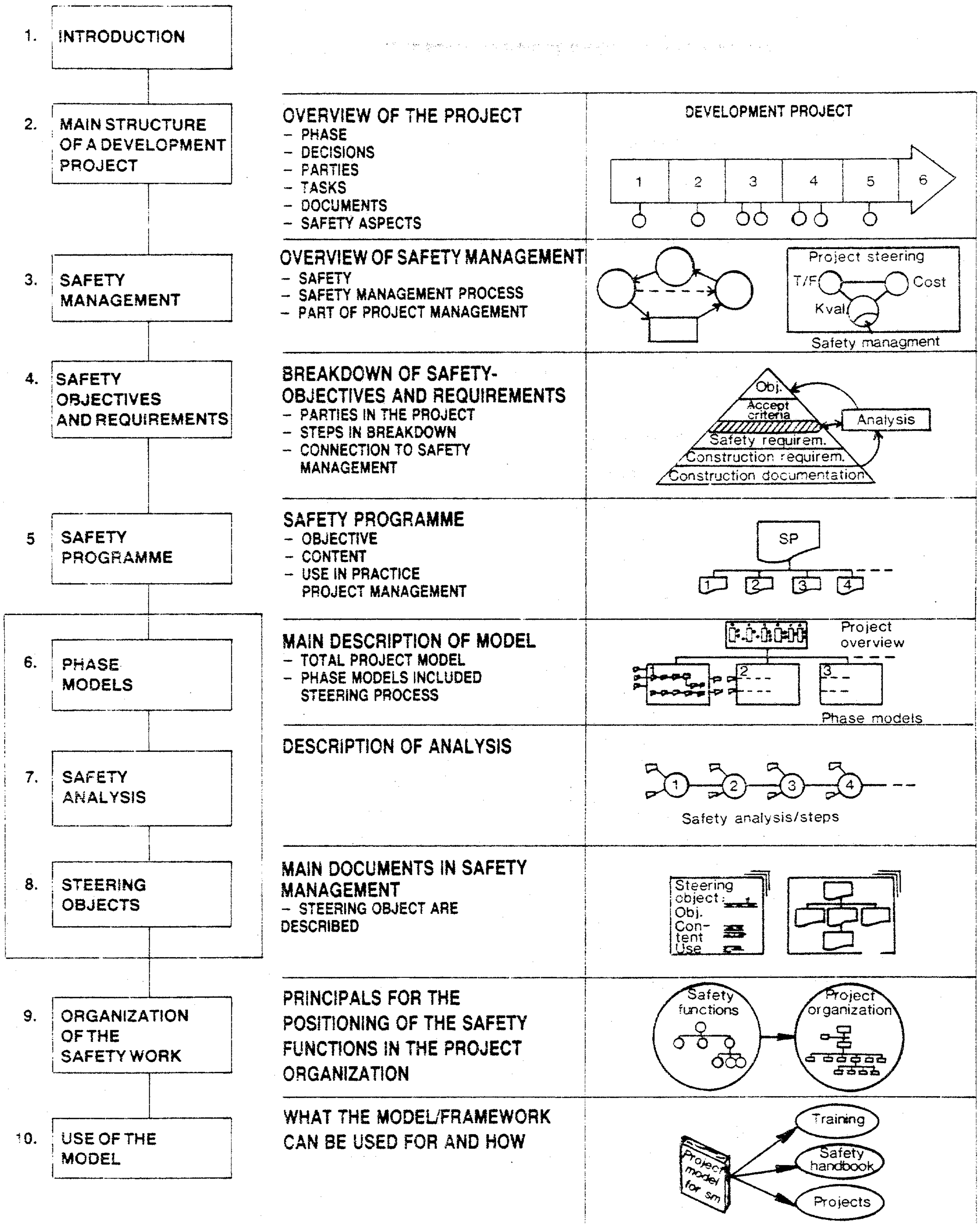
1. INTRODUCTION
2. MAIN STRUCTURE OF A DEVELOPMENT PROJECT
OVERVIEW OF THE PROJECT
– PHASE
– DECISIONS
– PARTIES
– TASKS
– DOCUMENTS
– SAFETY ASPECTS
DEVELOPMENT PROJECT
1
2
3
4
5
6
3. SAFETY MANAGEMENT
OVERVIEW OF SAFETY MANAGEMENT
– SAFETY
– SAFETY MANAGEMENT PROCESS
– PART OF PROJECT MANAGEMENT
Project steering
T/F
Cost
Kval
Safety managment
4. SAFETY OBJECTIVES AND REQUIREMENTS
BREAKDOWN OF SAFETY-OBJECTIVES AND REQUIREMENTS
– PARTIES IN THE PROJECT
– STEPS IN BREAKDOWN
– CONNECTION TO SAFETY MANAGEMENT
Obj.
Accept criteria
Analysis
Safety requirem.
Construction requirem.
Construction documentation
5 SAFETY PROGRAMME
SAFETY PROGRAMME
– OBJECTIVE
– CONTENT
– USE IN PRACTICE PROJECT MANAGEMENT
SP
1
2
3
4
6. PHASE MODELS
MAIN DESCRIPTION OF MODEL
– TOTAL PROJECT MODEL
– PHASE MODELS INCLUDED STEERING PROCESS
Project overview
2
3
Phase models
7. SAFETY ANALYSIS
DESCRIPTION OF ANALYSIS
1
2
3
4
Safety analysis/steps
8. STEERING OBJECTS
MAIN DOCUMENTS IN SAFETY MANAGEMENT
– STEERING OBJECT ARE DESCRIBED
Steering object:
Obj.
Con-tent
Use
9. ORGANIZATION OF THE SAFETY WORK
PRINCIPALS FOR THE POSITIONING OF THE SAFETY FUNCTIONS IN THE PROJECT ORGANIZATION
Safety functions
Project organization
10. USE OF THE MODEL
WHAT THE MODEL/FRAMEWORK CAN BE USED FOR AND HOW
Project model for sm
Training
Safety handbook
Projects

FIG. 2

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 6 separate phases (fig. 3):

1. Feasibility study
2. Concept study
3. Pre-engineering
4. Detail engineering
5. Construction
6. Commissioning & Start-up

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:

- the number of analysis should be limited as far as possible
- analysis should be performed where central decisions are made

This leads to five <u>types</u> of safety analysis:

1. Rough risk analysis
2. Concept safety analysis
3. Hazard analysis
4. Total risk analysis

5. Risk analysis in 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 particularily important:

- Safety program.
  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 decision making.

- 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 continous process running through the whole project. By means of a Safety Program (fig.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 consists of:

- Safety objectives.
  Establishement 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 the 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 fulfil them in design and construction. Organization and contract formulation are essential factors to make this possible.

- Realisation of objectives and requirements.
  Objectives and requirements are realised 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. Continous 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
    - 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.

- Experience.
  Relevant experience and information for the tasks to be carried out must be aquired 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)

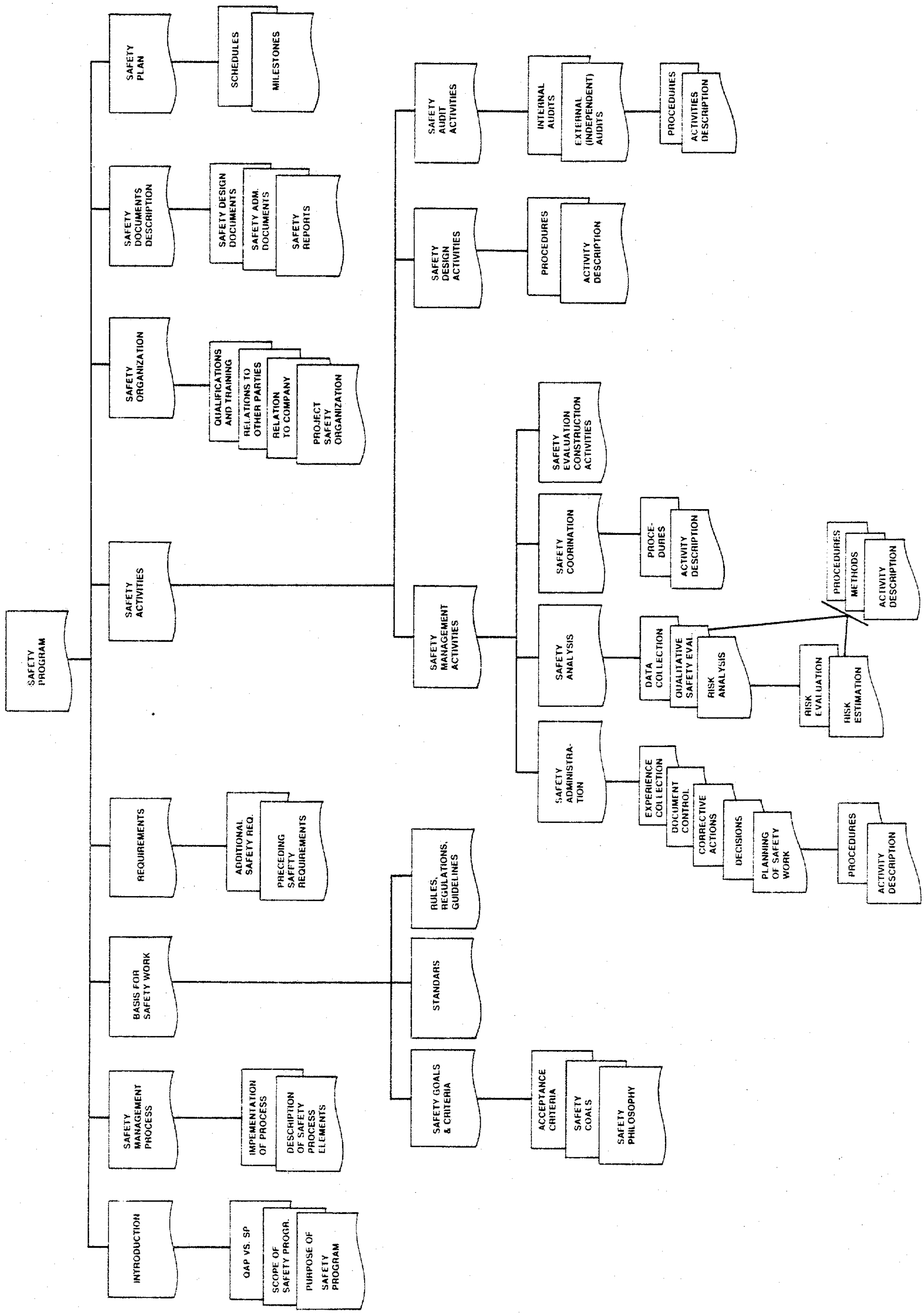
SAFETY PROGRAM
SAFETY PLAN
SCHEDULES
MILESTONES
SAFETY DOCUMENTS DESCRIPTION
SAFETY DESIGN DOCUMENTS
SAFETY ADM. DOCUMENTS
SAFETY REPORTS
SAFETY ORGANIZATION
QUALIFICATIONS AND TRAINING
RELATIONS TO OTHER PARTIES
RELATION TO COMPANY
PROJECT SAFETY ORGANIZATION
SAFETY ACTIVITIES
SAFETY AUDIT ACTIVITIES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

FIG. 3

MAJOR TASKS IN EACH PHASE (FIG. 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 an descripiton 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 extention of the reservoir´s characteristics of water depth, seabed conditions, 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 principially 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. This should comprise a comparison of the various 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 pre-engineering.

Should the result 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 specification of safety requirements for the installation, and performing of certain safety analysis:

- 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.

Pre-engineering

In this phase the engineering of the process system and other main areas and modules of the platform is carried out to a degree of detail 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, or alternatively design and construction contracts. In addition, purchase orders for long lead items and critical equipment should be awarded.

In this phase an extended detailed field development plan shall the "Main Plan" also be prepared. This shall be sent to the Norwegian Petroleum Directorate as a basis for consent for further engineering.

Safety activites 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 ,alomg sire 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 hook-up 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 administration.

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 numer 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 preceeding 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
- 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
- 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
- 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 realated consequences of the decisions to be made, thus avoiding major design changes at a later stage and resulting delay and possible cost escalation.

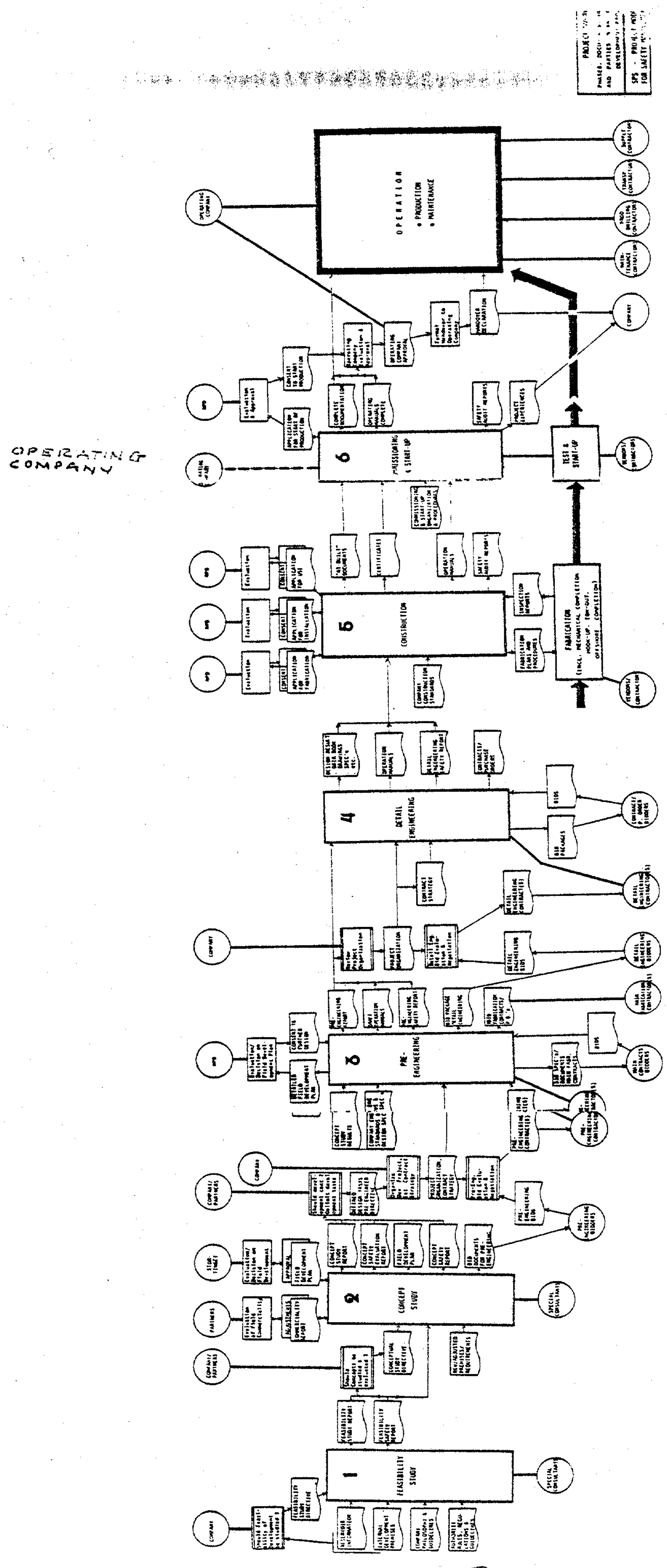
OPERATING COMPANY
OPERATION
• PRODUCTION
• MAINTENANCE
1 FEASIBILITY STUDY
2 CONCEPT STUDY
3 PRE-ENGINEERING
4 DETAIL ENGINEERING
5 CONSTRUCTION
6 COMMISSIONING & START-UP
TEST & START-UP
FABRICATION

FIG. 4

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 continous. The consistency that should achieved, is the iterative process illustrated in fig. 5.

From the description of the various phases of an offshore development project, it can be seen that there are 10 important safety studies to be performed. These studies are all to be found in the first 4 phases. 10 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. Fig. 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 description 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

2. 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, 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 give recommendations as regards 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 is for the operator to decide.

Phase 3. Pre-enginering

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 HasOp (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 plattform, a total safety evaluation should be performed. The analysis will differ from the concept safety evaluation in several ways, e.g. residual risk is 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 late pre-engineering 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 analysed in this study is not the platform during operation, but during it´s construction. The study will focus on accidents during construction work of the various platform elements, hook-up, tow-out and offshore construction work.

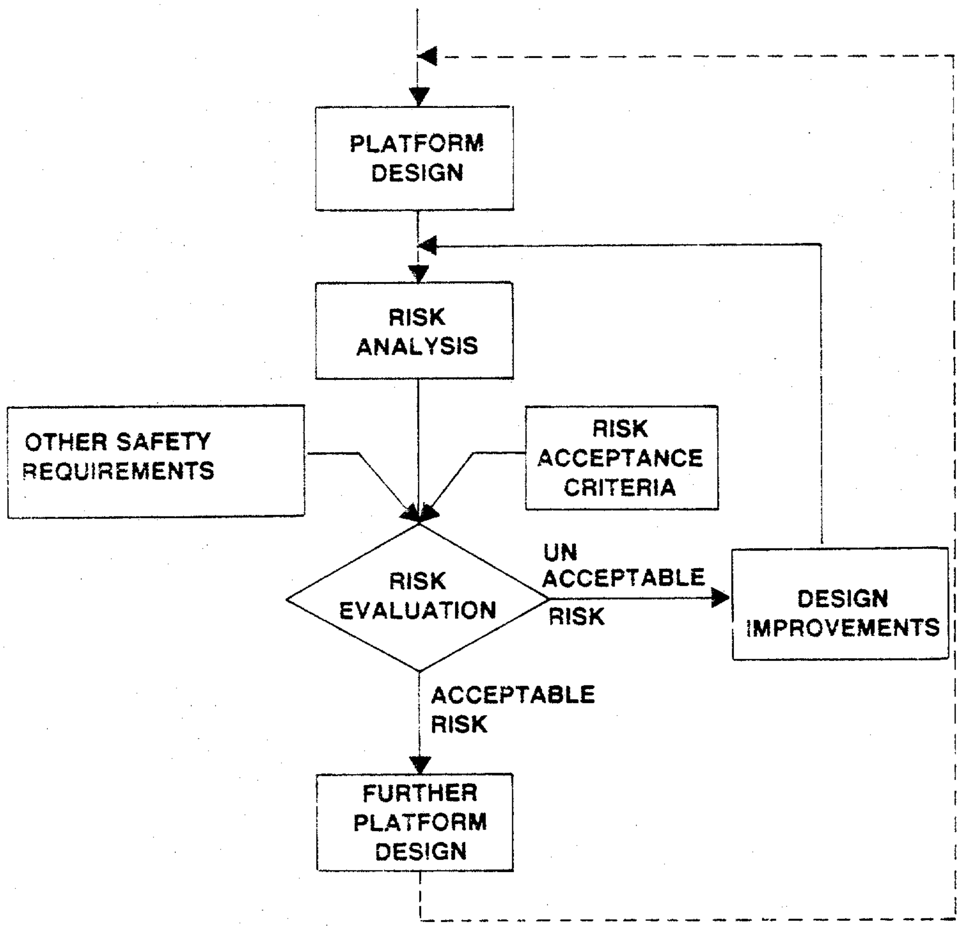

FIG. 5: The iterative process

PHASE	ANALYSIS NR.	TITLE	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

TYPE OF ANALYSIS: columns 4–8.

TABLE FIG. 6

APPENDIX:

REFERENCES:

- Regulations relating to safe practice etc in exploration and drilling sumarine petroleum resources.
  Issued by Royal Decree on 3 October 1975.

- Regulations realating to safe practice for production etc of submarine petroleum resources.
  Issued by Royal Decree of 9 July 1976.

- 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.

- Guidelines for safety evaluation of platform conseptual design.
  Issued by the Norwegian Petroleum Directorate 1 September 1981.

- M. Ognedal, the Norwegian Petroleum Directorate, "The Norwegian Safety Plan". (Lecture notes).

- M. Ognedal, the Norwegian Petroleum Directorate, "Future Trends in Influence and Control - A government view". (EPC Conference 1982).

- SINTEF REPORT STF 18 A83503, "Risk Analysis in Offshore Development Projects".

- Bjarne Hope and Per A. Johannesen, "Safety Management in Offshore Development Projects". (Tanum-Norli 1983).

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.

CONTENT

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 belowmentioned 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 establisheď 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

ISBN 82-7257-073-4

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).

TABLE OF CONTENTS:

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.

QUALITY ASSURANCE MANUAL

PHILLIPS PETROLEUM 66

PHILLIPS PETROLEUM COMPANY NORWAY

Quality Assurance Manual

PHILLIPS PETROLEUM 66

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Rev. date: May 1983	

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Concept Safety Evaluation for PHILLIPS PETROLEUM COMPANY NORWAY

Ekofisk Field Waterflood Project Platform 2/4K

September 1983

Technica

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CONCEPT SAFETY EVALUATION

EKOFISK FIELD WATERFLOOD PROJECT

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EKOFISK FIELD WATERFLOOD PROJECT

CONCEPT SAFETY EVALUATION REPORT

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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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

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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
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CONTENTS

28 February 1984

RISK ANALYSIS APPLICATION IN STANDARDS, CODES AND CERTIFICATION

Position Paper, Standards, Codes and Certification Working Group

by

S. G. Stiansen, Chairman

1. Introduction

The operation of an offshore oil and gas installation inevitably involves certain risks. Some of the risk in this operation may be generic as existing in any engineering system and some may be due to its unique nature related to its complexity and hostile operating environment. Traditional thinking often regards experience in design, construction and operation of offshore systems as the best safeguard against risks. In a restricted sense, 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 failures do occur 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. It should also be noted that failure of one component or one subsystem does not necessarily end with the loss of the component or subsystem. The consequence may propagate and trigger the failure of others and may ultimately lead to the failure of the entire system, depending on the individual design. In general, the greater degree of complexity of the system requires the consideration of greater number of critical paths or scenarios which may cause major failures.

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 60% of all failures. It is therefore logical to include human factors in risk assessment. Human error may be present in the design, construction, maintenance and operation of the offshore installation. Such errors can lead to component/system malfunction or damage.

Another factor that underscores the potential usefulness of a system approach in risk analysis is the variability of offshore installations. Unlike some other engineered systems such as an automobile system where the fundamental subsystems and general configuration among all makes and years are essentially the same, the variability in offshore structures dictates that past experience may be less applicable (applicable with less reliability). For instance, experience drawn from the successful design of risers operating in 100 foot water depth may not be directly transferred to the design of risers or riser groups for use in a tension leg platform in 1500 feet of water with complete confidence.

From the socio-economic standpoint, the use of risk assessment should also be viewed favorably. Obviously such an endeavor and the resulting remedial actions such as more sophisticated design, provision of redundancy, more elaborate maintenance and inspection programs, etc., translate into greater expenditure in developing and operating an offshore system. But as a trade-off for lower risks for loss of platform, loss of production and loss of life, it is believed justifiable if the correlation can be established.

For the standard making bodies, whether they are governmental regulatory agencies or private organizations, their primary concern is the safety and integrity of the offshore installation and the protection of human life and the environment. If risk assessment can be proven to enhance the chance of achieving this goal, then it should be included as a part of the general formulation of the standards, codes or certification requirements. On the other hand, standards, codes or regulations generally reflect the current state of practice of the industry. At times, these documents may lead the way in certain areas, with substantiated reasons, in requiring measures to guard against undesirable consequences. In this regard, new requirements must be shown accomplishable in the light of the present state of technology. Initiatives to include risk assessment in industry standards or government regulations should be evaluated against such criteria as: is it needed, is it beneficial, is it accomplishable.

This workshop is intended as a forum in which these basic issues may be given a critical review. Should risk analysis be considered as an integral part of the design, building and operating process? Where does it fit in the overall scope of standards, codes and regulations? Does the standard technology for implementation exist or is it emerging? What efforts in terms of research and data acquisition are necessary to enhance the chance of its success? In an attempt to provide some background for discussion the current status of these fundamental issues will be briefly reviewed in this paper.

2. State of Practice in Risk Assessment

2.1 Standards and Codes

Formal, explicit requirements, in a standard or code, of risk or reliability assessment concerning offshore oil and gas installations have come into being only quite recently. A clear-cut example is the "Guideline for Safety Evaluation of Platform Conceptual Design" issued by the Norwegian Petroleum Directorate (NPD) in 1981 which supplements other regulatory documents. Several characteristics of the NPD document are worth noting for the purpose of demonstrating the current state of practice.

Safety evaluations are 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 relevant types of accidents, extreme weather conditions, and relevant combination of these accidents."

No specific methods of approach have been specified except that the risk assessment "..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 assessment would suffice. However, as an order or 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 readily be 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. These are called "design basis accidents" and are required to be considered at the earliest phase of design. Moreover, quantitative risk analysis is not required and the Guideline is basically performance oriented.

The recommended remedial actions generally follow two paths, namely, to reduce the probability of occurrence of events in the sequence of events within a scenario which could lead to the occurrence of the most damaging top event, and to reduce the consequences of failure along the failure chain. Again the term "probability" is believed to be used in a notional sense. While some form of numerical characterization may be necessary, a kind of ranking (e.g., on a scale of 1 to 5) may suffice rather than pursuing to establish the mathematical probability literally.

Referring to the items of hazard analysis mentioned in the second item in the foregoing, one may find resemblance among other standards or codes. For example, in the "Requirements for Verifying the Structural Integrity of OCS Platforms" issued by the Mineral Management Service (MMS), formerly the U.S. Geological Survey in 1979, similar requirements are stated:

> "Consideration 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.

While the intention of the MMS Requirements is to recognize the potential danger of such accidental events, the key words "risk analysis" are not used throughout the document. It requires, instead of prevention (or reduction of probability of occurrence) of the accidental events, that the platform should be able to survive such events (i.e., minimization of consequences). It probably also implies that the accidents can be treated as independent events. Neither does it require the consideration of the chain of events that may follow.

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 all be 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", RP2A, recommended that a risk analysis be performed to determine design environmental conditions for platform sites for which environmental 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 title listing of relevant regulations and the governmental agencies accorded the mandate to regulate the U.S. offshore oil and gas installations has been compiled in a pamphlet 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 Risk Assessment

Of the several typical codes and standards regarding treatment of risks cited in the preceding, it appears that the NPD Guideline is the most stringent in both broadness and depth. In the aspects of compliance, the state of practice can be highlighted by the following sequence of analyses. It should be understood that these analyses are by no means typical and they are presented to exemplify what can be done in light of the present state of technology under the overriding principle of reduction of risks and consequences, or at least to achieve compliance with various codes, standards and rules.

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 the 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 Failure Mode and Effect Analyses (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 functional 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 treatment of these items may not be within the present state of practice. However, engineering judgment 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.

In such an assessment, the greatest impact index would correspond to a failure mode with the highest frequency and the highest severity, which in a reasonably well designed system, is improbable. 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.

2.2.3 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 analysis is by no means complete. It simply demonstrates that within the state of technology, means of analysis to satisfy the risk assessment requirements 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 humanistic sources rather than from the method employed. The separation of conceptual design and reliability analyses, as recommended by the NPD Guidelines, may create a problem of communication between the designer and the reliability analyst in that neither one possesses in-depth understanding of the other's domain. A possible improvement, perhaps, is to pursue the system reliability analyses during the next (detail design) phase. This may enable the design team to ensure that the failure of a particular component to fulfill its intended function has been considered and the associated risk is acceptable. The system approach pursued in this manner helps the designer to be aware of the existence of novel failure modes and critical paths of events which may otherwise be ignored.

3.2 Quantification of Variables and Their Roles in Impact Rating

The second difficulty relates to the simplicity in quantification in the FMEA. 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 a 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 needs 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 modelling.

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 pool used in the statistical analysis. Data of this sort are generally non-controversial. Others may be quantifiable but, due to a variety of reasons such as the relative young age of the product which precludes the existence of a sufficient data pool, engineering judgments 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.

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. Even in the secondary objective of a quantitative analysis to provide a relative reliability ranking of failure paths, given the range of inaccuracy which exists in the data, the conclusion arrived at is also subject to doubt.

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 or lack 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 to this dilemma is not available at the present, continued research appears to hold the key to the prospect of meaningful use of quantitive risk analysis.

3.3.2 Statistical Modelling

Regarding probabilistic modelling, potential problems are again numerous. Data, whether they are hard data or engineering judgment, 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 modelling 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 interconnection 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 modelling 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 modelling 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 fail 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 non-conservative 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 modelled 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, however, how failure would be properly represented statistically remains an outstanding issue.

4. <u>Data Acquisition and Research Needs</u>

Given the numerous problem areas as discussed in the foregoing, and surely many others can be added to the list which frustrates design engineers and risk analysts alike, perhaps one proposition that would meet universal agreement is the need for more reliable, or simply more data and a better understanding and broader 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 while attempts to forecast what is needed for some future (and thus non-existing) approaches would be pointless. Within this limited scope, a compilation of required data can be accomplished provided that all existing methods, some better known than others, can be identified. This is believed to be the responsibility of this work group. In our efforts towards this goal, the scope should be further limited to addressing the acquisition of data responding to codified requirements. The same frame of reference also applies to assesssing future research needs.

5. <u>Concluding Remarks - Opportunities for Implementation and Application</u>

The foregoing discussion can now be summarized in simple terms. The operation of an offshore oil and gas installation involves numerous risks. Therefore, a systematic assessment of risk leading to the identification of risks of failure, reduction of their probability of occurrence and alleviation or lessening of consequences provides an attractive framework for increasing the safety of offshore installation. Presently, standards and codes that deal with safety of offshore structures have begun to address the issues of risk and there are reasons to believe that standards, codes and certification requirements may play an increasingly significant role in the area of risk assessment and analysis.

The state of practice in standards, codes and certification requirements remains largely at the level of performance oriented requirements or recommended practices, the 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 accidental events that could lead to failure should be carried on throughout a logical chain of events rather than being viewed as isolated events in the design process. On this basis, even a qualitative assessment at the system level can succeed in identifying critical paths of damaging sequences of events at an early stage of design, given the state of technology as it now stands. Within the present state of technology, compliance with the existing requirements appearing in standards, codes and certification requirements cast in their present limited scope is possible.

However, it is to be realized that qualitative risk assessment does not produce as much benefit as intended without a defensible quantitative risk analysis. On the other hand, it is equally evident that quantitative risk analysis is in a state of infancy, at least within the engineering professions involved in the design, construction and operation of offshore oil and gas installations. A great deal of effort, both in terms of theoretical development of the methodology and necessary data base, appear to be needed before making qualitative risk analysis an integral part of the design procedure.

On the other hand, a well conceived risk analysis, successfully carried out, is undoubtedly desirable. Therefore, owners, designers and operators alike should be encouraged to undertake such investigations on their own initiative. Meanwhile, efforts toward building up a reliable, scientifically justifiable data base and research efforts to advance the general understanding of the subject of risk analysis and to develop better methods should also be encouraged and supported on a nationwide basis. As it now stands, the state of technology is believed to be only at the beginning of a long, evolutionary process.

CASE WESTERN RESERVE UNIVERSITY • CLEVELAND, OHIO 44106

July 26, 1983

Dr. Felix Y. Yokel
Leader, Geotechnical Engineering Group
Center for Building Technology
Building 226, Room B-162
United States Department of Commerce
National Bureau of Standards
Washington, D.C. 20234

SUBJECT: International Workshop on the Application of Risk Analysis to Offshore Oil and Gas Operations, October 3 and 4, 1983

Dear Dr. Yokel:

Enclosed is a brief working paper for Group II of the workshop.

It obviously reflects my own background and interests and I look forward to comments and elaboration by other members of the group.

I am looking forward to the workshop.

Sincerely yours,

Fred Moses

Fred Moses
Professor of Civil Engineering

am

enc.

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INTERNATIONAL WORKSHOP ON THE APPLICATION
OF RISK ANALYSIS TO OFFSHORE OIL AND GAS OPERATIONS
OCTOBER 3 AND 4, 1983

WORKING GROUP II - CONCEPT EVALUATION AND DESIGN
CHAIRMAN: Fred Moses

OUTLINE

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 acceptibility and includes value judgements.

Risk determination for complex technologies such as the offshore industry has three components:

Hazard--Vulnerability--Consequences

A hazard is a natural or man-made phenomena that may induce unwanted events and may include storms, mudslides, fire, collision, dropped objects, excessive operating demands, 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 depends 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 intangibile.)

It has been difficult within offshore developments to quantify overall risks because the uncertainties include many disciplines describing natural phenomena (wind, wave, soil properties, etc.)and modelling assumptions (theory, verification, accuracy, 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 ably put it in the title of a paper, "No Risk May be the Greatest Risk of All".

1. STATE OF PRACTICE

Considerable probabilistic analysis is done in offshore operations especially 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 conservative 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 difficult in offshore engineering because of the many disciplines involved. Some integration has nevertheless been carried out for specific projects.

One early example is the work by Stahl and Knapp at Amoco utilizing reliability analysis to optimize remedial construction strategies for existing structures when field observations changed the original design assumptions. (Reliability equals one minus risk and the use of the term reliability is often favored as opposed to risk in describing offshore project activities.) These remedial strategy studies identified potential failure modes and balanced risks and relative cost trade-offs.

Studies by Marshall and Bea on "fleets" of similar eight-pile platform structures helped establish their respective environmental design criteria. This review for Shell Oil Company considered a reliability analysis based on best estimates of the environmental loading, strength and capacity data and the incorporation of field performance with these structures during hurricane storms. These studies helped stimulate other investigations to combine different uncertainties into a single decision model for offshore platform risk studies.

More recently, offshore risk studies have considered specific project applications such as jack-up rigs or tension leg platforms and also other generic applications. The latter include reliability formulation of design code safety factors such as API studies (Moses), DnV (Fjeld), UK (Baker) and fatigue (Wirsching, Stahl). A major effort has also gone into defining system risks which incorporate multiple hazards and/or multiple damage modes (See Lloyd, Bea, Marshall, Moses, Edwards, Ang, Wirsching, Stahl, etc.).

2. PROBLEM AREAS

A number of limitations in our present risk analysis applications can be readily noted.

A. Notional Description of Risk Assessments - In most studies reliability (or risk) is a convenient measure of safety. It has only a limited accuracy in an actuarial (statistical) sense since only the relative but not absolute risks between different hazards may be correct. To permit full utilization of risk as a trade-off criteria between a variety of different concepts, control or even construction activities requires more accurate risk assesments. This accuracy requires considerably more data as well as reliability techniques.

B. System Analysis - Most studies concentrate on well-defind damage modes usually involving a single event. These studies may not produce bounds on system risk because of the complex interrelationships 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 assesments.

C. Evolution of Reliability Estimates - In most applications many components have significatant field histories from previous project observations. This information needs to be quantitatively integrated into the risk assessment. Reliability should be viewed as a dynamic phenomenon which changes over the life of the project as new information is made available on performance, proof-loading, costs and even consequences.

D. Nontechnical Aspects of Risk - Many if not most reported failures are due to hazards and events which were not considered in the design or conception stage. In particular human errors are frequently responsible for major catastrophies but these are often difficult to model. One notable development is a recent IABSE conference on quality assurance which reported statistical data on human errors in design, inspection and construction. This report also emphasized creation of the scenarios in which possible hazards are identified at the project conception stage. It is this phase of risk analyses which may warrent more future attention.

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 property 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 reponses include allocation of material and human resources within the system, such as redundant inspection, quality assurance and damage mitigation. Within this scope there are specific research needs for studies on:

A. Damage scenarios and failure-tree illustrations

B. System reliability methodologies

C. Incorporation of historical data through Bayesian and fuzzy set description

D. Development of research priorities for describing modelling uncertainties in offshore design disciplines

4. OPPORTUNITIES FOR IMPLEMENTATION AND APPLICATION

This topic is clearly the most difficult since risk analysis must avoid becoming another program such as environmental impact statements which one accepts in theory but doesn't like when it impedes their own project. Demonstration projects of risk analysis are needed in which costs as well as benefits are included and the flexibility rather than the rigidity of risk analysis is emphasized. Opportunities for trade-offs in concepts, design criteria, redundancy, material selection, design verification, inspection scheduling, etc. must be made clear. Examples of implementation projects should show the difference between projects with significant historical experiences and hence updated (Bayesian) parameter estimates and projects with significant innovation which require more quality assurance.

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

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

B. Realistic applications ranging from the adventuresome to the mundane.

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

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Date 18 November 1983

File No.

To: Dr. Felix Y. Yokel
Building 226, Room B-162
National Bureau of Standards
Washington, D.C. 20234

Gentlemen:

The following technical documents are transmitted herewith for your action and/or information:

Article or Dwg. No.	Rev.	No. Copies	Title
		1	Initial Position Paper, Working Group
			IV

THE GLOSTEN ASSOCIATES, INC.

Bruce L. Hutchison

Enclosure/s

cc:

PREFACE

The organizing committee for the International Workshop on the Application of Risk Analysis to Offshore Oil and Gas Operations has requested that each working group chairman submit an initial position paper covering 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.

As chairman of the working group concerned with logistics and support activities, I have opened with a philosophical statement concerning my understanding of what activities are to be classed as logistics and support, and what risks are to be included for consideration. Even following critical review, the class of activities and risks to be considered covers enumerable possibilities. This is not perhaps of great concern because the breadth of possibilities encompassed by current theory is greater still.

The totality of modern theoretical approaches to risk analyses such as we are to address includes several diverse branches. Though these branches find unity in the fundamental principles of set theory and probability, they often so quickly diverge in their own peculiar directions that specialists in one branch may be only vaguely aware of the state-of-the-art in an allied branch. Because of these provincialisms I may have unintentionally slighted some branch of risk analysis or some topic which is dear to some member of our working group. If I have done so let me hasten to apologize. However, it is this very purpose of sharing perspectives and broadening our outlooks which motivates workshops such as this. Let us keep in mind that the product of our working group's efforts will be a new position paper which should reflect the diverse outlooks we may find.

My own brand of provincialism, as it will be revealed in the following pages, is to focus on marine risk analysis as a branch of second-order stationary random processes. Within this context the essential element which transforms an engineering study of response into a risk analysis seems to be the proper marriage in the probability domain of information concerning both climatology and response. To this must be added consideration of the effects of operators which can alter system operating parameters and the criteria which delineate the limits of the safe operating domain.

It is intended then that this initial paper serve to focus our attention and stimulate our thoughts, so that when we come together we can forge a better product.

Nomenclature

σ = "critical" response variable $-\infty < \sigma < \infty$
Υ = spatial domain
Λ = season
x, ξ = general real variables
Ψ = course
H_s = significant wave height
T_m = mean period of irregular sea state
Φ = predominant wave direction
χ = relative heading
V = speed
Δ = displacement
k_{xx}, k_{yy}, k_{zz} = mass radii of gyration
A_{x_i}, A_σ = complex valued frequency response function
ω = radian frequency
$S_{\zeta\zeta}$ = wave spectral density
ϵ = spectral breadth parameter
$m_\sigma^{(n)}$ = nth moment of σ-response process
$p(x)$ = probability density function
$P(x)$ = discrete probability
$P(x < \xi)$ = cumulative probability
$P(x,y)$ = joint probability
$P(x|y)$ = conditional probability
$p(i|j)$ = Markov transition probabilities

INTRODUCTION

This group has been charged with the task of considering the current state of practice and the prospects for future development in the application of risk analysis to marine logistics and support activities, particularly as these apply to the offshore oil and gas industry. It seems appropriate to begin by briefly reviewing our understandings concerning what activities are included in logistics and support, and similarly to enquire concerning what concepts are to be included as risks.

The advance announcements concerning this workshop stated that logistics and support involved the movement of men and materials to and from moored and fixed offshore facilities. This is a good beginning but perhaps leaves the domain of inquiry a little too broad. This definition would include, for instance, the transport directly to shore of oil or gas via submerged pipeline. Similarly it would include the transportation by helicopter of personnel between shore and a fixed platform. Consider the delivery of a large module to a fixed production tower. The final stages of this activity involve a delicate heavy lift operation. Is this logistics or operations (or both)?

It appears that there is no sharp division between logistics activities and operations. Many activities may properly be regarded as both, either in their entirety or during some specific phase of the process. Likewise the process of delivering a petroleum product via pipeline or personnel via helicopter may properly be regarded as logistic activities. However, to the extent that we are gathered to consider risk analysis as applied to the offshore oil and gas industry, and therefore in a marine environment, it is my opinion that we should consider such logistic activities only to the extent that the risks examined are engendered by the marine environment. Under this criteria one could consider the risks associated with helicopter landings and takeoffs from a landing pad on a floating (i.e. motion responsive) structure but would not include risks associated with landings and takeoffs from a fixed structure. Similarly, the loads imposed by mooring a large product carrier to a marine riser would qualify for consideration but not the risks to this same pipeline/riser system associated with earthquakes.

The principle involved in making these distinctions is that the qualified system must be both a logistic and/or support activity, and the risk considered must be a marine risk.

What do we mean by risk? Do we intend to include only those events which are dramatic, catastrophic and irreversible, such as structural failure and capsize? Or are the economic risks associated with issues of operability to be considered? The inability due to heavy weather to perform the heavy lift operation on the fixed platform may result in no failure whatever, but the economic loss can be very great. Where there are seasonal considerations or other operational windows these losses can be greatly magnified. For example the logistic activity of wet towing a large caisson to the Arctic must be planned so as to arrive during the brief summer ice window during which the Arctic pack ice is withdrawn from the beach. The penalty associated with either too late an arrival, or the ice not withdrawing can be nearly a full year delay in a project.

CURRENT STATE OF PRACTICE

The modern application of risk analysis may be broadly classified into the divisions of actuarial risk analysis and engineering risk analysis. Both approaches to risk analysis apply the same fundamentals of set theory and probability. Actuarial methods rely on statistical analysis of historical record to develop estimates of risk. Application of actuarial methods does not normally require appeal to causal mechanisms or application of physical law. Engineering risk analysis normally appeals to causal mechanisms and applies physical law. The causal mechanisms and physical laws used in engineering risk analysis connect appropriate distributions of causal phenomenae with suitable distributions of final effects. The distributions of causal phenomenae are frequently established through application of actuarial methods.

Actuarial risk analysis methods are particularly appropriate for the study of processes that are intrinsically random and subject to no known causal mechanism. Processes such as human error are examples of such random events. Once rates have been established for such random events, engineering methods may be applied to extend these root causal events to secondary and further removed effects.

Both actuarial and engineering risk analysis methods are capable of generating useful answers to specialized questions, however, it is in the marriage of these two techniques that we forge our most powerful tool.

The major functional elements of an operating marine system are illustrated in figure (1). It is the task of those engaged in marine risk analysis to model this interacting system and produce appropriate estimates of the risks (both catastrophic and operational) which are associated with the system. Problems which may be addressed range from the quite specific (e.g. a particular supply vessel in a particular operating environment) to quite general (e.g. the class of all supply vessels in any operating environment). In its most complete form an analytical model will utilize probabilistic representations for all four major elements depicted in figure 1.

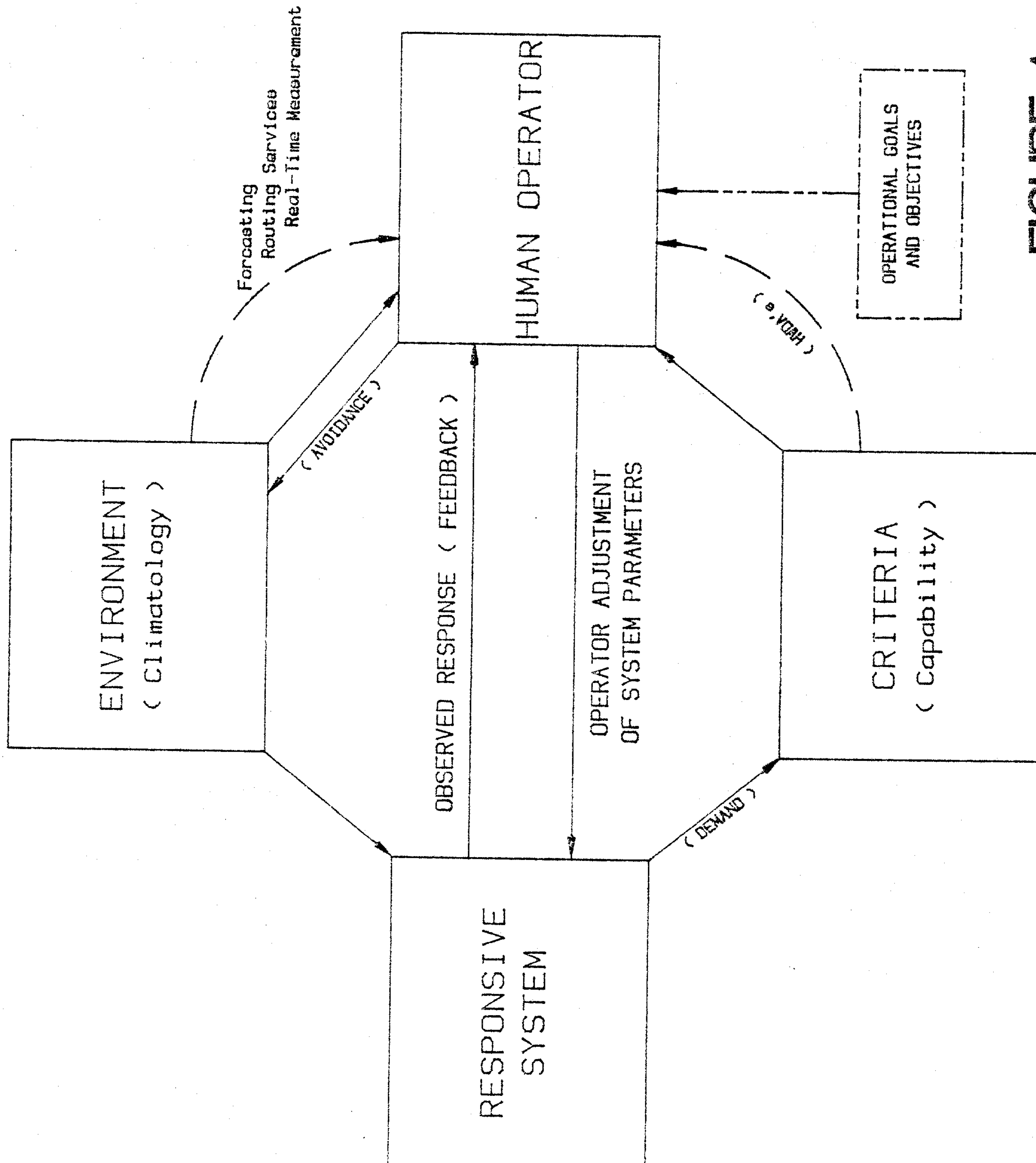


FIGURE 1

FIGURE 1

The Determination of Risk

Modern probabilistic theory assesses risk based on the intersection of two probability density distributions, one for demand, $p_D(\sigma)$ and one for capability, $p_c(\sigma)$, (see figure 2). If:

$$P_D(\sigma) = \int_0^{\sigma} p_D(\xi)d\xi \text{ and } P_c(\sigma) = \int_0^{\sigma} p_c(\xi)d\xi$$

are the cumulative distribution functions for demand and capability respectively, then the probability that the demand exceeds the capability is the risk, which may be evaluated as:

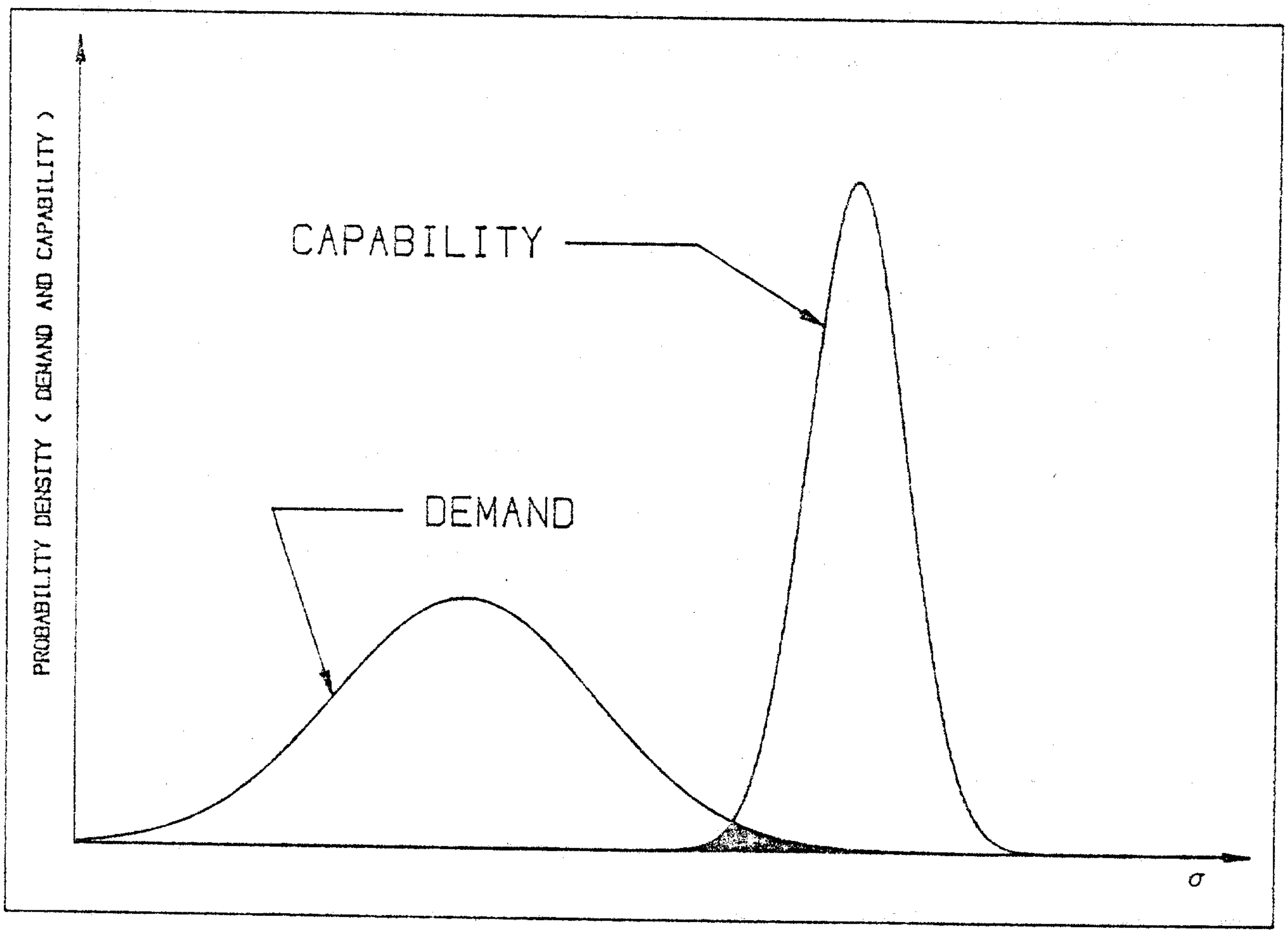
$$\begin{aligned} \text{Risk} &= \int_0^{\infty} p_D(\sigma)\ P_c(\sigma)d\sigma \\ &= 1 - \int_0^{\infty} P_D(\sigma)p_c(\sigma)d\sigma \end{aligned}$$

Reliability = 1 - Risk

The task of determining risk therefore becomes that of evaluating the relevant demand and capability functions. That task will be further reviewed in the following sections.

Before passing on to more detailed considerations, it should be observed that there is no difficulty in extending this concept of risk to encompass demand and capability functions defined in terms of joint variables:

$$\text{Risk} = \int_0^{\infty} \int_0^{\infty} \dots \int_0^{\infty} p_D(\sigma_1, \sigma_2, \dots, \sigma_n) P_c(\sigma_1, \sigma_2, \dots, \sigma_n) d\sigma_1 d\sigma_2 \dots d\sigma_n$$



THE DETERMINATION OF RISK FROM THE INTERSECTION

OF DEMAND AND CAPABILITY DISTRIBUTIONS

FIGURE 2

DEMAND DISTRIBUTIONS

The task we have set is to determine p(σ) (that is, the probability distribution of σ) for the σ-response process of a vessel engaged in a voyage traversing spatial domains T_i during the seasons Λ_j. Here σ refers to any generalized response process that has been identified as a matter of concern. Examples of σ-processes would be roll angle, local acceleration, the motion induced stress in a cargo tiedown member, or crane boom tip motion. The list of possible σ-processes is virtually limitless and obviously depends on the vessel and mission under examination. As a class, all of the σ-processes may be referred to as the "critical processes" - those on which the success or failure of the mission is assumed to depend. In general, any real mission will depend on a multitude of critical processes. The exposition in this paper, however, develops the determination of p(σ) in terms of a single critical process. The procedures for determining the demand functions for a number of critical processes consists of repeated application of the procedures appropriate to a single critical process together with consideration of any appropriate effects of joint processes (for example, the joint process formed of roll angle and roll momentum).

As we approach the task of determining the probability distribution of the σ-process , it can be observed that the problem divides into four major subparts: route, climatology, seamanship and response. Each of these areas is discussed separately and then the task of properly combining their effects to obtain the demand distribution is developed.

Most of the variables studied herein are defined over the positive real-number line (for example, significant wave height) and are therefore properly associated with probability density, p(x) and the cumulative probability, $P(x \leq a)$ distributions. Common practice, dictated primarily by numerical processing considerations, frequently transforms these continuous variables into indexical point processes with associated point probabilities

$$P(x_i) = P(x \leq \xi_i + 1) - P(x \leq \xi_i)$$

where: $\xi_i + 1 > \xi_i$ is a mesh imposed on the real number line.

Where the variable under consideration is continuously defined on the real numbers, it is presented as continous or discrete, whichever is most appropriate within the context of the presentation. Integration is the preferred form of presentation with the understanding that upon proper treatment the integrals can be replaced by summations in a numerical analysis procedure.

Route

The route is perhaps the simplest of the topics to be considered. The problem of the mission route determination involves three variables, location T_i; season Λ_j; and of course Ψ_k. The location can be thought to consist of a sequence of contiguous regions lying along the intended course. Each region might, for instance, consist of the one degree square centered over a segment of the intended course. The season is the time of year either by month ($j = 1,2,\ldots,12$) or week ($j = 1,2,\ldots,,52$). And the course is the course heading in degrees (true). It will frequently prove advantageous to divide the courses into the compass sectors in which they fall. If, for example, 45-degree sectors are utilized, then $k = 1,2,3,\ldots,\ldots8$ and $k = 7$ would apply to any course falling between 247-1/2 and 292-1/2 degrees.

The problem of determining the route is to determine the joint probability distribution $P(T,\Lambda,\Psi)$. Using a relative frequency interpretation for probability, it is generally fairly straightforward to determine $P(T,\Lambda)$, the joint probability of route segment and season. It is also usually not difficult to determine the conditional probability distribution for course heading given the location and season, $P(\Psi\ T,\Lambda)$. Given these two distributions, the desired joint distribution may be obtained as a product

$$P(T,\Lambda,\Psi) = P(\Psi|T,\Lambda)P(T,\Lambda)$$

Use will be made in following subsections of both $P(T,\Lambda)$ and $P(T|\Lambda,\Psi)$.

Seamanship

A modifying influence on the probabilities to be developed for the critical processes are the seamanship actions of the vessel's officers. The first logical division of these actions is into those actions taken before severe conditions are encountered, and those taken once severe conditions are encountered. The principal form of prior action is avoidance of severe weather.

Avoidance is a prominent factor influencing the risks experienced by many small vessels, particularly those in coastal day boat or sortie-type activities, which enjoy the luxury of some choice or discretion in selecting their periods of sea duty. For those vessels which do not enjoy this luxury there is still the possibility of maneuvering around major storms, thereby reducing the severity of the conditions encountered. Nearly all vessels modify their risk exposure in this fashion to some degree. The basic variables affecting the degree of success in this avoidance activity are the skill of the officers and the quality of weather information available to them.

The avoidance type of seamanship modification to demand can be represented as a Markov mapping $P(i|j)$, from the probability of encountering each sea state in the absence of seamanship to the probability of encounter with seamanship. An example transition matrix $[P(i|j)]$ is:

i	j= 1	2	3	4	5
1	1.0	0	0	0	0
2	0	1.0	0.2	0	0
3	0	0	0.8	0.5	0.1
4	0	0	0	0.5	0.6
5	0	0	0	0	0.3
	1.0	1.0	1.0	1.0	1.0

This transition matrix states that, on 60 percent of the occasions that a sea state 5 would be encountered in the absence of seamanship, the master takes avoidance actions that result in the vessel encountering only sea state

4, and in 10 percent of those occasions where a sea state 5 would be encountered, the master's actions result in exposure to only a sea state 3. On 30 percent of the occasions where a sea state 5 would normally be encountered, the master either takes no avoidance action or his actions are not effective in reducing the vessel's exposure. In the case of sea state 4, fifty percent of the time the master is effective in taking actions that result in encounter with only a sea state 3. For sea states 2 and below the master does not alter his actions in response to anticipated weather. On no occasions does the master, represented by this matrix, take actions which backfire and result in encounter with a higher sea state.

If the natural probability of encountering sea states 2 through 5 are 0.40, 0.30, 0.20, 0.08 and 0.02 respectively, then under the command of this master the probability of encountering these sea states is given by

$$P'(i) = \sum_{j=1}^{5} P(i|j)P(j)$$

where

$$\begin{aligned}
P(1) &= 1.0 \times 0.40 && = 0.400 \\
P(2) &= 1.0 \times 0.30 + 0.2 \times 0.20 && = 0.340 \\
P(3) &= 0.3 \times 0.20 + 0.5 \times 0.08 && \\
&\quad + 0.1 \times 0.02 && = 0.202 \\
P(4) &= 0.5 \times 0.08 + 0.6 \times 0.02 && = 0.052 \\
P(5) &= 0.2 \times 0.02 && = \underline{0.006} \\
& && 1.000
\end{aligned}$$

The seamanship actions taken once severe sea conditions have been encountered consist principally of changes in speed or heading or both. These can be represented as conditional probabilities of speed and relative heading given the sea state and unaltered relative heading $P(V,\chi|H_s,T_m,\chi_o)$.

Climatology

Conceptually a sea surface climatology may be expressed as $P(S_{\zeta\zeta}(\omega,\theta),\vec{x},T)$; the joint probability of the directional variance spectrum $S_{\zeta\zeta}(\omega,\theta)$ at spatial location $\vec{x}$ and temporal instance T. Let us immediately replace $\vec{x}$ with an indexical spatial domain T and T with an indexical season Λ, to obtain the more benign form, $P(S_{\zeta\zeta}(\omega,\theta),T,\Lambda)$. The concept implied is, I believe, readily apparent but any attempt to provide a practical interpretation (suitable for application to real problems) will quickly become enmeshed in an intractable morass created by the infinite degrees of freedom.

The conventional solution to this dilemma is to apply a parameterization to $S_{\zeta\zeta}(\omega,\theta)$ and proceed in terms of a countable set of parameters. The usual implementation of this strategy is to represent $S_{\zeta\zeta}(\omega,\theta)$ by analytical spectral forms (e.g. Pierson-Moskowitz, ISSC, JONSWOP, etc.) employing a few parameters (usually from one to six parameters). The most common parameterization is the reduce $S_{\zeta\zeta}(\omega,\theta)$ to a one-parameter form based on significant wave height, H_s. This is quickly followed in popularity by two-parameter forms based on the H_s and T_m (some characteristic period). If directionality is considered, it is usually introduced as a static analytical form and not treated as subject to variation. These parameterizations lead to climatologies such as $P(H_s,T,\Lambda)$ and $P(H_s,T_m,\Phi,T,\Lambda)$.

These last climatological forms are the limits of what can be accomplished based on analysis of synoptic compendia of observations. Such compendia still represent our most complete a priori data bases for such problems. This situation is changing with the development of the Navy's 20 year hindcast climatology, and with the sattelite and buoy observational programs.

Response

For a particular vessel and in a given load condition [Δ, LCG (longitudinal center of gravity), VCG (vertical center of gravity), k_{xx}, k_{zz}] and operational status (V, χ), the complex valued frequency response function $A_{x_i}(\omega, V, \chi)$, at a suitable origin (usually "G" or the image of "G" in the waterplane "O"), can be determined using standard ship motion techniques.[1] These can in turn be transformed, using the techniques of [1-3], to apply to the desired σ-process (for example acceleration induced force, stress) at an arbitrary location in the vessel frame of reference, $A_\sigma(\omega, V, \chi)$.

Given a directional sea spectrum $S_{\zeta\zeta}(\omega, \Theta)$, the techniques first elucidated by St. Denis and Pierson [4] can be utilized to determine the moments, $m_\sigma^{(n)}$, of the σ-response process.

$$m_\sigma^{(n)} = \int_0^{2\pi}\int_0^{\infty} A_\sigma(\omega, V, \chi) * \bar{A}_\sigma(\omega, V, \chi)\omega^n \, S_{\zeta\zeta}(\omega, \Psi - \chi) d\omega d\chi$$

A conventional assumption is that the instantaneous ordinate of the (zero-mean) σ-process is normally distributed, and the maxima are distributed according to a Rayleigh distribution:

Rayleigh Distribution

$$p(\sigma) = \frac{\sigma}{\sqrt{m_\sigma^{(o)}}} e^{-\sigma^2/(2m_\sigma^{(o)})} \qquad 0 \le \sigma < \infty$$

1

Standard ship motions programs generate and solve a set of second order differential equations for the frequency response functions $A_{x_i}(\omega, V, X)$. In order to generate the dynamic equations, a set of partial differential equations (a Cauchy problem) must be solved over the fluid domain (followed by application of suitable surface integrals) to obtain the fluid-structure interaction forces. These forces are represented in the dynamic equations by frequency dependent coefficients for added mass and damping, and by a wave forcing function dependent on frequency, heading and speed.

For non-shiplike bodies there are comparable programs available based on 3-D diffraction methods, or in the case of tubular structures, based on Morrison`s equation.

Cartwright and Longuet-Higgins defined a spectral bandwidth parameter, ε, as follows:

$$\varepsilon = \sqrt{1 - \frac{[m_\sigma^{(2)}]^2}{m_\sigma^{(o)} \quad m_\sigma^{(4)}}}$$

Generalizations of the probability distribution have been presented by Ochi [5] in terms of the zero-order moment and the spectral bandwidth parameter. It has been concluded that the Rayleigh distribution is a reasonable approximation except when $\varepsilon \to 1$, in which cases the distribution approaches a truncated normal distribution.

Under the application of the Rayleigh distribution the short-term response statistics can be determined from the zero-order moment utilizing familar techniques [5 - 8]. If risk is the focus of attention, then processes such as the expected maximum will be of greatest interest. If operability concerns predominate, then average-type processes such as the significant response (average of the highest one-third responses) and the average of the highest one-tenth responses will most likely be the focus of interest. Where structural fatigue is a factor, the number of cycles at each response level will be of greatest interest.

Voyage Risk of Occurrence (Final Demand Distribution)

We are now at the point where we can combine the component probabilities using the concepts we have discussed to arrive at the demand distribution for the σ-process. In the preceding sections we have discussed the development of probability distributions describing the route $[P(T,\Lambda,\Psi)$ and $P(\Psi|T,\Lambda)]$, sea-state climatology $[P(H_s,T_m|\Phi,T,\Lambda)]$, and seamanship $[P(H_s'|H_s)$ for avoidance and $P(V,\chi|H_s,T_m,\chi_o)$ for heading/speed changes], and functional relationships between the response σ , and the set (H_s,T_m,V,χ).

The natural relative heading (the relative heading that would be obtained if no seamanship actions were taken) is $\chi_o = T - \Phi$. Using the expression to form a substitution into the sea-state probability distribution, the sea-state probabilities can be recast in terms of relative heading as follows:

$$P(H_s,T_m,\chi_o|T,\Lambda) = \int_0^{2\pi} P(\Psi|T,\Lambda)P(H_s,T_m,(\Psi-\chi_o)|T,\Lambda,)d\Psi$$

The seamanship influences shall now be incorporated. First we shall consider the avoidance activities, $P(H_s`|H_s)$.

$$P(H_s',T_m,\chi_o|T,\Lambda) = \int_0^{\infty} P(H_s'|H_s)P(H_s,T_m,\chi_o|T,\Lambda)dH_s$$

Hereafter the prime on H shall be dropped and it shall be assumed that the avoidance bias has been incorporated.

Now the relative heading and speed change actions taken by the master in response to severe sea conditions shall be incorporated.

$$P(H_s,T_m,V,\chi|T,\Lambda) = \int_0^{2\pi} P(V,\chi|H_s,T_m,\chi_o)P(H_s,T_m,\chi_o|T,\Lambda)d\chi_o$$

Now to every set (H_s,T_m,V,χ) a set of response spectral moments, $(m_\sigma^{(o)}, m_\sigma^{(1)}, m_\sigma^{(2)}, m_\sigma^{(4)})$, can be associated. In the following development it will be assumed that ε is small and the elemental distributions will therefore be treated as possessing simple Rayleigh probability density functions. However, there is no intrinsic obstacle to following the same lines of development using a generalized Rayleigh density function such as given by Ochi [5].

The associated elemental simple Rayleigh density function is:

$$p(\sigma|H_s,T_m,V,\chi,T,\Lambda) = \frac{\sigma}{\sqrt{m_\sigma^{(o)}}} e^{-\sigma^2/2m_\sigma^{(o)}}$$

where: $m_\sigma^{(o)}$ is the associated zero-order moment of the σ-response.

The "local" joint probability density function is:

$$p(\sigma, H_s, T_m, V, \chi, T, \Lambda) = p(\sigma | H_s, T_m, V, \chi, T, \Lambda) * P(H_s, T_m, V, \chi | T, \Lambda) * P(T, \Lambda)$$

Now to every set $(H_s, T_m, V, \chi, T, \Lambda)$ there is an associated mean

zero-crossing period for the σ-process: $T_2 = 2\pi \sqrt{\frac{m_\sigma^{(o)}}{m_\sigma^{(2)}}}$

and therefore an associated number of σ-response cycles:

$$n = \frac{T_{exp}}{T_2} P(H_s, T_m, V, \chi | T, \Lambda) * P(T, \Lambda)$$

where: T_{exp} is the total exposure time of the vessel over the entire T-Λ domain.

This then leads to a normalization process which should be applied before the elementary Rayleigh distributions are summed to produce the demand function. The expected total number of cycles in an exposure scenario is:

$$N = T_{exp} \sum_{H_s} \sum_{T_m} \sum_{V} \sum_{\chi} \sum_{T} \sum_{\Lambda} \left\{ \frac{P(H_s, T_m, V, \chi | V, \Lambda) P(T\ , \Lambda)}{T_2} \right\}$$

Placing each elemental distribution on a consistent rate we can sum the elemental distributions to obtain the demand distribution.

$$p(\sigma) = \frac{\sum\limits_{H_s}\sum\limits_{T_m}\sum\limits_{V}\sum\limits_{\chi}\sum\limits_{T}\sum\limits_{\Lambda}\left\{\frac{\sigma}{T_2\sqrt{m_\sigma^{(o)}}}\, e^{-\sigma^2/2m_\sigma^{(o)}}\, P(H_s, T_m, V, \chi | T, \Lambda) P(T, \Lambda)\right\}}{\sum\limits_{H_s}\sum\limits_{T_m}\sum\limits_{V}\sum\limits_{\chi}\sum\limits_{T}\sum\limits_{\Lambda}\left\{(1/T_2) P(H_s, T_m, V, \chi | T, \Lambda) P(T, \Lambda)\right\}}$$

Observe that the demand distribution is independent of exposure time. However, the total number of exposure cycles, N, indicates the risk level associated with the minimum first crossing failure value, $P = 1/N$. The minimum first crossing failure value is that value of σ which satisfies:

$$\int_0^\sigma p(\xi)d\xi = 1/N$$

If one wishes to introduce a confidence parameter, $\alpha < 1.0$ then the minimum first crossing failure value of σ satisfies: $\int_0^\sigma P(\zeta)d\zeta = \alpha/N$

where: α is the probability of exceeding the minimum first crossing failure value ($1-\alpha$ is the confidence that it will not be exceeded).

Another observation to be made is that $p(\sigma)$ will be fairly unaffected by the T_2 normalization process for narrow band sharply peaked response processes (e.g. lightly damped roll) and the approximation:

$$P(\sigma) \approx \sum_{H_s}\sum_{T_m}\sum_{V}\sum_{\chi}\sum_{T}\sum_{\Lambda}\left\{\frac{\sigma}{\sqrt{m_\sigma^{(o)}}}\, e^{-\sigma^2/2m_\sigma^{(o)}}\, P(H_s, T_m, V, \chi | T, \Lambda) * P(T, \Lambda)\right\}$$

CRITERIA AND CAPABILITY

With the exception of structural reliability very little is in fact known about suitable criteria or capability distributions. For structural issues a good source for guidance in developing capability distributions is "Ship Structural Design Concepts" [9]. For logistics and support activities many other issues may present themselves as potential critical processes. To name a few:

1) Speed made good
   a) Slamming
   b) Shipping of green water
   c) Added resistance
   d) Propulsive performance in a seaway
   e) Voluntary speed reduction
2) Transfer at sea
   a) Station keeping
   b) Relative motions
   c) Cable forces
3) Habitability and human factors
   a) Malaise and seasickness
   b) Accelerations
4) Dynamic loads on deck cargo
5) Stability and capsize safety
6) Crane operability

With perhaps a few exceptions these topics have not yet been adequately researched to permit more than the most elementary guesses at suitable criteria or capability distributions. The dynamic loads on deck cargo may be regarded as a structural problem and therefore we may be more advanced in our knowledge of that topic. Kai Kure has done some work on the stability and capsize safety problem [10). Manley St. Denis [11] has presented some information on the topic of tolerable motion, malaise and safe footing.

OTHER METHODS

I will attempt to just mention a few alternate methods currently employed in the field. There are first of all "Partial Safety Factor" and "Safety Index" methods which have been proposed as alternatives to the full demand-capability approach. Then there is Markov modeling and event trees which have found application to some specialized types of problems.

Where important nonlinearities are present there are, of course, time domain simulation and Monte-Carlo sampling methods available as alternative rcutes to the demand distribution.

PROBLEM AREAS

The topic area of marine risk analysis is subject to a number of problems. A list of some that have occurred to me are listed below and will be briefly elaborated upon in this section, I am sure that you can think of others.

List of Problem Areas

Criteria and Capability
Seamanship
Variability and Confidence
Nonlinearities
Joint Probabilities
Resolution and Convergence
Better Environmental Distributions

Many of these problems may be regarded as growth areas where the nexus of the problem is that the necessary background work has not been accomplished. Presumably when the background data exists there will be no instrinsic difficulty in merging the solutions to problems such as seamanship into our existing methods. Other areas, such as nonlinearities, are not so simply addressed. Even for weakly nonlinear problems the effort required to obtain a solution is very great, and extends from the basic hydro-mechanical roots clear through to the final probabilistic solutions. For strongly nonlinear problems we do not at present have promising solution prospects in sight.

Before departing our general overview of the problem areas for more specific examination it should be observed that many of the problem areas cited are intimately inter-connected, each one with the other. Thus for instance suitable definitions for criteria and capabilities may be intertwined with the issues of joint probabilities and seamanship.

Criteria and Capability

Current methods for estimating risk are usually based on the intersection between a "demand" distribution and a "capability" distribution. In many problems of practical interest we are more advanced in our ability to determine a reasonable demand distribution than we are in our ability to determine the corresponding capability distribution. This is particularly true where the issue under examination is one involving operability. Our knowledge of what processes a supply boat operator responds to, and what threshholds prompt voluntary operator reaction (such as reduction in speed or change in heading) are very poorly developed. Or, to consider another example, what processes and threshholds cause voluntary cessation of activities by a crane operator engaged in an offshore transfer activity? The case of structural analysis is amongst the best understood, but even here the capability function is often given a simplified representation consisting of Dirac spike with zero variance (e.g. a spike at the nominal yield or ultimate strength).

It may well be that proper development of capability functions will, in many cases, be in terms of joint variables. Some interesting work along these lines has been initiated for the capsize problem by Kai Kure [10]. Motion induced malaise has also been explored in terms of joint variables [11]. If capability functions ultimately require expression in terms of joint variables, then it will also be necessary to develop the corresponding description of demand over joint variable domains.

Seamanship

This topic must, of necessity, be mentioned under the heading of problem areas because it has been the subject of so little research, and yet it plays an important role in logistic and support activities. Two types of seamanship seem worthy of careful study. The first is to determine the proper probabilistic description of the actions of a typical human vessel operator. The second is to determine the comparable description of the actions of an "optimal" operator.

This latter topic, that of the "optimal" operator, requires that a suitable penalty and reward function be developed to represent the motivation of the operator. The problem can then be addressed with the application of concepts obtained from games theory and statistical decision theory.

In the case of both the human and the "optimal" operator a careful examination is required of what information (both objective and subjective) is available to the operator on which to condition his responses. This, together with the operational criteria the operator seeks to work within, and the objectives he seeks to achieve, describe the seamanship setting.

Variability and Confidence

At an elementary level the goal of risk analysis is to estimate an expected value. The nature of the expected value sought will depend on the application. Examples illustrating some of the different types of expectations are listed below:

1) The expected extreme value of a response process (e.g. vertical acceleration at a specified location).
2) The mean value of a process (e.g the mean wave drift force).
3) The expected operability performance of a system or vessel (e.g. the mean speed made good, or the operating fraction for a crane barge).
4) The expected risk of failure, or "down-time" fraction for a system or vessel.

The first two examples involve estimates of expected physical values, the second two involve estimates of expected probabilities. An expected value is a minimum statement concerning the results of a risk analysis. The completeness with which a risk situation is described is considerably enhanced if information concerning the variability of the distribution and confidence limits are provided. Current practice frequently omits information concerning variability and confidence from the final results.

In estimating variability and confidence we must be careful to maintain an awareness of the many sources of variability and uncertainty. A striking example of the systematic loss of information concerning variability is the use of synoptic climatological information (e.g sample joint probability of H_s and T_m based on 20 years of observations). This data base retains information about the mean distribution of wave height and period but has smoothed out the year-to-year variability. Such a data base would be a good guide for long-term performance encompassing many years, but could be misleading concerning an activity spanning only a very few years. The example synoptic data base does not permit insight into the possibility of systematic grouping of severe conditions into some years and mild conditions into others. This failure to retain information concerning "good years" and "bad years" means that results of risk and operability analyses based on this data are strictly valid only in the long-term mean and that an important issue of variability has been lost. Likewise it means that our confidence that the expected result will fall within specified limits in a given year is reduced.

Improving our general practice concerning variability and confidence should be treated as a major goal by those participating in marine risk analysis. Such a goal requires that we be alert to sources of both systematic variability and uncertainties in our models. Ultimately this objective will require the utilization of more complete and detailed data bases and stochastic models.

Nonlinearity

Nearly all of the problems to be addressed in the marine environment are instrinsically nonlinear. The Navier-Stokes equations are nonlinear, and even rigid body motions are nonlinear with regard to rotations (i.e. the Euler angle problem). We have been most fortunate that so many practical problems have found useful solutions within the context of first order approximation. However, in the field of risk analysis we are particularly sensitive to the effects of even weak non-linearities, as our solutions are generated on the tails of distributions, and it is these tails which are frequently modified by the nonlinearities which are present.

In situations of interest to many risk analysis problems the seaway itself is clearly nonlinear and inadequately described by a variance spectrum. Seaways of moderate steepness manifest sharper crests and flatter troughs which cannot be derived from a linear variance spectrum. Severe seaways also exhibit haunched wave profiles and breaking waves. There are nonlinear interactions between waves of different wave number and frequency in the steep seaway. Our model of the velocity field and the associated diffraction forces are not well evolved for application to problems in steep seaways.

At least for the problem of seaways of moderate steepness there is some hope that higher order models, such as bi-spectra or full three-dimensional power spectra with non-Airy disperson relationships, may provide an adequate statistical model. Work must be done however to relate these statistical models for wave elevation to corresponding velocity fields and ultimately is the diffraction forces.

The problem of severe seaways exhibiting strong nonlinearities may not be solvable by any simple extension to higher order theory.

Another source of nonlinearities is associated with what may be refered to as nonlinear geometrical issues. To cite a few chief examples we have 1) the effect of inclined surfaces (flare) at the waterline; 2) the problem of integrating to the instantaneous intersection of the water surface and the hull instead of truncating the integral at the stillwater plane; and 3) the problems associated with changing geometry when a vessel rolls its deck edge under the water surface.

These nonlinear issues lead to the threshold of a final class of nonlinear problems which must be recognized. These are the problems of parametric excitation and strong nonlinearities in general. The class of problems addresses manifest unstable solutions and multiple solution branches (bifurcation). Uniqueness, on which we implicitly rely in linear analysis, is no longer guaranteed. These problems are real and may be observed in the physical marine world but we are far from ready to treat these strongly nonlinear problems in our risk analyses.

Joint Probabilities

Much of what is intended under this sub-heading has already been raised under the sub-heading of Criteria and Capability. It is appropriate however to underscore the importance of using an adequate variate base to describe marine/environment systems. A univariate wave climatology, $p(H_s)$, is almost never adequate but it is particularly inadequate for dynamic systems described by sets of second order differential equations. A wave climatology containing joint information concerning wave height and period, $p(H_s,T_m)$, will be much more effective in defining the risks to be associated with a dynamic system. This thought can be carried forward by successive steps since the irregular sea state has infinite degrees of freedom along both the frequency and wave number (vector wave number, $\vec{K} = |\vec{K}| e^{i\theta}$) axis. Since many marine systems are quite directional as well as tuned, it can be argued that a wave climatology should reflect all of these degrees of freedom in terms of joint variables. We have thus been led to a point where our considerations merge into the issue of resolution and convergence (i.e. how coarse a descretization can we get away with)?

Climatoligical Descriptions

Considerations of confidence, uncertainty, and computational resolution lead in themselves to the desire for more and better climatoligical information. The dynamic systems we examine require descriptions of the distributions of wave energy both along the frequency and direction axis. Ochi has given some six-parameter analytical spectral forms that attempt to cover the principal frequency domain characteristics of actual spectra. Ochi's six parameters, H_{s_1}, H_{s_2}, ω_{m_1}, ω_{m_2}, λ_1, and λ_2, could, following sufficient study, become the basis of a more complete frequency domain climatology, $p(H_{s_1}, H_{s_2}, \omega_{m_1}, \omega_{m_2}, \lambda_1, \lambda_2)$.

This still leaves the directional characteristics inadequately specified. A simple two parameter spectrum can be given approximate directional characteristics using two parameters, θ_o, and n, describing respectively the central heading angle and the power of a cosine power spreading function of the form:

$$\psi(\theta) = \gamma \cos^{2n}(\theta-\theta_o)$$

$$\text{on } \frac{\pi}{2} \leq (\theta-\theta_o) \leq \frac{\pi}{2}$$

$$\psi(\theta) = 0 \text{ otherwise}$$

where γ is a constant selected such that $\psi(\theta)$ satisfies the unary operator condition $\int_0^{2\pi} \Psi(\theta) d\theta = 1.0$

Ochi's six-parameter spectra could then be extended to directional spectra by adding four more parameters, θ_{o_1}, n_1, θ_{o_2} and n_2 with the understanding that there are implicit constants γ_1 and γ_2 necessary to satisfy the unary operator condition. Thus a ten-parameter climatology could conceivably be developed,

$p(H_{s_1}, H_{s_2}, \omega_{m_1}, \omega_{m_2}, \lambda_1, \lambda_2, \theta_{o_1}, \theta_{o_2}, n_1, n_2)$.

APPLICATIONS

The theory of marine risk analysis is already a useful tool in addressing real world problems. Among its most useful functions is serving as an aid to systematic comparisons of the risks associated with alternatives (e.g. comparing a wet-tow to a dry-tow for jack-up drilling rigs). These methods are routinely applied to the design of sea fastenings for high value and unusual cargo items. The design and analysis of internal structural systems, for instance cryogenic piping in a plant module which must be delivered by barge, are also suitable topics to which these methods have been applied.

A major area of application has been in the operation of offshore crane barges. In the case of crane barges more than just simple measures of risk have frequently been produced. In particular, optimizations have been performed affecting vessel parameters (e.g. principal dimensions) and operational parameters (e.g. heading and boom azimuth). These risk analysis concepts have also formed the basis for some real-time operations advisory systems which monitor response and sometimes the sea state as well.

The cargo thru-put of alternative vessels serving the same site could also be studied in this manner.

An interesting related technique has been applied to estimating the probability distribution for a wet-tow delivery voyage subject to uncertain drag, wind and current effects. This analytical approach was of assistance in determining the towing thrust required to complete the delivery voyage within a specified time (at a confidence level) in order to meet a brief Arctic ice window.

DATA ACQUISITION AND RESEARCH NEEDS

The needs which exist for data acquisition and research closely parallel the problems outlined earlier in this paper.

Foremost perhaps is the need to systematically and carefully identify those processes which are in fact "critical processes". Following identification it is hardly less important to follow up and study the criteria or capability functions which are appropriate to each critical process.

A second distinct need is to systematically study the actual practice of seamanship. Such studies should ultimately result in characterizations of seamanship actions which can be adopted to our probabilistic models. Attempts should also be made to relate seamanship actions, either to variables which automatically reflect ship scale (e.g. local acceleration on the bridge), or else parometrically to ship size.

Lastly, it is important to pursue better sea surface climatologies. Better climatological data is needed in many aspects of sea surface climatology, but it is particularly important to gain better insight into the directionality of wave fields. Studies which lead to a probabilistic distribution of wave spreading function parameters are therefore needed.

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RELIABILITY EVALUATION OF TENSION LEG PLATFORMS

by C. A. Cornell[1], M.ASCE, R. Rackwitz[2], Y. Guenard[3] and R. Bea[4], M. ASCE

A framework for the reliability analysis of marine structures is presented and applied to a TLP. The system analysis is made possible by the use of simple models; resulting uncertainties being accounted for. Important information (e.g., identification of critical subsystems and parameters) that can be used to guide the design process is obtained.

Introduction

The detailed reliability analysis of a complex structure remains an impossible task at present, even with the most recent probabilistic tools available. Yet, mathematical models used for the analysis and design of structures, and particularly offshore structures, become more sophisticated and therefore less easy to incorporate in a probabilistic framework. However, if these models are kept simple enough, so that a probabilistic analysis becomes possible, reliability considerations can be introduced in the design process, especially at an early stage when important decisions have to be taken (e.g., between different configurations).

Among various types of offshore structures presently under study for deepwater oil production, the so-called Tension Leg Platform (TLP) concept is receiving particular attention. The basic idea behind the TLP concept is to restrict the heave, pitch, and roll motion of a floating platform by anchoring it to the sea-floor with tendons (cables or assembly of tubes) in tension. The main subsystems of a hypothetical TLP (and their principal modes of failure) are shown in Fig. 1.

Models and assumptions

It is assumed that over time periods of variable durations (severe sea-states), the sea elevation can be described as a stationary gaussian process characterized by two usual parameters, the significant wave height H_s and the mean zero up-crossing period T_z (see Ref. 5). It is also assumed that a wind speed parameter V_W and a duration parameter τ can be associated with each sea-state. The four parameters H_s, T_z, V_W, and τ, characterizing a particular sea-state, are not mutually independent; hence, conditional distributions based on recent measurements (4) are introduced. Finally, it is supposed that the sequence of severe sea-states forms a (Poisson-arriving) set of independent events. The current parameter and mean water level variable, also random, are assumed to be independent of each other and of the sea-state parameters. The four preceding factors -- wave, wind, current, and water level variation -- are the main sources of loading on a TLP and are included in the analysis.

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As mentioned above, the physical model is kept simple. The fluid kinematic parameters are obtained by linear wave theory and the hydrodynamic forces on the structure are evaluated by the usual Morison equation (5). For a given wave, the forces or stresses in the various subsystems are obtained by a dynamic analysis of the model. In the two-dimensional representation of Fig. 1, the structure has only two legs and two columns, with m tendons per leg and n tendon-elements per tendon. Each foundation subsystem is made of p piles which may fail individually; the possibility of a group failure is also included. The structural system is shown in Fig. 2, with the usual system conventions for parallel and series structures. Based on the environment and hydrodynamic models, the worst loading condition can be obtained for each component of the system and then used to evaluate failure probabilities under extreme loading. Fatigue failure is discarded at this stage.

Reliability Analysis

As is usually done in reliability analyses, a failure mode is associated with a function $g(\underline{X})$, where $\underline{X}$ is a vector of random variables involved in the failure mode. Failure occurs if $g(\underline{X})$ is negative. The first-order techniques commonly used to obtain the probability of failure in a given mode are well known (6) and need not be discussed here.

Several types of uncertainties, including natural (e.g., environmental parameters), material, fabrication, and physical model (e.g., hydrodynamic, resistances) uncertainties are considered. However, probabilistic model (e.g., distributions, processes) and statistical (e.g., parameters of distributions) uncertainties are not yet accounted for.

Two important factors in system reliability are redundancy and dependence between failure modes of a system. Through newly developed first-order reliability techniques (3) those two factors can be considered. This will be illustrated by a simplified reliability analysis of a foundation system. Although the whole TLP system is not analyzed in this example, it is sufficient to show the main features of the method.

Example

Consider the foundation subsystem in Fig. 2 and assume for simplicity that waves are the only source of loading. To further simplify we consider a given sea-state (H_S, T_Z, and τ are its parameters, deterministic in this case) and we are interested in the system reliability for the duration of the sea-state only. The real tension amplitude T_{real} applied to the foundation is of the form:

$$T_{real} = P_L \times T_{model} = P_L \times f_{T_Z}(H) \qquad (1)$$

where P_L is the load model uncertainty variable, H the wave height variable, conditioned on H_S, and $f_{T_Z}(H)$ the transfer function between wave and tension amplitudes. T_{real}^{max} is then defined as the maximum of T_{real} over the duration τ.

If the system of p piles is designed to resist a "design wave" H_D (period T_D) with a safety factor γ, the real capacity of one pile is:

$$Q_{real} = P_F \times S_F \times Q_{nominal} = P_F \times S_F \times \left(\frac{1}{p} \times \gamma \times f_{T_D}(H_D)\right) \qquad (2)$$

where P_F accounts for the foundation model uncertainty and S_F for the uncertainty introduced by the estimation of a soil parameter (undrained shear strength in this case). Assuming a perfectly ductile behavior for tension piles, the capacity of the individual piles system simply is:

$$Q^1_{real} = \sum_{i=1}^{p} Q_{real,i} = P_F \times \left(\sum_{i=1}^{p} S_{F,i} \right) \times Q_{nominal} \tag{3}$$

P_F is supposed to be the same for all the piles (introducing a correlation between the pile capacities) while the $S_{F,i}$'s are assumed here to be independent and identically distributed. A similar formula has been derived for the pile group capacity Q^2_{real}, but is not given here. The system failure probability is finally written:

$$P_f = P(\{Q^1_{real} < T^{max}_{real}\} \cup \{Q^2_{real} < T^{max}_{real}\}) \tag{4}$$

The analysis is carried out for three possible configurations (4, 6, and 8 piles). Reasonable distributions and parameters (1,2,4) are assumed for the random variables. The safety factor γ is first adjusted to obtain acceptable reliability levels for each pile marginally, expressed by the so-called reliability index β. A value of 3, in accordance with usual recommendation for pile design, is necessary. The results of the analyses are summarized in the following table:

Number of piles	β_1 for successive pile failures	β_2 for group failures	β for series system
4	2.49	3.11	2.45
6	2.57	2.72	2.40
8	2.61	2.35	2.21

TABLE 1

For practical purposes, the spacing between the piles must be reduced as the number of piles increases, resulting in a decrease of β_2. The more likely failure mode changes from successive individual pile failures to a group failure with increasing n. Despite the increased redundancy, the overall β index decreases as the number of piles increases (for constant design load). The relative weights of the various random variables in the total uncertainty are measured by the so-called sensitivity factors (6) resulting directly from the analysis and for which typical results are given in Table 2 (superscript 2 refers to group failure).

Random Variables:	H	P_L	$S^1_{F,i}$	P^1_F	S^2_F	P^2_F
Sensitivity factors:	.18	.50	.11	.65	.34	.34

TABLE 2

We notice the importance of the model uncertainties, resulting from the large values assigned to the corresponding coefficients of variation. These sensitivity factors can form the basis for detailed, final design schemes with a deterministic load and resistance factor format (6).

Conclusion

The same type of analysis is under development for the whole structure, all sources of loading included, allowing the identification of the critical subsystems (e.g., foundations versus "legs") and parameters (e.g., number of piles, tendons per "leg", etc.). Load and resistance factors can be adjusted in the various subsystems in order to obtain a balanced design format for a given overall reliability level. Although only a particular type of structure is considered here, the approach is very general and should be easily applicable to assess the reliability of any structural system.

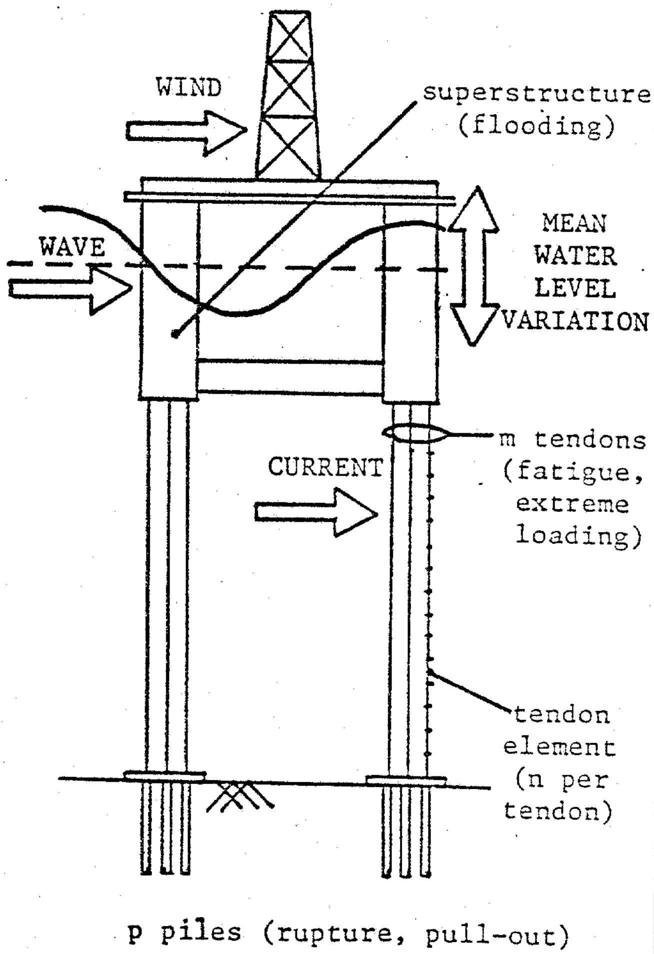

Figure 1. TLP and Failure Modes.

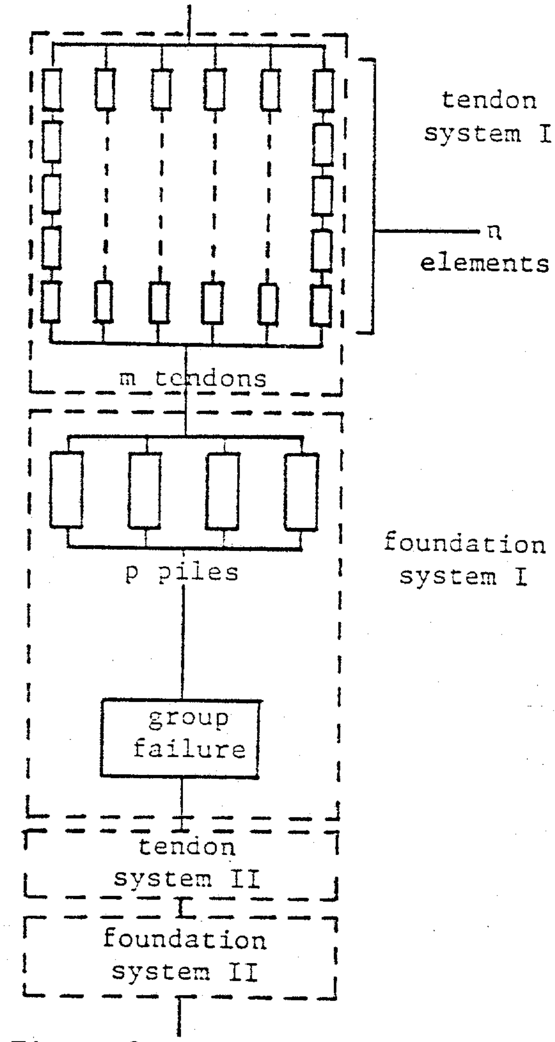

Figure 2. TLP System Model.

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

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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:

Fault Tree Analysis - for evaluating the reliability of safety systems or estimating the frequency of process system failures

Event Tree Analysis - for evaluating the possible accident sequences following some initial failure

Hazard and Operability Study - for checking adequacy of complex process designs and identifying likely modes of failure

Risk Analysis - for estimating risks to people, equipment and the environment, evaluating possible changes or improvements etc.

"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

Simulation Techniques - these are used for many purposes. A good example is simulation of evacuation sequences, using Monte Carlo or event tree methods.

Structural Reliability Analysis - this covers several distinct areas. It includes analysis of extreme seismic, wind and wave loadings (say 10000 year return period) and considers collapse states rather than design (elastic) states. Structural redundancy, defect-tolerance and impact resistance are also considered.

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